[PS]Upper Bakken Shale Resource Play, Williston Basin*

Stephen A. Sonnenberg[1]

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Abstract

The Upper and Lower Bakken shales are the source beds for the Bakken Petroleum System of the Williston Basin. Reservoirs for this system include the shales, the lower Lodgepole, Middle Bakken silty dolostones, and Three Forks silty dolostones. The Upper shale was a drilling target in the late 1970s through the early 1990s in southwest part of the basin in North Dakota (termed the depositional limit play or Billings Nose play). The discovery of the giant Elm Coulee Field changed drilling strategies to focus on the Middle Bakken dolostone member. As this play extended into North Dakota, drilling success was also encountered in the upper Three Forks dolostones. The Upper Bakken shale has recently been targeted with horizontal drilling and multistage fracture stimulations along the southwest edge of Elm Coulee Field where the Middle Member pinches out. In this area wells are drilling into the Upper shale and then completed with multistage fracture stimulations. The fracture stimulations extend into the adjacent Lodgepole and Three Forks formations. So in essence, these new wells target multiple pays. Factors thought to be important in this Upper shale play include: orientation of horizontal laterals, bed thickness, natural fractures, shale mineralogy, abnormal pressure, and TOC content. This play is a similar to the previous depositional limit play in North Dakota except the wells are completed with multistage fracture stimulations. Exploration success in the Upper Bakken shales suggests that future drilling should also target the Lower Bakken shales.

Upper Bakken Shale Resource Play, Williston Basin

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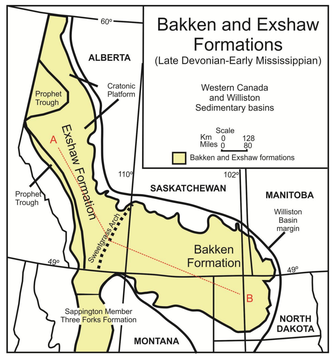
ABSTRACT

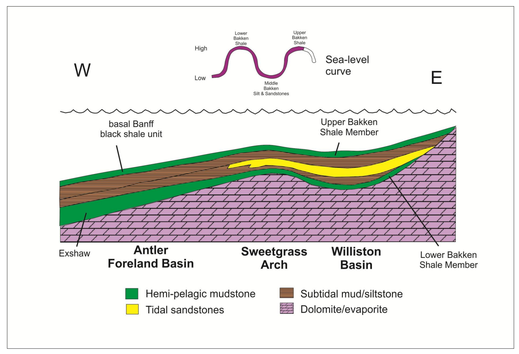
The Upper and Lower Bakken shales are the source beds for the Bakken Petroleum System of the Williston Basin. Reservoirs for this system include the shales, the lower Lodgepole, Middle Bakken silty dolostones, Pronghorn dolostones, and Three Forks silty dolostones. The Upper Shale was a drilling target in the late 1970s through the early 1990s in southwest part of the basin in North Dakota (termed the depositional limit play or Billings Nose play). The discovery of the giant Elm Coulee Field in Montana changed drilling strategies to focus on the Middle Bakken dolostone member. As this play extended into North Dakota, drilling success was also encountered in the upper Three Forks dolostones.

The Upper Bakken Shale has recently been targeted with horizontal drilling and multistage fracture stimulations along the southwest edge of Elm Coulee Field where the Middle Member pinches out. In this area wells are drilling into the Upper Shale and then completed with multistage hydraulic fracture stimulations. The fracture stimulations extend into the adjacent Lodgepole and Three Forks formations. So in essence, these new wells target multiple pays. Factors thought to be important in this Upper Shale play include: orientation of horizontal laterals, bed thickness, natural fractures, shale mineralogy, abnormal pressure, and TOC content. This play is a similar to the previous depositional limit play in North Dakota except the wells are completed with multistage fracture stimulations.

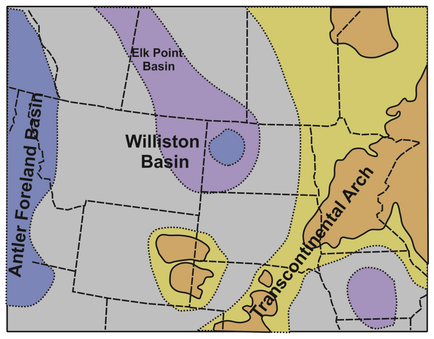
Exploration success in the Upper Bakken shales suggests that future drilling should also target the Lower Bakken Shale.



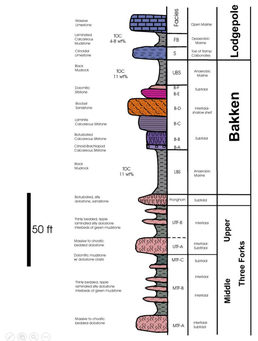
Distribution of Bakken and Exshaw sediments.



Cross section A-B showing Bakken and Exshaw correlations.



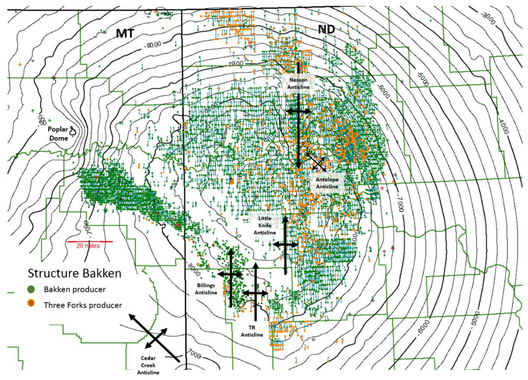
Paleogeography of the Williston Basin, Late Devonian.



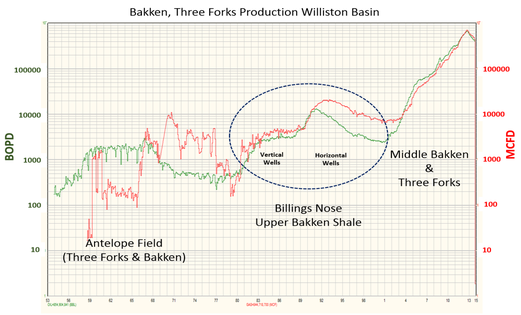
USGS 2013
7.4 BBO
6.7 TCFG

Production
North Dakota only
548 MMBO cumulative
847,000 BOPD

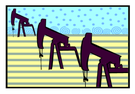
Stratigraphic column for the Bakken Petroleum System.



Structure map top Bakken. Three Forks and Bakken producers also indicated. Wells shown are Bakken, Three Forks producers only.



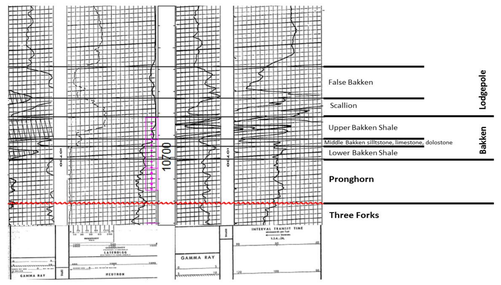
Bakken and Three Forks production, US Williston Basin. The Billings Nose part of the plot illustrates production from the Upper Bakken Shale and adjacent beds.



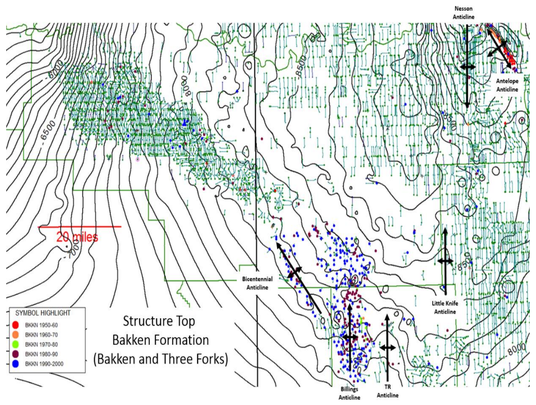
The Bakken Cycles

- **Vertical drilling: Bakken (pre--1987)**
  - **Antelope Structure (1950s--60s)**
  - **Depositional Edge (1970s--80s)**
- **Horizontal Drilling of the Bakken Shale (post-1987)**
- **Horizontal Drilling of the Bakken Middle Member (2001 to present)**
- **Horizontal Drilling of the Three Forks (2008 – P)**

Modified from LeFever, 2004



Type log Billings Nose area, Shell Federal 41X-5-1 (Sec. 5, T143N, R101W). Discovery well for the Billings Anticline Bakken play drilled in 1961.



Structure top Bakken, southern Williston Basin showing completion of wells by various decades. Wells shown are Bakken, Three Forks producers only.

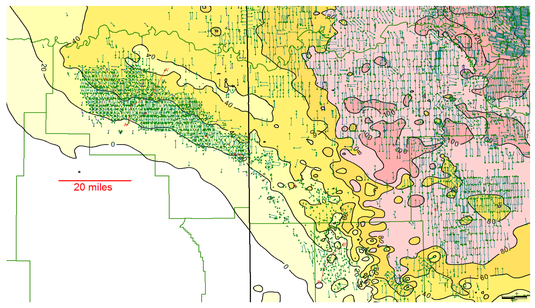
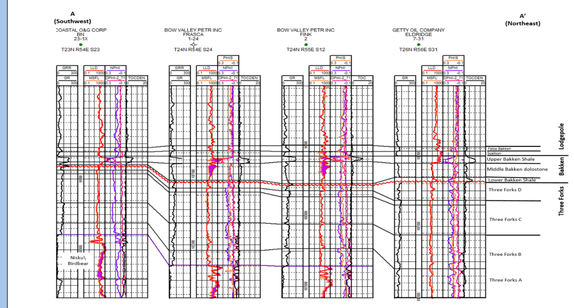
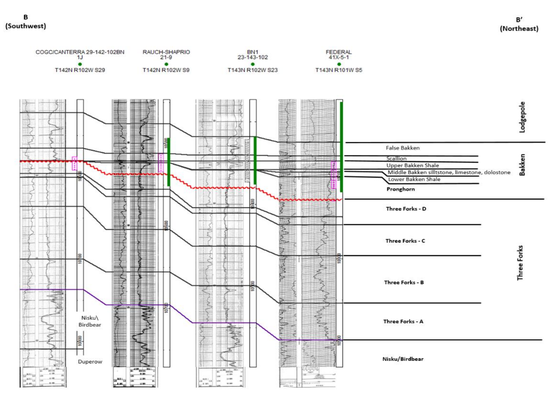


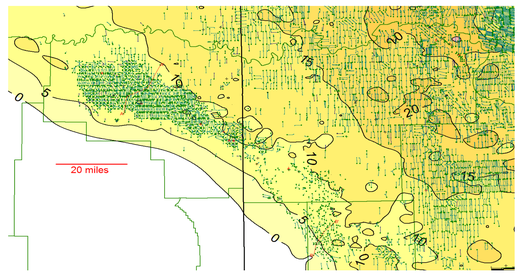
Figure 5. Isopach total Bakken, Billings Nose area. Wells shown are Bakken, Three Forks producers only.



Cross-section Elm Coulee. Shaded area on resistivity track is where MSFL is less than LLD curve resistivity. This is an indication of matrix and/or fracture permeability. Shaded areas on resistivity logs indicate mud filtrate invasion caused by salt based mud and the presence of fracture or matrix permeability.



Cross-section Billings Nose area. Note dramatic pinchout of Bakken to the southwest. Note also thickening of False Bakken in this area. The 21-9 and BN 1 wells show resistivity separation in the Upper Bakken Shale suggesting the presence of fractures.



Isopach Upper Bakken Shale. Wells shown are Bakken, Three Forks producers only.

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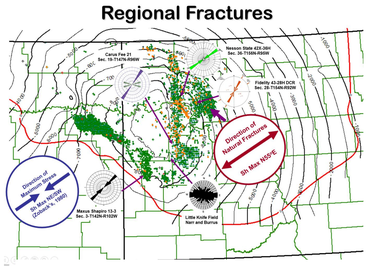
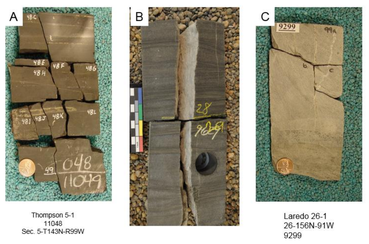
Bakken Fractures

- Regional
- Tectonic
- Diagenetic (expulsion)

"mineralization on fracture surfaces is absent" Carlisle et al., 1992

Regional Fractures





Thompson 5-1
11048
Sec. 5-T143N-R99W

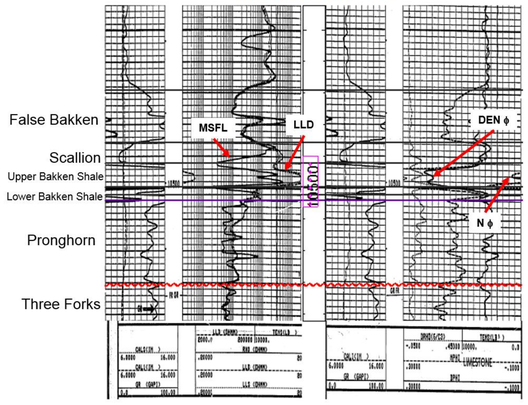
Laredo 26-1
26-156N-91W
9299

Core photographs showing regional fractures. A) Photo illustrates regional fractures in upper Bakken shale from Thompson 5-1 (11048 ft, Sec. 5, T143N, R99W). B) fractures in middle Bakken from Liberty 2-11H (9629 ft, Sec. 11, T151N, R91W); fractures are mineralized partially open; C) fractures in middle Bakken from Laredo 26-1 (9299 ft, Sec. 26, T156N, R91W); fractures are cemented with calcite and partially open.

LOG RESPONSES

MERIDIAN OIL INC
MOI
21-11

T143N R102W S11

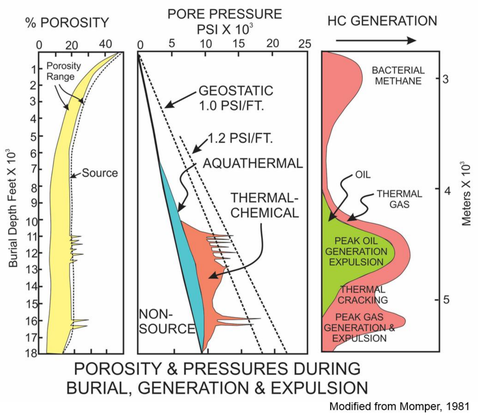


Pfs: 10490-10506
IP: 217 BOPD; 178 MCFD
CUM: 199 MBO
258 MMCF

Separation between MSFL and LLD can indicate fracture permeability (invasion)

"Separation between neutron and density porosity curves can indicate the presence or absence of fractures" Carlisle et al., 1992

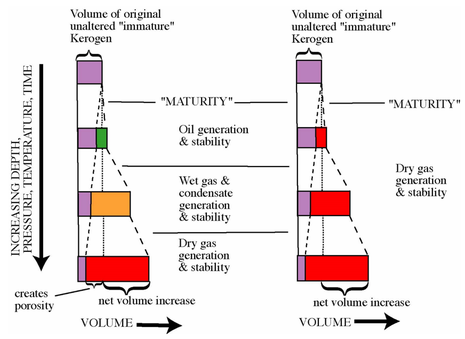
Conceptual Burial History of Unit – Volume of Oil - Source



POROSITY & PRESSURES DURING BURIAL, GENERATION & EXPULSION

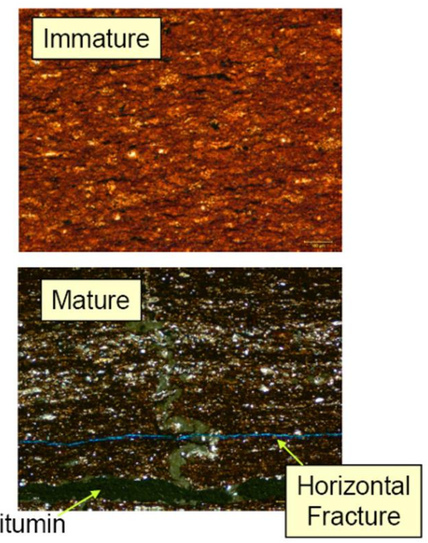
Modified from Momper, 1981

Overpressures generated by HC generation



Meissner, 1980

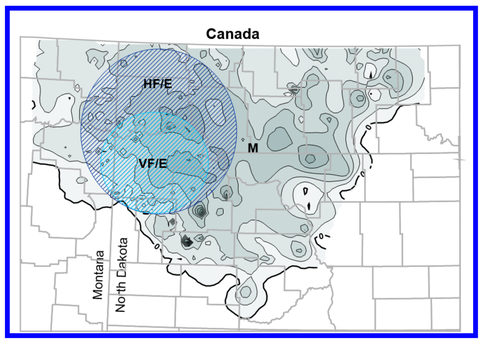
Bakken Maturity



LeFever et al., 2008

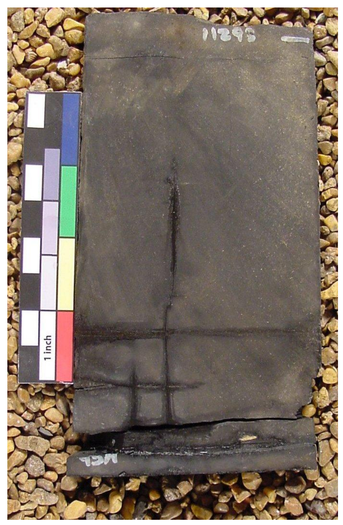
Non-Tectonic Fractures

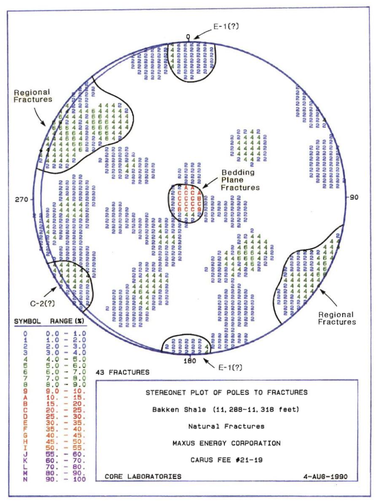
HC Generation - Upper Bakken Shale



From LeFever

Carus Fee 21
Sec. 19-147N-96W





Stereonet plot of poles to fractures, Bakken Shale. Note "bedding plane fractures"

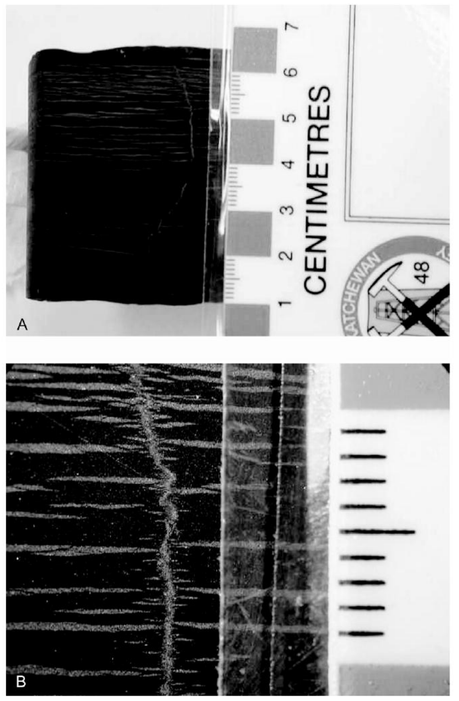
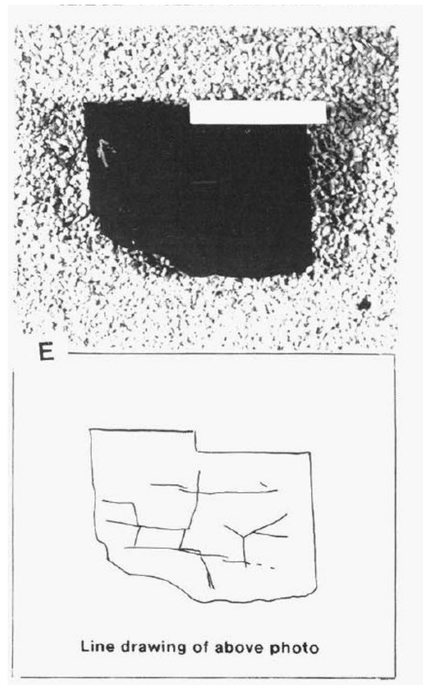


Figure 16 - A) Network of calcite-filled horizontal fractures cross-cut by a vertical calcite-lined fracture which starts and terminates within a 5 cm thick interval (well 12-27-1-6W2, between approximately 2081.0 and 2082.0m. B) Magnified view of a portion of this 5 cm thick interval.

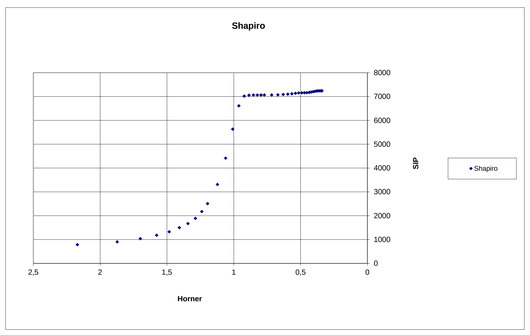
Kreis, Costa, Osadetz, 2006

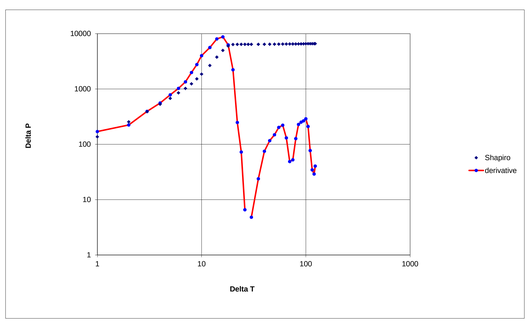


"microfractures occur in all Bakken units"
Carlisle et al., 1992

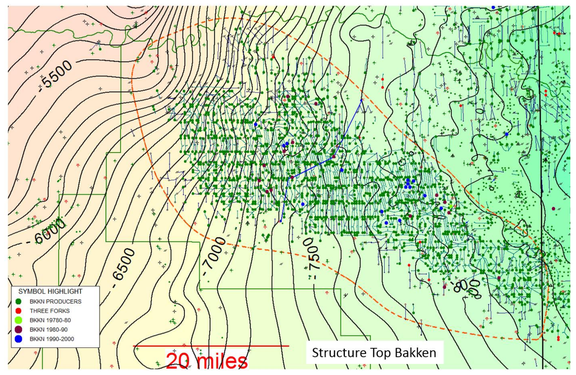
Upper Bakken Shale Resource Play, Williston Basin

Calcite-lined horizontal fracture networks.

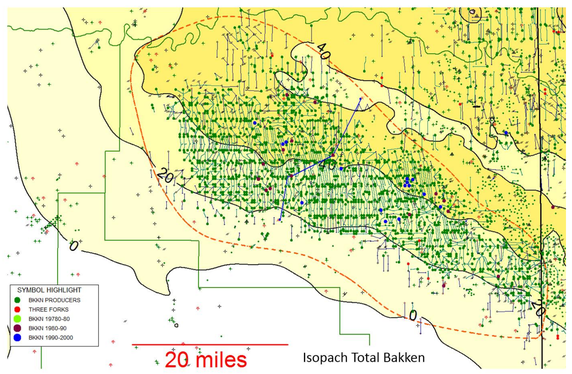




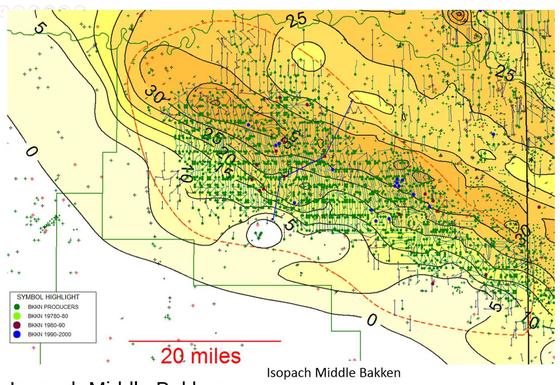
Horner plot for Shapiro 21-9 (Sec. 9, T142N, R102W). B. Delta P and delta T plot with derivative analysis. The derivative plot suggests the presence of fractures. See Figure 7 for Shapiro log.



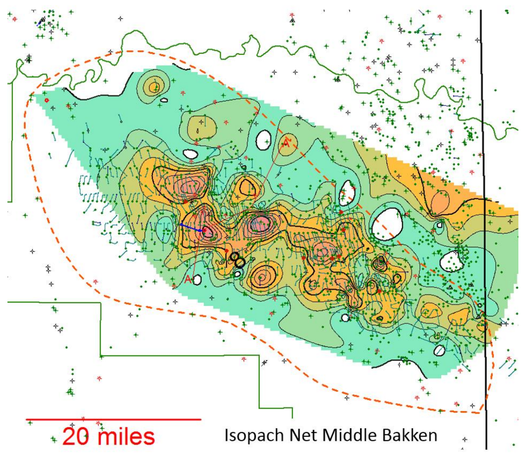
Structure top Bakken.



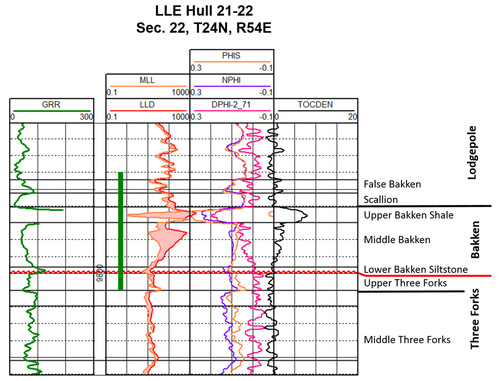
Isopach total Bakken.



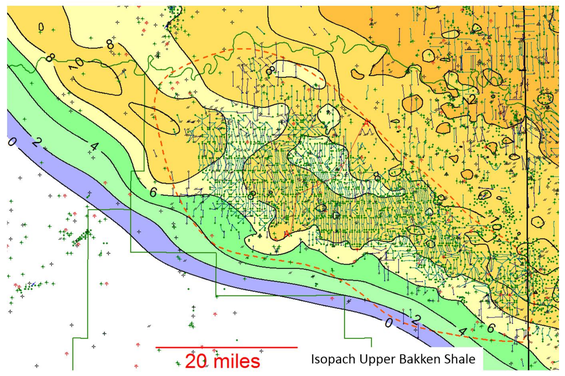
Isopach Middle Bakken.



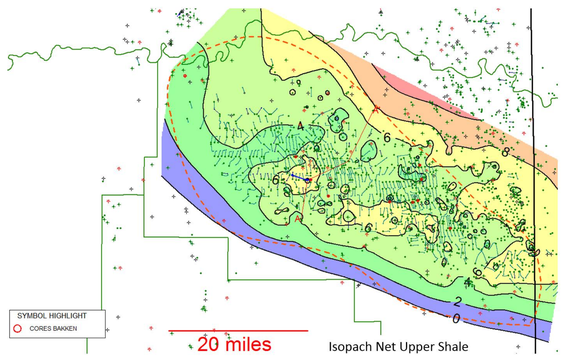
Isopach Net Middle Bakken.



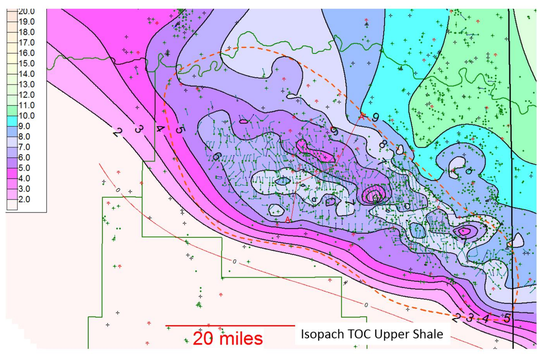
Log response for Bakken and Three Forks intervals from Elm Coulee.



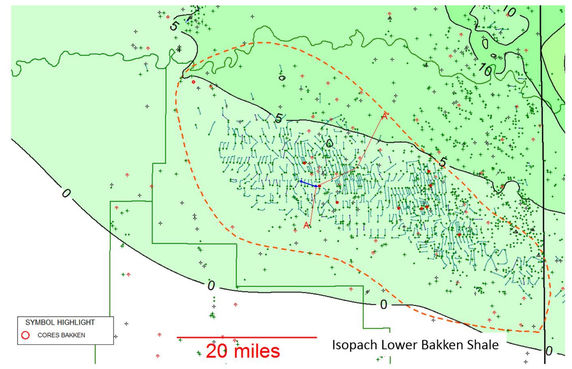
Isopach Total Upper Bakken Shale.



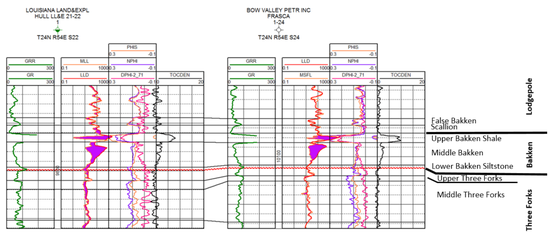
Isopach Net Upper Bakken Shale.



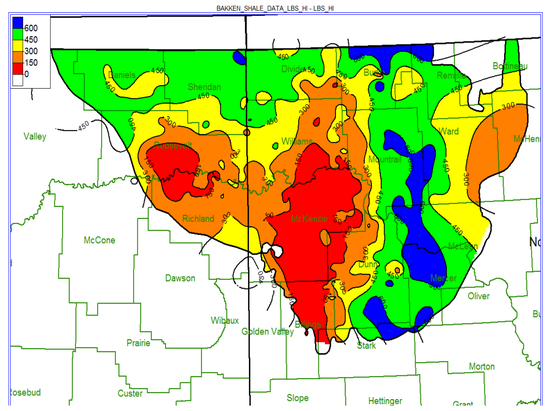
Isopach TOC Upper Bakken Shale.



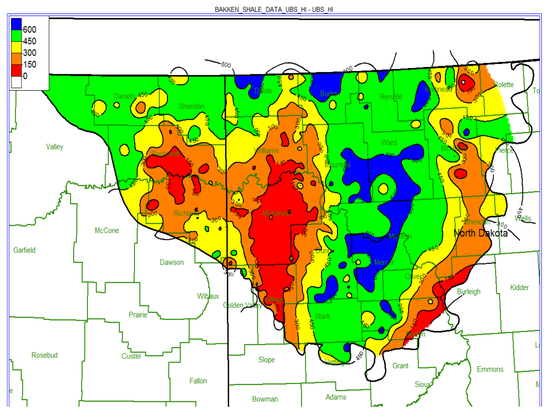
Isopach Lower Bakken Shale.



Cross section indicating fractures, Upper Bakken Shale and matrix permeability in Middle Bakken, from Elm Coulee.



Hydrogen Index map for lower Bakken shales.



Hydrogen Index map for upper Bakken shales.

Upper Bakken Shale Resource Play, Williston Basin

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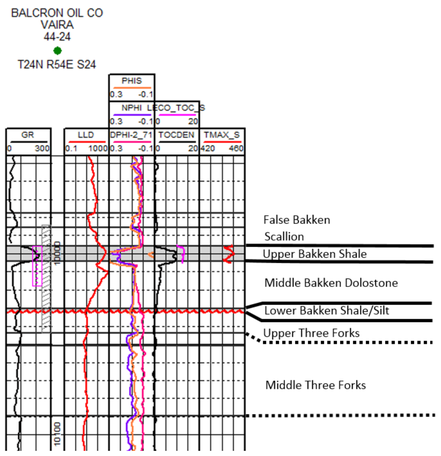
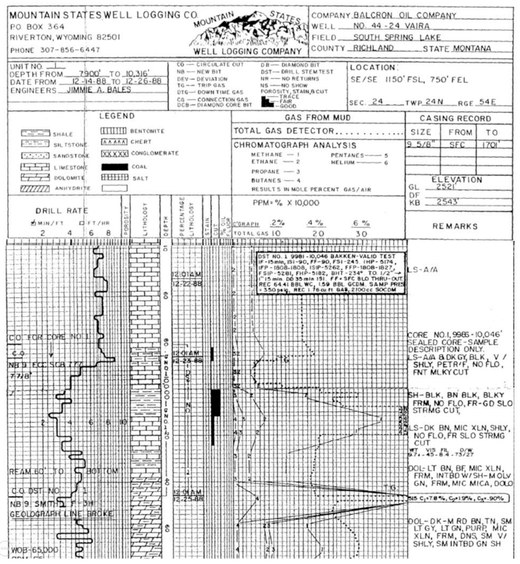
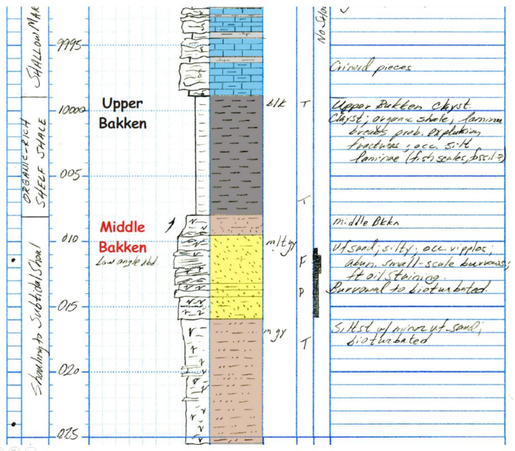


Log for Vaira well, Elm Coulee Field, Bakken Petroleum System.

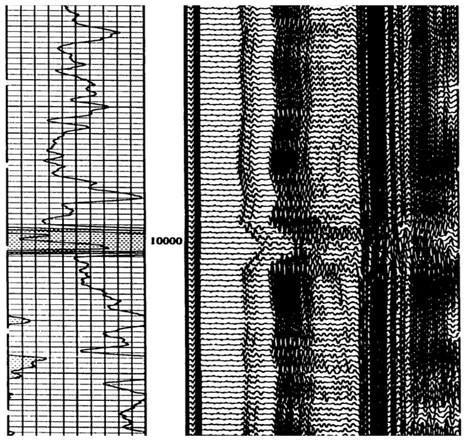


Mud log for Vaira well. Note shows in Upper Bakken Shale.

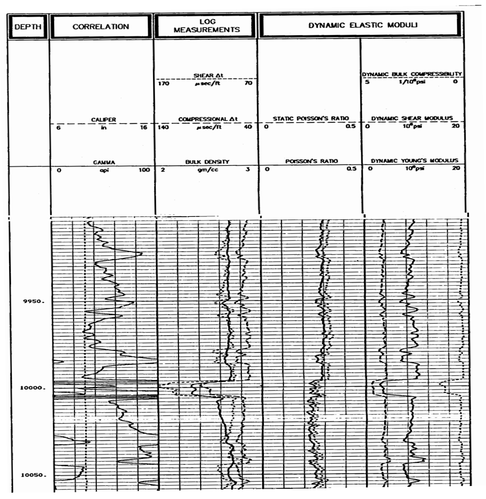


Core description for Vaira well, USGS files (Smith et al.) Expulsion fractures noted in the Upper Bakken Shale.

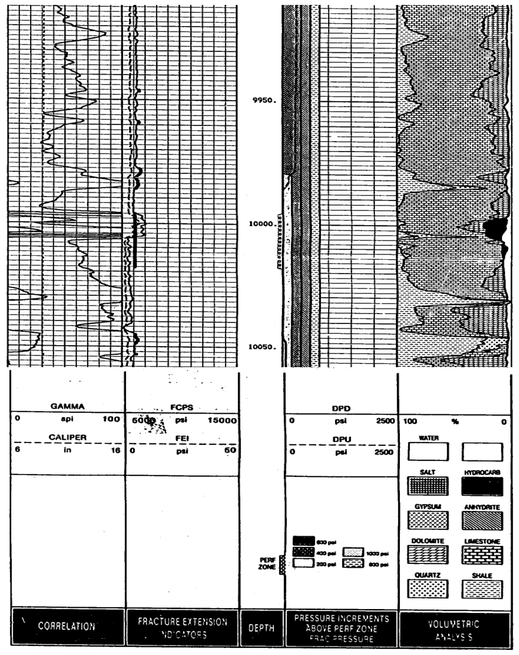
Core photos for Upper Bakken Shale, Vaira Well.



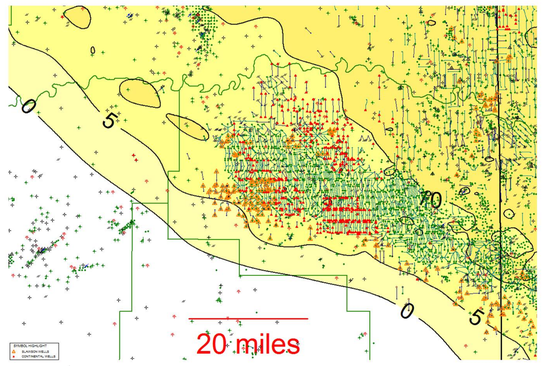
Full sonic waveforms, Vaira well. Note response in Upper Bakken Shale (suggests presence of fractures).



Sonic, gamma ray, and dynamic elastic moduli for Vaira well, Elm Coulee Field.



Lithology, gamma ray, fracture extension indicator, frac pressure, and volumetric analysis for Vaira Well.



Isopach Upper Bakken Shale

Isopach Upper Bakken Shale, and new activity on southern flank of field targeting Upper Bakken Shale.

CONCLUSIONS

The Upper Bakken Shale is an important part of the Bakken petroleum system. It serves both as a source rock and also contributes as a reservoir to production. The Upper Bakken Shale is fractured and fracturing has been observed in cores, drill stem test data plots, and well logs from the Billings Nose area. The success of the Upper Bakken Shale in the Billings Nose area is in part due to production from the adjacent formations (Lodgepole, Pronghorn, Three Forks). The key to production in the Billings Nose area appears to be due to the following: presence of mature source rocks, natural fractures, presence of reservoirs adjacent to the Upper Shale, along with drilling and completion technologies.

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