Parameters that are associated with producible oil in the Middle Bakken Member

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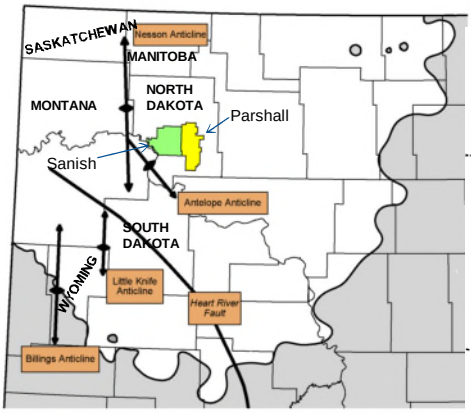
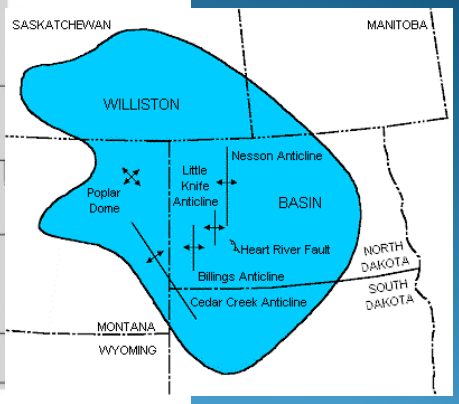
Outline

- Introduction
- Depositional system of the Upper, Middle, and Lower Bakken Members and that of the Pronghorn
- Contrast of microfractures system in immature Bakken Formation with the microfractures system at the onset of the oil window in the Middle Bakken Member
- Rock Pyrolysis evaluation of potentially producible Middle Bakken oil and condensates

Williston Basin: Major Structures

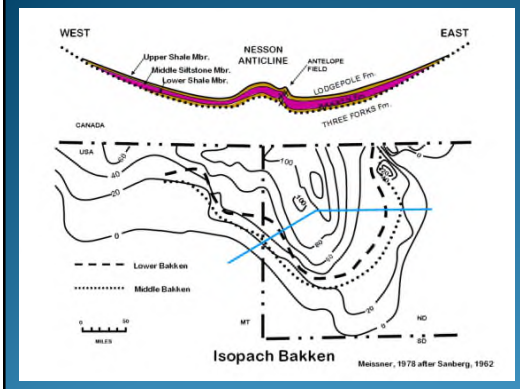




(Nordeng S. H. et. al., 2010)

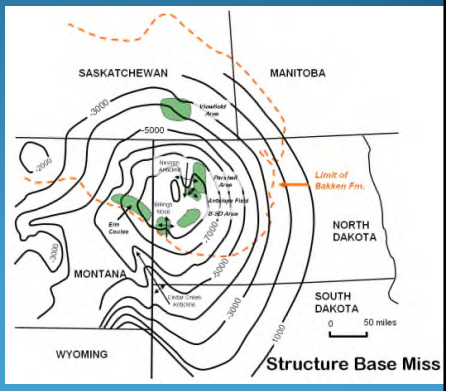
- Parshall Field
- Williston Basin major structures: N, NW trends, Wrench faulting; Rocky Mtn trend

Bakken Isopach Map



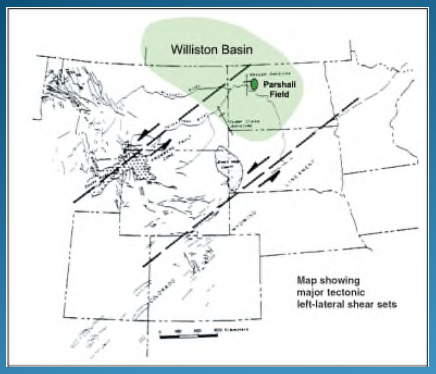
Isopach map and cross-section of the Bakken

Structure, base Mississippian, Williston Basin



(Sonnenberg S. A. et. al., 2011)

Parshall Field Area, North Dakota

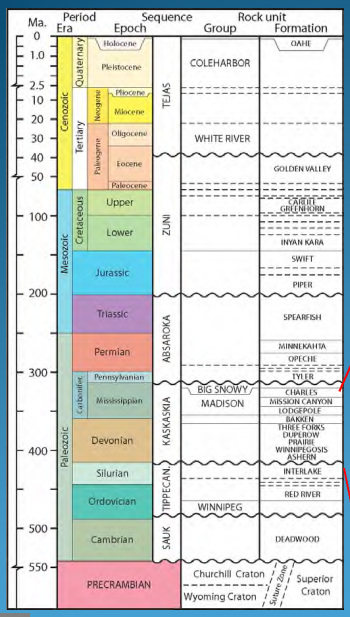


Tectonic setting of Williston Basin, after Gerhard et. al., 1987 (Jarvie, 2010)

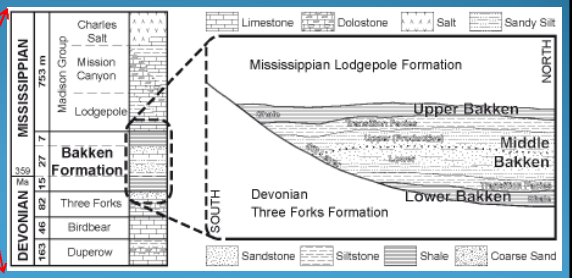
(Johnson, 2009)

Parshall Field:
- NW trending strike slip with torsional movement (wrench faults)
- NW trending Rocky Mtn grain

Depositional system of the Upper, Middle, and Lower Bakken Members and that of the Pronghorn in Williston Basin



Bakken Formation is Upper Devonian to Mississippian

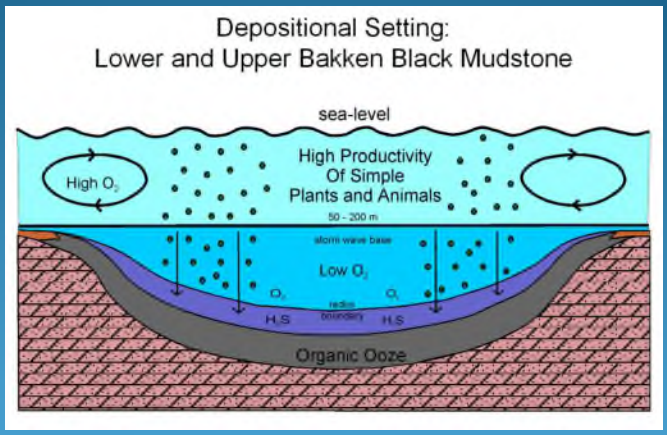


(Hill *et. al.*, 2011)

Depositional system of the Upper, Middle, and Lower Bakken Members and that of the Pronghorn

Sanish sand (now renamed "Pronghorn" is described as being a Basal Bakken Bed at the top of the Three Forks Fm ; LeFever et. al., 1991 refer to it as being "Skolithus Sandstone" inferred to be intertidal.

A thin, very dolomitic sandstone at the top of the Three Forks Formation was termed the "Sanish Sand"
(Murray, G.H., 1968)

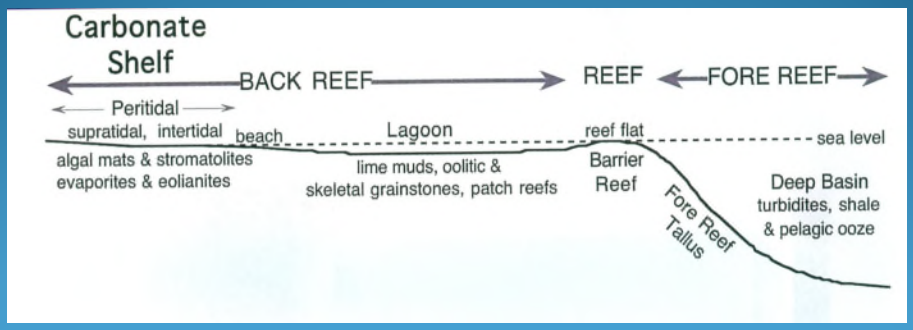


Deposition setting of Upper and Lower Bakken shales under anoxic conditions (modified from Smith and Bustin, 1996; Meissner et. al., 1984) in Sonnenberg, S. A. et. al., 2010

Depositional System of the Upper, Middle and Lower Bakken Members and that of the Pronghorn

The Bakken Formation consists of a middle member bounded by two black, organic rich shale units (Steptoe and Carr, 2011)

- Upper and Lower Bakken Shale , deep marine anoxic (>200 m depth)
- Pronghorn and Middle Bakken , shallow water, high energy, epicontinental (<10 m depth)

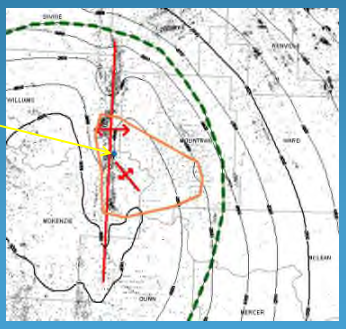


(Modified from Gregg, 2006 in Steptoe and Carr, 2011)

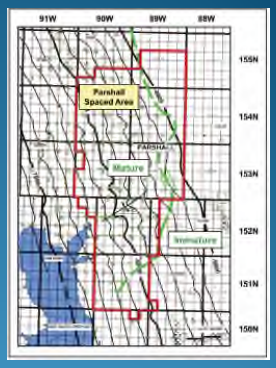
Middle Bakken Member that is located in Parshall Area, Williston Basin

- The carbonate-siliciclastic Middle Bakken member acts as the reservoir
- Natural and artificial fractures are;
- Conduits for oil along horizontal well bores drilled through the tight middle member (Nordeng et. al., 2010)

Blue dot shows Location of cored well (including Middle Bakken core): XTO Energy's Sakakawea 13X-35 well located within Parshall Field thermal mature zone at boundary of Williams, Mountrail and McKenzie counties: Core with 5 facies in Middle Bakken



(Steptoe and Carr, 2011)



Lodgepole structure contour map of Parshall Field. C.I = 100 ft: Thermal maturity boundary (Jarvie et. al., 2010)

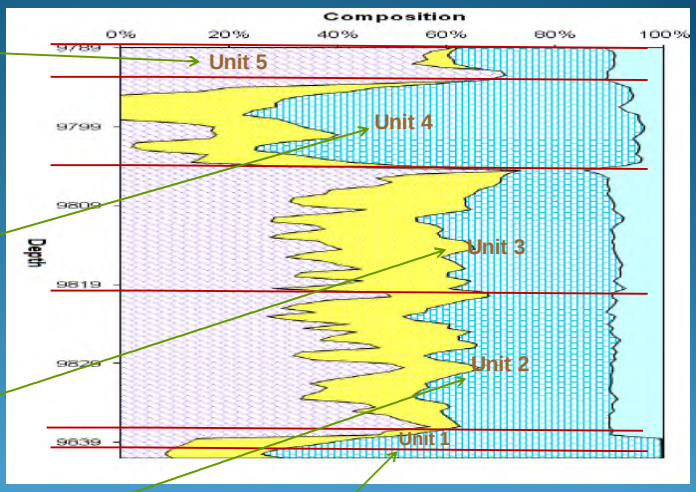
The Parshall Field "sweetspot" appears to be related to overpressuring.

Middle Bakken Lithofacies: XTO Energy's Sakakawea 13X-35 Well Core

Has the most dolomite (~50%) of all the facies

Mostly calcite and quartz plus a gas effect: indicator of overpressuring

Similar to Unit 2 but slightly more quartz rich

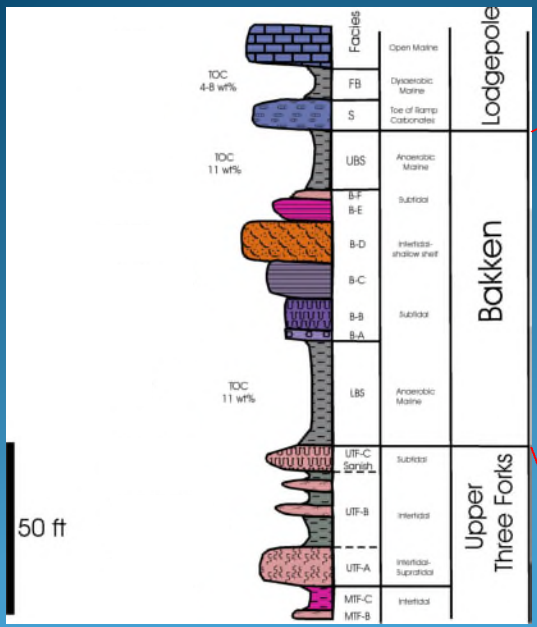


(Steptoe and Carr, 2011)

~40% calcite, ~40% quartz, 20% dolomite

>75% calcite, 25-35% dolomite

Middle Bakken Lithofacies



Six Middle Bakken lithofacies have been documented (Pitman, et. al., 2001, LeFever, et. al., 1991 in Sonnenberg et. al., 2011):

- F – SILTSTONE, mottled dolomitic
- *E – Parallel interbeds of dark-grey SHALE and buff SILTSTONE*
- *D (this is the oil productive lithofacies in Parshall Field) – SILTY SANDSTONE gradational to and from COARSE SANDSTONE, Skolithus ichnofacies. Equivalent to Unit 4 of XTO Energy's Sakakawea 13X-35 well*
- *C – Laminated CALCAREOUS SILTSTONE*
- B – Bioturbated CALCAREOUS SILTSTONE
- *A – SILTSTONE, mottled very calcareous*

Contrast of microfractures system in immature Bakken Formation with that at the onset of the oil window in the Middle Bakken

The Bakken Petroleum System consists of the Middle Bakken: a brittle dolomitic siltstone that grades into a sandstone sandwiched between two excellent, kerogen-rich marine Upper and Lower Bakken shales (Stockton, 2011).

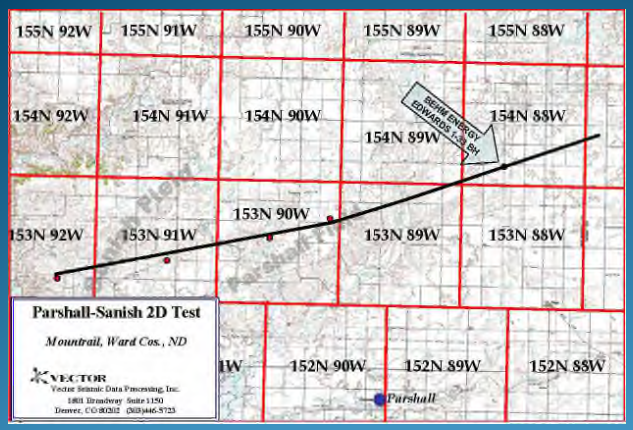
- Creation of in-situ horizontal fractures parallel to bedding: mainly in Middle and Lower Bakken; these occur as swarms in Middle Bakken Silstone and Sandstone that has high residual oil content

- Increase in Middle Bakken horizontal fracture swarms in proximity to thick, high TOC, mature Upper and Lower Bakken Shales and decrease in proximity to the low TOC, immature, thin ones

- High lithostatic pressure increase from the great increase in oil volumes within the oil window zone when the upper and lower Bakken kerogen is converted into oil ; Four products of the Kerogen conversion are released into the brittle Middle Bakken:

- Horizontal fracture swarms, CO_2, C_1-C_4 light gases and oil expelled from Upper and Lower Bakken

Dry hole and productive hole seismic in Bakken



Approximate location of the Parshall-Sanish 2D/3 –component seismic test; tying the dry hole with production in Parshall and Sanish Fields (Stockton, 2011).

- Seismic character change between the image at the dry Behm Energy's Edwards 1-33 well and four producing wells in Parshall and Sanish Fields.

- Converted wave processing and the subsequent common conversion point (CCP) stacks (seen in Figures 1 and 2) show a distinctive seismic character change in the vicinity of the fractured Middle Bakken.

Dry hole and productive hole seismic in Bakken

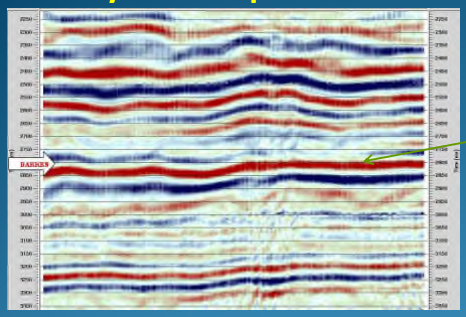


Fig 1 – Dynamite converted-wave (radial shear) image. Note the continuity of the Bakken reflector indicating the absence of hydraulic fractures.

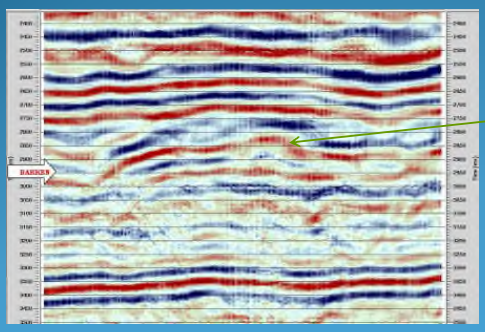


Fig 2 – Dynamite converted-wave (radial shear) image. The acoustic "time structure" is a manifestation of the rock mechanics in the presence of fractures.

Rock Pyrolysis evaluation of potentially producible Middle Bakken oil and condensates

TOC content of Middle Bakken is diagnostic of this zone since it is consistently between 0 and 1%.

Middle Bakken zones that have producible oil are those with Oil Saturation Index (OSI) > or = 100 (However, if oil based mud was used in drilling any of these zones then these OSI values greater than 100 could be due to contamination.

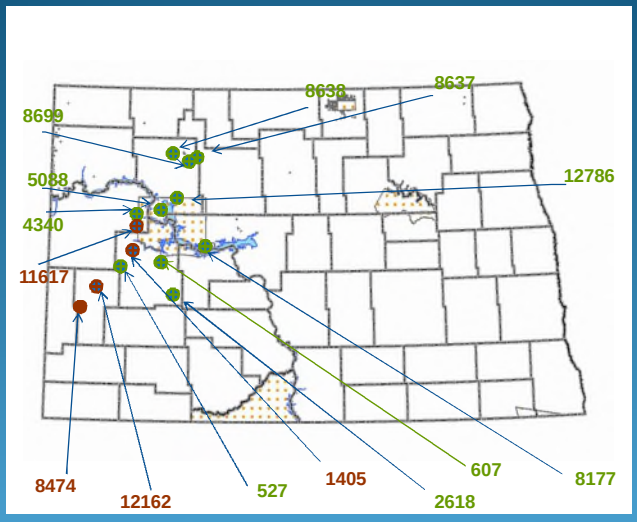
The Middle Bakken Facies that is described as lithofacies 3 and 4 (LeFever et. al., 1991) and is also described as Facies D (Sonnenberg et . al., 2011) is most likely equivalent to Unit 4 of the Middle Bakken (Steptoe, A. P. and Carr, T. R., 2011).

Six Middle Bakken lithofacies have been documented (Pitman, et. al., 2001, LeFever, et. al., 1991 in Sonnenberg , S. A., et. al., 2011) .

The Middle Bakken retrieved from XTO Energy's Sakakawea 13X-35 well is described as consisting of 5 units (Steptoe and Carr, 2011)

Note: The Pronghorn has *Skolithos ichnofacies* which is also present in sandstone of lithofacies 3 and 4 of the Middle Bakken (LeFever, et. al., 1991)

Rock Pyrolysis evaluation of potentially producible Middle Bakken oil and condensates: Location of wells sampled for Oil Saturation Index Analyses , N. Dakota



Legend:

8699 – Well No. (NGS), dry hole, 8637 – Well No. (NGS), Oil Productive (after North Dakota Geological Survey, 2011); these wells were all drilled prior to 1993 and so the current horizontal drilling technology was not readily applicable so some of these wells that were designated as dry but have low risk producible Oil Saturation Index values could be bypassed oil.

Middle Bakken Oil Saturation Index (OSI)

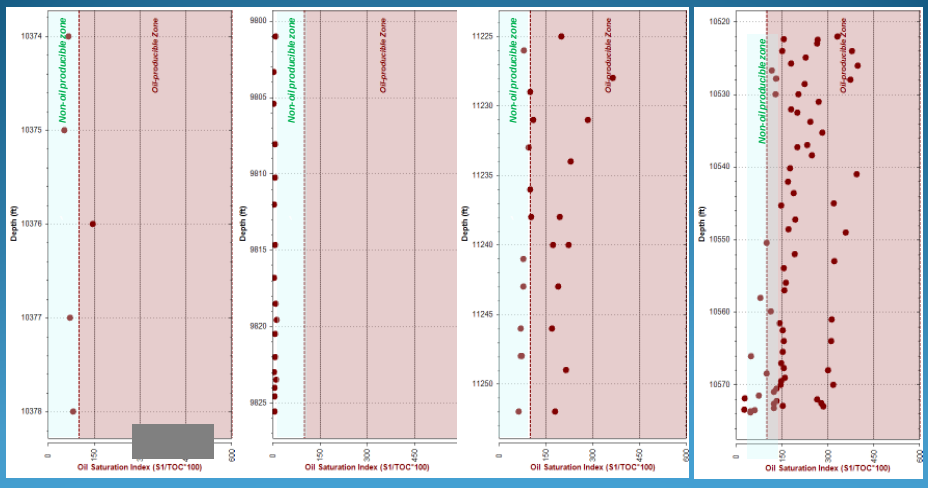
[OSI = S1*100/TOC in mg oil/g TOC]

Tenneo Oil Co. 1-15 Graham USA (NGS #8474)

Pan American Jacob Huber #1 (NGS #2618)

California Co. # 1Rough Creek Unit (NGS #527)

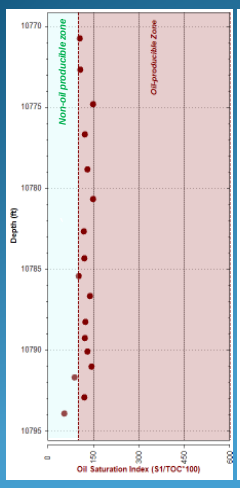
Socony Vacuum Angus Kennedy F32-24-D (NGS #607)



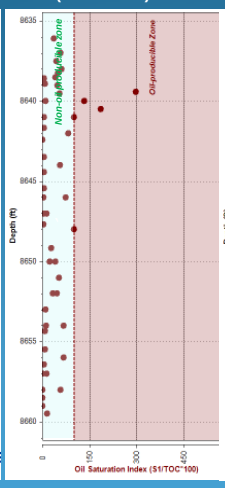
Middle Bakken Oil Saturation Index (OSI)

1992 status: Oil Productive, wells with OSI > or =100 but with dry hole status maybe bypassed oil due to lack of present day horizontal wells drilling technology

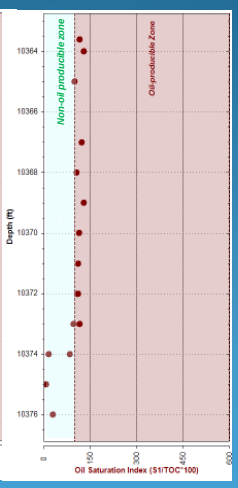
Ameratada #2 C. E. Peck (NGS #1405)



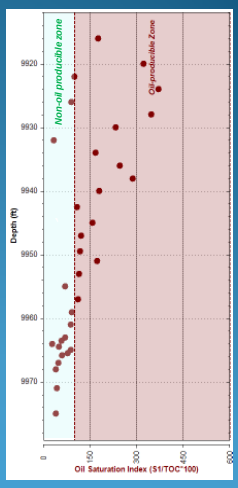
Marathon Dobrinski 18-44 (NGS #8177)



Edwin I. Cox and Berry R. Co Hagen #1-13 (NGS #11617)

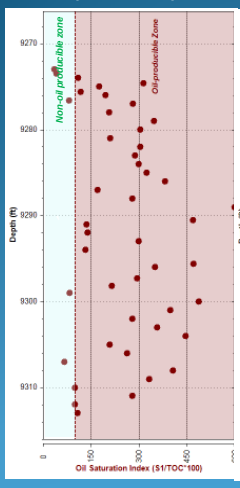


Pan American #1 Clifford Marmon (NGS #4340

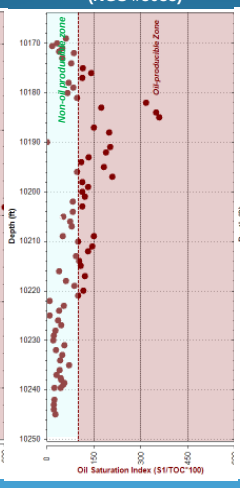


Middle Bakken Oil Saturation Index (OSI)

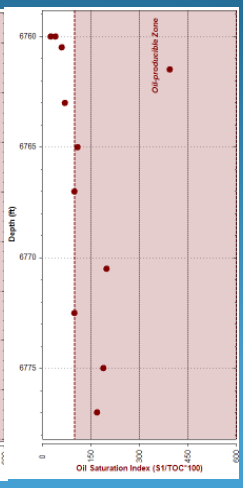
Marathon Oil Co. Laredo 26-1 (NGS #12786)



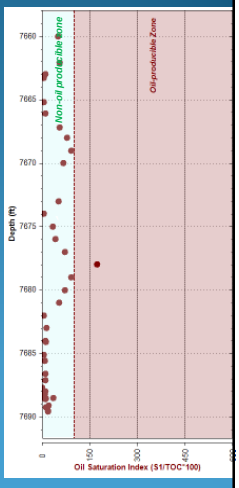
Shell Oil Co. L. Texel #21-35 (NGS #5088)



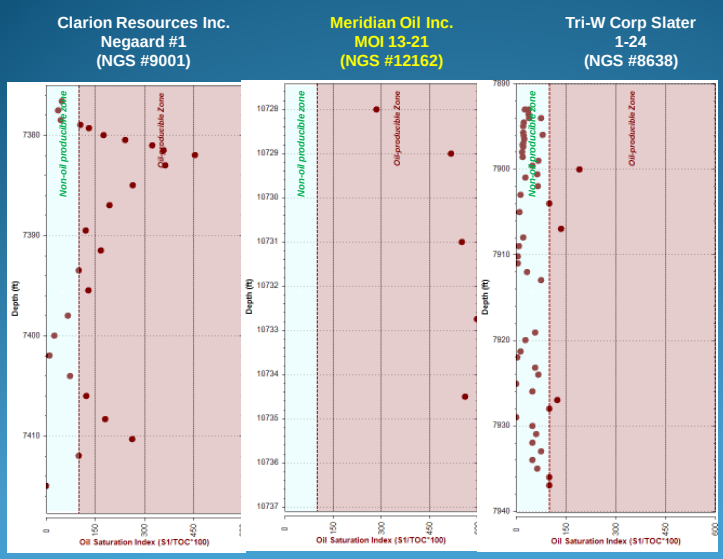
Clarion Resources Inc.Pierce 1-18 (NGS #8637)



Clarion Resources Inc. Fleckten 1-20 (NGS #8699)



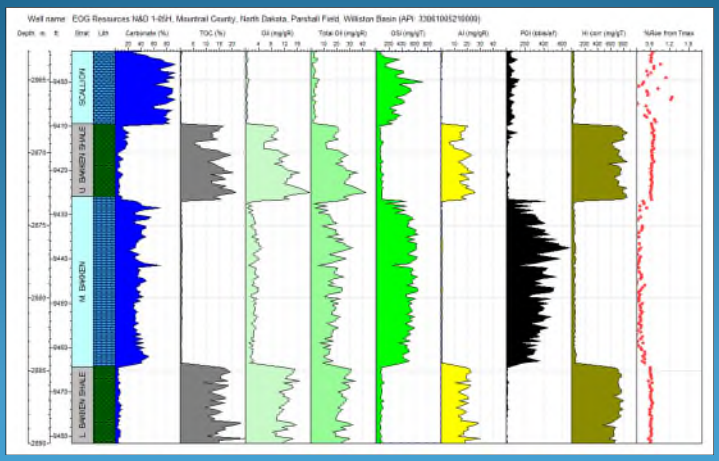
Middle Bakken Oil Saturation Index (OSI)



A pyrolysis instrument is required for measuring Oil Saturation Index values (S_1/TOC) and Wildcat Technologies is currently developing the HAWK, which is a cutting edge technology TOC and Pyrolysis instrument geared primarily at providing the unconventional shale resource system analytical needs not only in the laboratory but also directly at the rig-site

Geochemical Log of EOG Resources N&D 1-05 H Well, Parshall Field

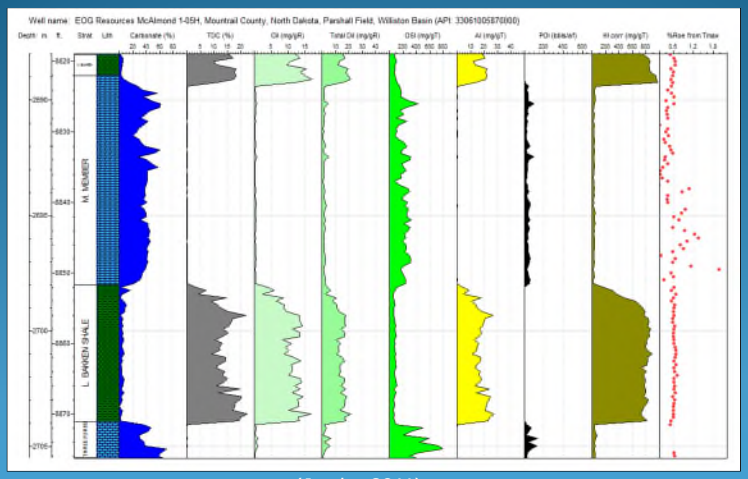
- **Overpressurred**
- **POI = OSI - AI**



(Jarvie, 2011)

Geochemical Log of EOG Resources McAlmond 1-05 H Well, Parshall Field

- Normal Pressure
- POI = OSI - AI



(Jarvie, 2011)

Summary

- Deposition of the Middle Bakken in an epicontinental, intertidal, <10 m depth setting while that of the Upper and Lower Bakken was in a deep marine environment at >200 m depth has created the "sandwich" Bakken Petroleum System .
- Conversion of kerogen in the Upper and Lower Bakken Shales to create the oil that is reservoired in the Middle Bakken is a process that can to some extent be tracked using seismic data by mapping the swarms of microfractures created in this process and which occur at the thermal maturity boundary.
- The Middle Bakken has been subdivided by various authors into between five and seven sedimentological facies, one of which is marked by occurrence of *Skolithus ichnofacies* that is also found in Sanish Sand.
- Middle Bakken zones that have the least risk for producible oil are those with Oil Saturation Index (OSI) that is greater or equal to 100.
- Oil Saturation Index (OSI) and Producible Oil Index (POI) are critical parameters for identifying "Sweet Spot" occurrence in the Middle Bakken Shale. Other useful parameters for identifying this "Sweet Spot" are occurrence of swarms of horizontal microfractures and light gases ($C_1 - C_4$).

Thank you !

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