The Three Forks and Pronghorn in McKenzie Co., ND: More Than a Simple 'Basin Centered Oil Accumulation'*

Mark Millard[1] and Murray Dighans[1]

Search and Discovery Article #10600 (2014)**
Posted May 26, 2014

*Adapted from oral presentation at AAPG 2014 Annual Convention and Exhibition, Houston, Texas, April 6-9

[1]SM Energy, Billings, Montana, US (mmillard@sm-energy.com)

Abstract

Basin centered oil accumulations have played a significant role in the exploration of hydrocarbons in North America in recent years. The large-scale development of resource plays ("feeding the rig" and "drilling to hold acreage") often leads to an oversimplified geological understanding of key play elements. The interaction between the Pronghorn member of the Bakken Formation and the underlying Three Forks in North Dakota provides a great example of how continuously updating geological models can lead to improved understanding and lower risk in basin centered oil accumulations. The Pronghorn is a recently renamed member of the Bakken formation in the Williston Basin, North Dakota. The presence of the uppermost facies, described as grey shale with laminations of siltstone to fine-grained sandstone, has a negative impact on production of the underlying Three Forks Formation. A combination of various data types aids in understanding the influence of Pronghorn deposition on oil migration into the Upper Three Forks. In addition, Pronghorn deposition had an influence on the depositional patterns of the Middle and Lower Bakken source and reservoir intervals, which in turn negatively affects their potential. Also discussed in this talk are key drilling concerns associated with drilling near the pronghorn.

Selected References

Bottjer, R. Stertling, A. Grau, and P. Dea, 2011, Chapter 8: Stratigraphic Relationships and Reservoir Quality at the Three Forks-Bakken Unconformity, Williston Basin, North Dakota: RMAS, The Bakken-Three Forks Petroleum System in the Williston Basin, p. 173-228.

Johnson, R.L., 2013, The Pronghorn Member of the Bakken Formation, Williston Basin, USA: Lithology, Stratigraphy, Reservoir Properties: AAPG Search and Discovery Article 50808, 40 p. Website accessed May 5, 2014.
http://www.searchanddiscovery.com/pdfz/documents/2013/50808johnson/ndx_johnson.pdf.html

Lefever, J.A., R.D. LeFever, and S.H. Nordeng, 2011, Chapter 1: Revised Nomenclature for the Bakken Formation (Mississippian-Devonian), North Dakota: RMAG, The Bakken-Three Forks Petroleum System in the Williston Basin, p. 11-26.

Loucks, R.G., R.M. Reed, S.C. Ruppel., and U. Hammes, 2012, Spectrum of pore types and networks in mudrocks and a descriptive classification for matrix-related mudrock pores: AAPG Bulletin, v. 96/6, p. 1071-1098.

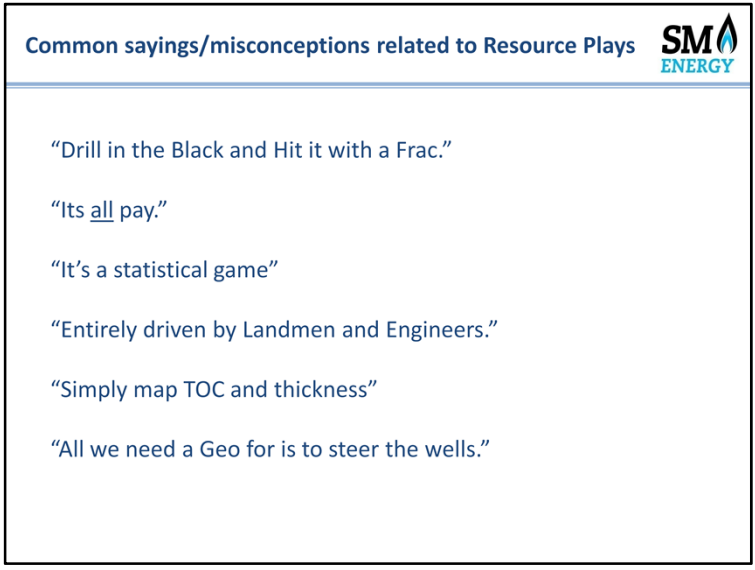
Nodeng, S.H., The Bakken petroleum system; an example of a continuous petroleum accumulation: DMR Newsletter, v. 36/1, p. 19-22.

Webster, R.L., 1984, Petroleum source rocks and stratigraphy of Bakken formation in North Dakota, *in* J. Woodward, F.F. Meissner, J.L. Clayton, eds., Hydrocarbon source rocks of the Greater Rocky Mountain region: RMAG, p. 57-81.

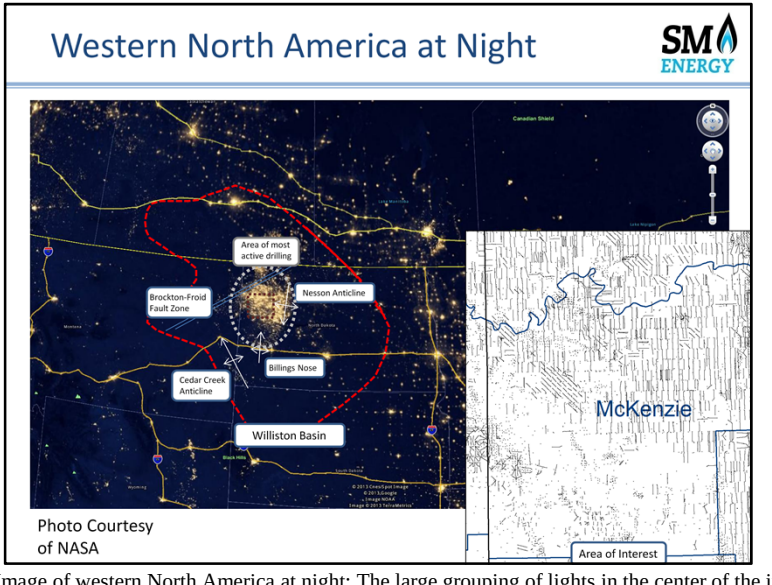
The Three Forks and Pronghorn in McKenzie Co., ND: More than a Simple "Basin Centered Oil Accumulation"

Mark Millard
Murray Dighans

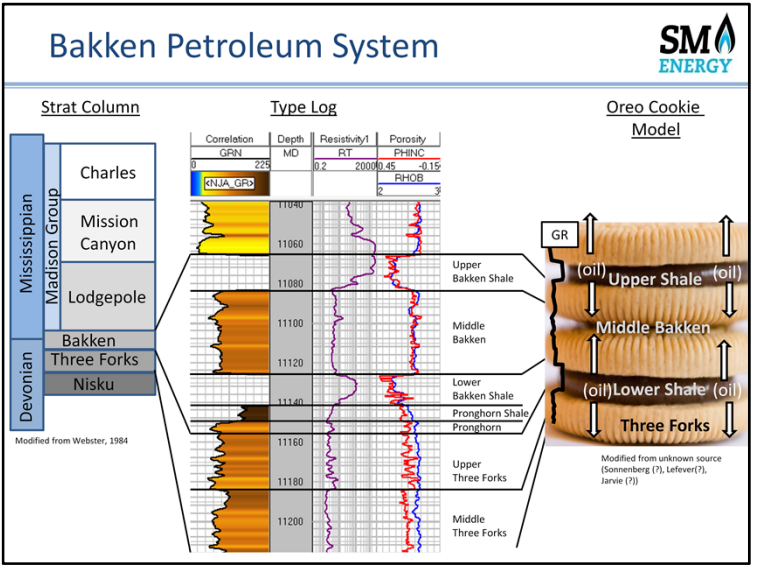
SM Energy Company
Billings, MT



Presenter’s notes: There are many common sayings/misconceptions related to resource plays. While they are amusing, they do give us some insight in to the way that [some] people view resource plays. There is a common misconception that once the "sweetspot" has been identified, no more detailed work is necessary. This is a big misconception. In this presentation, I provide an example from the basin centered Three Forks where continuous geologic characterization in a “basin centered oil accumulation” can lead to better results.



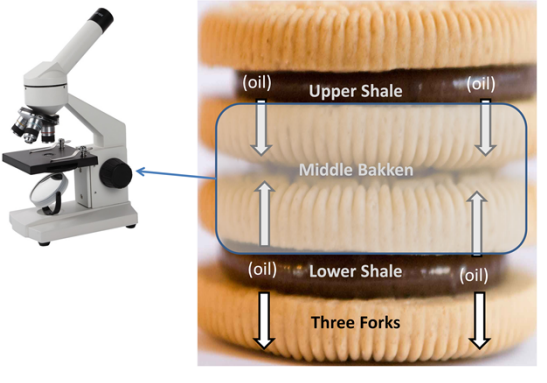
Presenter's notes: Image of western North America at night: The large grouping of lights in the center of the image is the Bakken/Three Forks oil play of North Dakota. The focus area of this talk is central McKenzie County, ND.



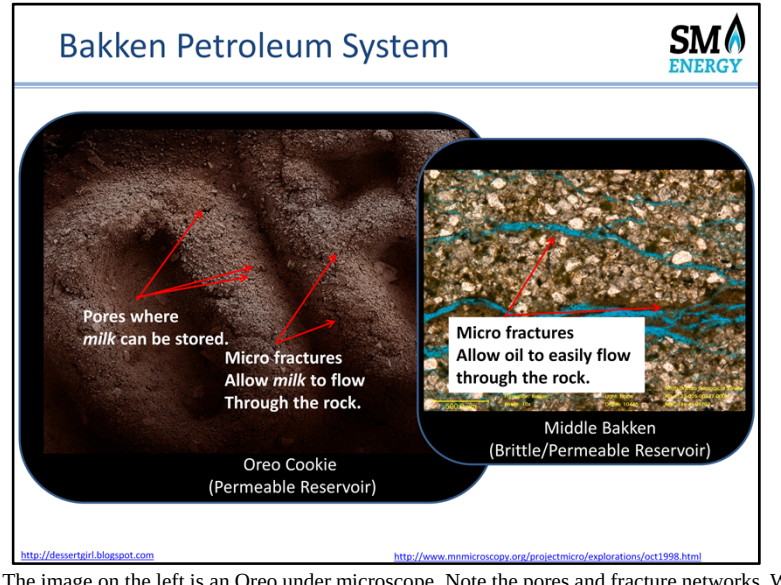
Presenter's notes: Type log for the Bakken/Three Forks Petroleum System. In the past the system has been compared to that of an Oreo cookie; the Middle Bakken and Three Forks act as the brittle reservoirs (cookie) while the upper and lower Bakken shales are the source (cream). In this talk, we will be focusing primarily on the interaction between the lower Bakken shale, upper Three Forks, and the Pronghorn "shale" (higher gamma portion of the Pronghorn).

Bakken Petroleum System

SM ENERGY



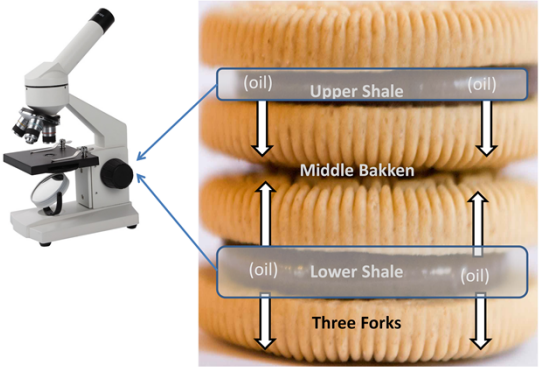
Presenter's notes: Going along with the Oreo cookie theme, I want to show the risk of using a search engine to find analogs (joke). In this case, we will be comparing microscopic images of Oreo cookies to that of the Bakken.



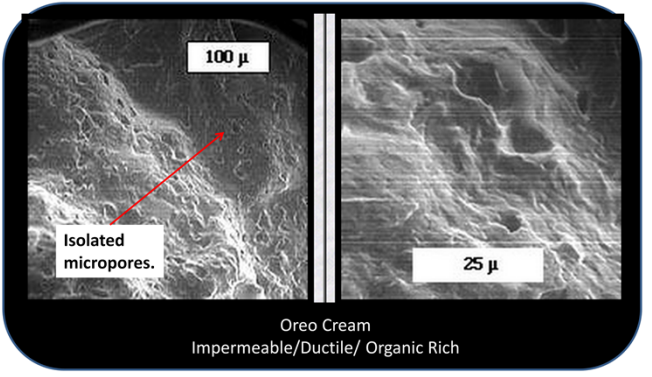
Presenter's notes: The image on the left is an Oreo under microscope. Note the pores and fracture networks. We see similar porosity and fracture systems in the Middle Bakken (again, this analogy is only in fun).

Bakken Petroleum System

SM ENERGY



Bakken Petroleum System

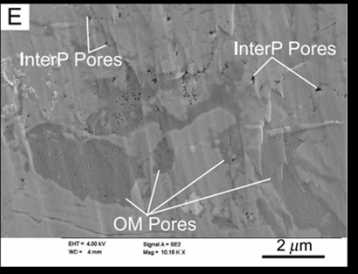


Loucks, et al, 2012

http://www.mnmicroscopy.org/projectmicro/explorations/oct1998.html

Presenter's notes: Likewise, similar trends can be seen in comparing the Oreo cream to organic shales. Note the small isolated micropores and lack of interconnectivity.

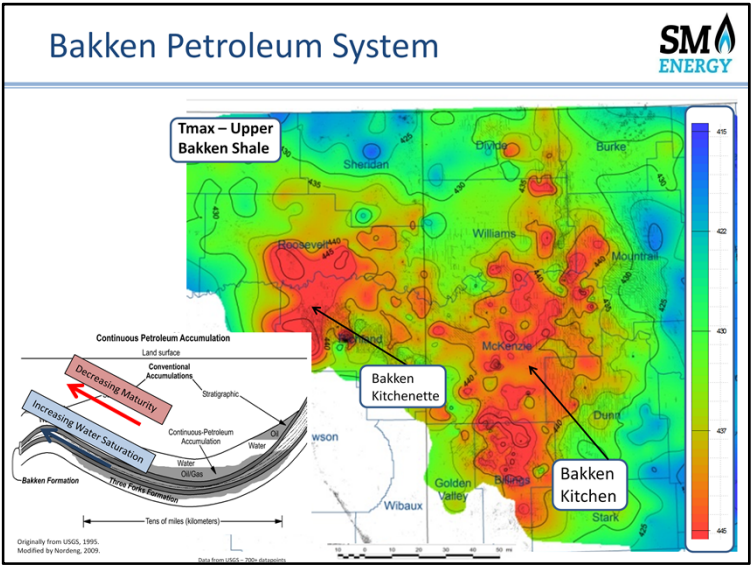
Bakken Petroleum System



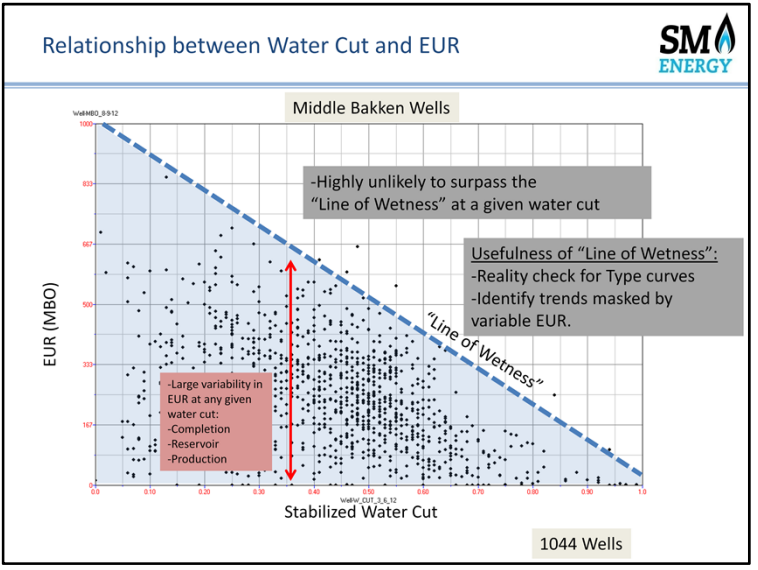
Black Shale (Mississippian Barnett)
Impermeable/Ductile/ Organic Rich

Loucks, et al, 2012

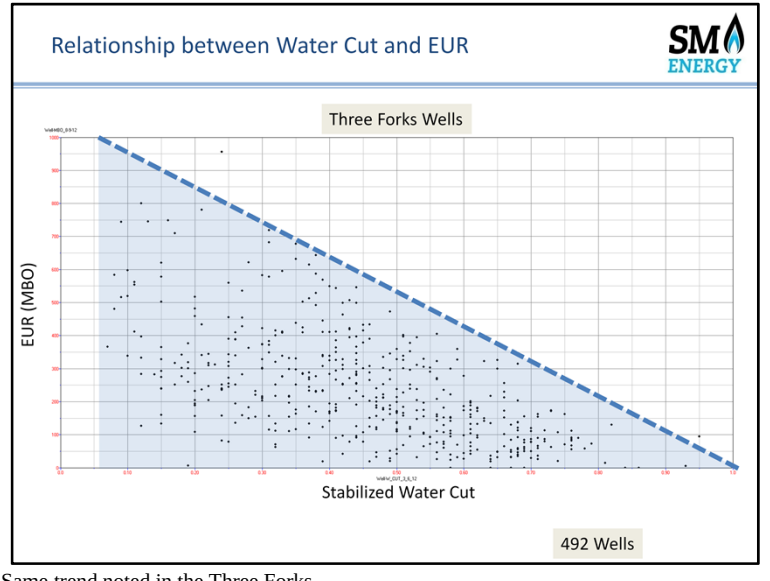
Presenter's notes: Organic rich shale (Barnett) for comparison.



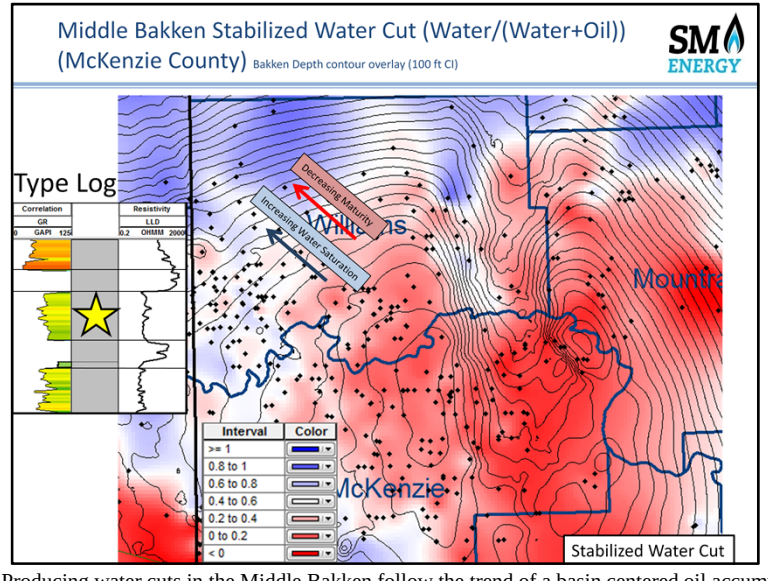
Presenter's notes: Above is a map of maturity of the upper Bakken shale (TMAX). Note red is more mature, blue is less mature. The original model for the Bakken/Three Forks (that still holds true today) is that of a "basin centered oil accumulation." Essentially, the reservoir is such poor quality that oil being generated in the shales migrates into the Middle Bakken and Three Forks and essentially stays in place (there is some migration updip, but a large quantity remains in the basin). Noted on the map are the Bakken Kitchen, and what I like to refer to as the Bakken Kitchenette, in eastern Montana.



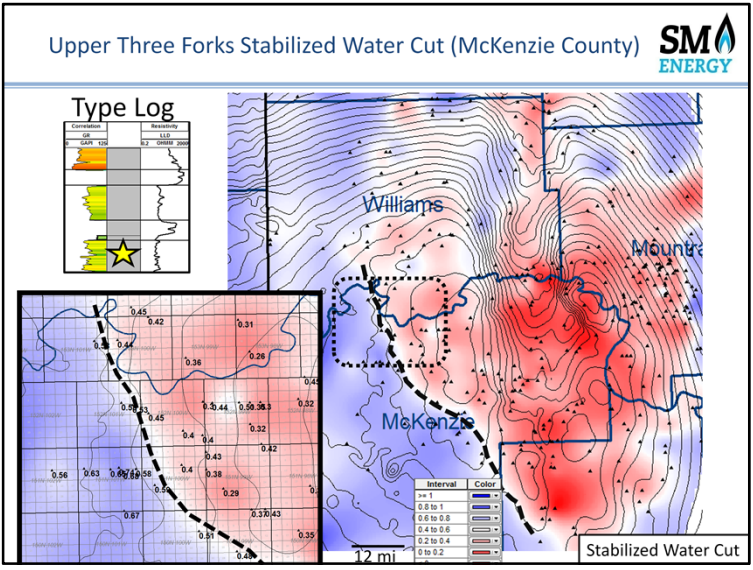
Presenter's notes: Above is a plot of EUR vs. stabilized water cut for 1044 Middle Bakken wells in the basin. At any given water cut the EUR can vary greatly due to completion style and vintage, production methods (i.e. Pumps, etc), and reservoir characteristics. While there is a large degree of scatter, a trend can be noted. At any given water cut, with current technologies, there is a line upon which EURs statistically do not surpass. I refer to this line as the "Line of Wetness." This trend can be used to reality check type curves and identify local and regional trends masked by variable EURs.



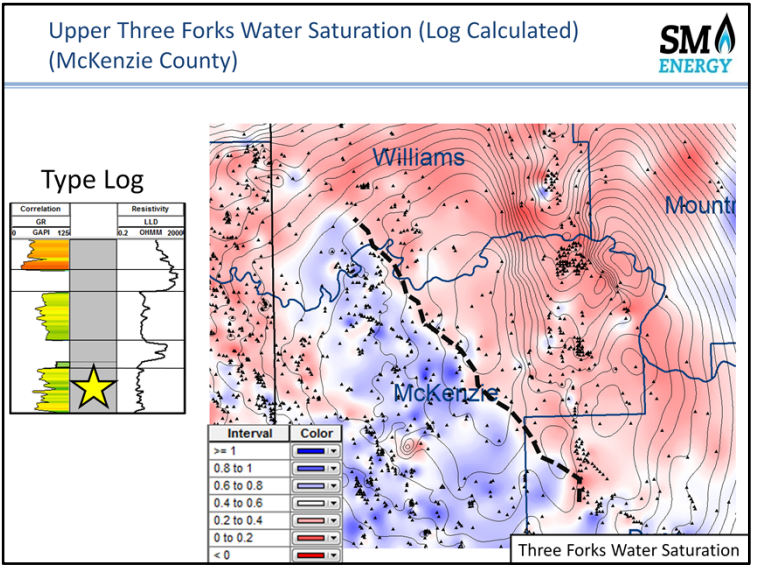
Presenter's notes: Same trend noted in the Three Forks.



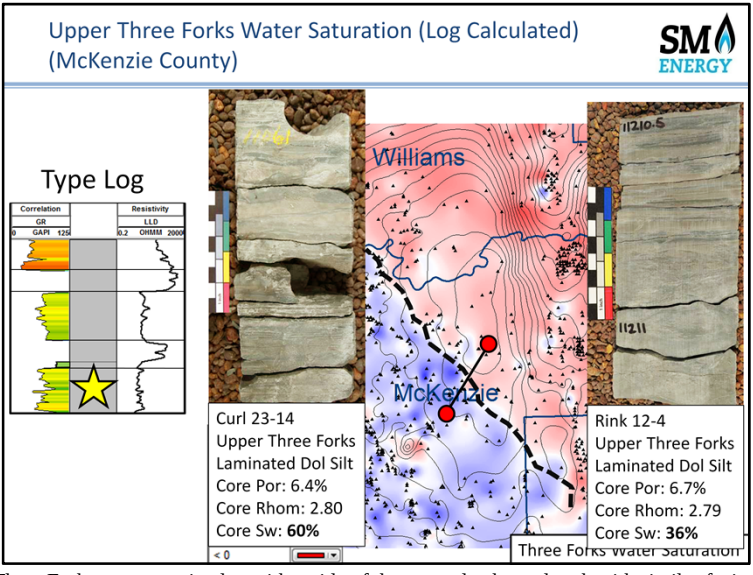
Presenter's notes: Producing water cuts in the Middle Bakken follow the trend of a basin centered oil accumulation in that wells drilled up-dip, in less mature rock, tend to produce higher water cuts while wells deeper in the basin produce lower water cuts.



Presenter's notes: However, examination of water cuts in the Three Forks tells a different story. We do see the "basin centered oil accumulation" trend to the north, east, and southeast, however water cuts in the center of the basin (moving SW) behave abnormally. In the center of the basin, where lack of maturity is not a concern, there is a very abrupt change in water cuts (changing from 30-40% to 60-70% within a few miles). In the zoomed in map you can see how quickly this change occurs. The rest of the talk will examine theories that describe the abrupt change.



Presenter's notes: Since the previous map consists of producing water cuts, it was obviously created after the fact (after wells with higher than normal water cuts were drilled). Ideally, the anomaly should be identified before drilling the wells. Above is a map of calculated water saturation that we created before any of the higher water cut wells were drilled. At the time, we noticed the large anomaly, but did not have a working model to explain it.



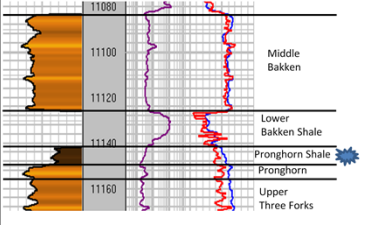
Presenter's notes: Three Forks core examined on either side of the anomaly showed rock with similar facies and similar petrophysical characteristics. The only significant variability was in the core water saturation. The next step was to focus on the impact that the overlying Pronghorn could be having on Three Forks results.

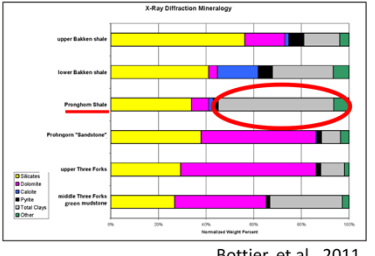
Pronghorn Member of the Bakken

SM ENERGY

- Lowest member of Bakken Formation.
- Most recently divided into 4 lithofacies (Johnson, et al., 2013).
- Divided into 2 wireline-log facies

Pronghorn Shale – Dark brown mudstone with scattered pyrite. Average 48% clay, and .5-3% toc in some intervals (Bottjer, et al., 2011, and Lefever, et al., 2011).



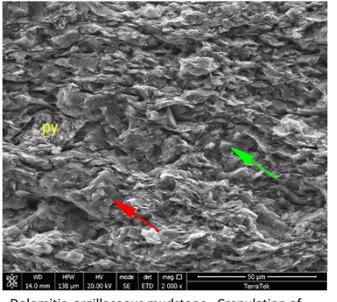


Bottjer, et al., 2011

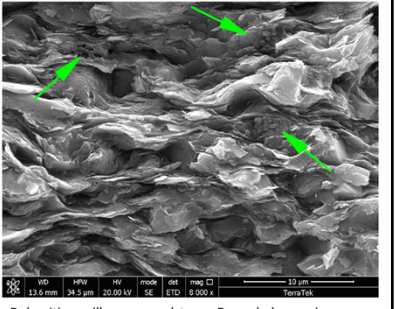
Presenter's notes: This slide covers the stratigraphy and mineralogy of the Pronghorn. In this talk, we are focusing entirely on the upper, high-clay portion of the Pronghorn. Note that the Pronghorn Shale has ~48% clay minerals based on xrd data.

Pronghorn Member of the Bakken

SM ENERGY



Dolomitic, argillaceous mudstone. Crenulation of clays. Dolomite rhombohedra (green arrow) are sporadically distributed. Some Silica cement (red). (Scale bar = 50 microns).



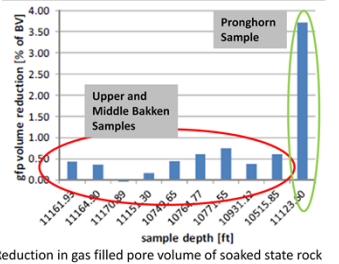
Dolomitic, argillaceous mudstone. Degraded, organic material (arrows) between clay flakes. Organic material is sparse and not interconnected. Clays appear illitic. (Scale bar =10 microns).

Presenter's notes: SEM images show the argillaceous nature of the upper Pronghorn.

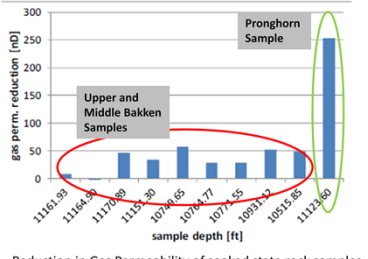
Pronghorn Member of the Bakken

SM ENERGY

Granular Imbibition Tests – Tendency of a rock to imbibe water based fluids.
Impacts permeability



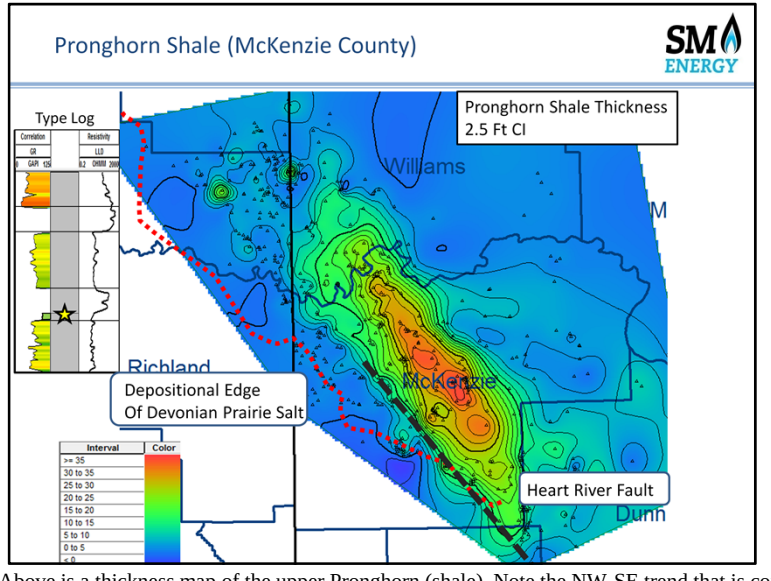
Reduction in gas filled pore volume of soaked state rock samples.



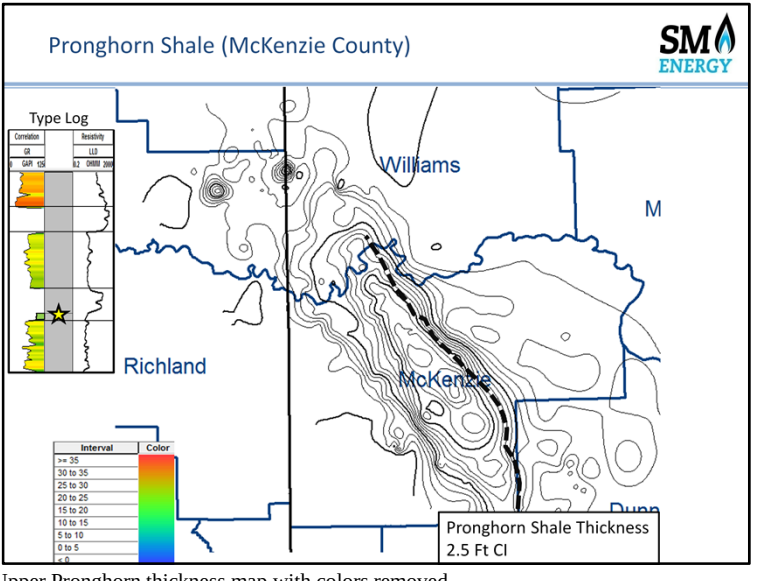
Reduction in Gas Permeability of soaked state rock samples.

Proppant Embedment - Significant embedment compared to Middle and Upper Bakken samples.

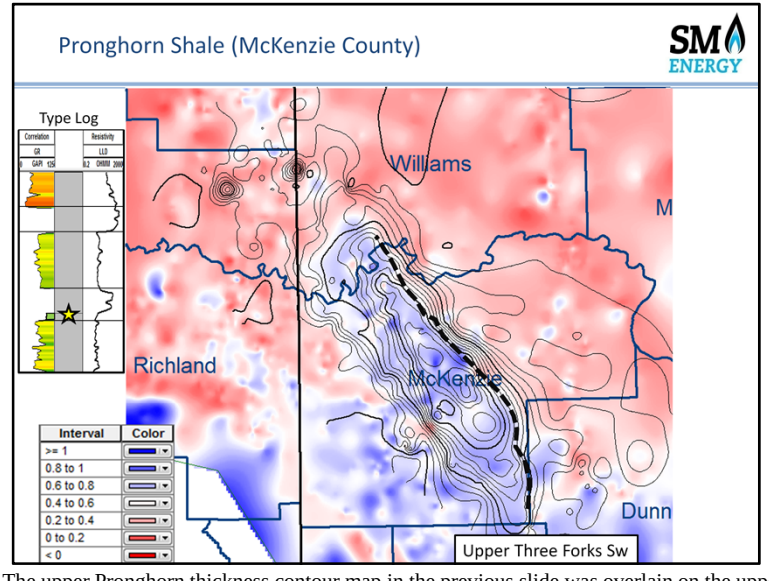
Presenter's notes: Granular Imbibition Tests were performed on various samples and show that the upper Pronghorn is highly prone to imbibition of water based fluids.



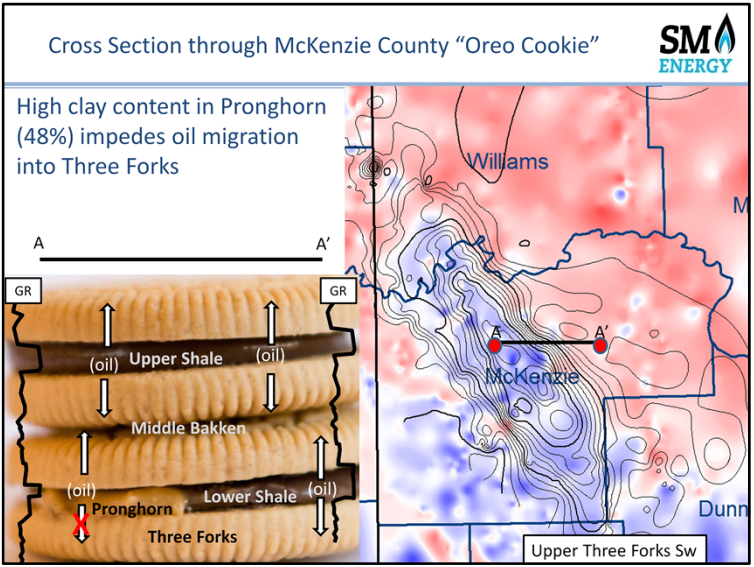
Presenter's notes: Above is a thickness map of the upper Pronghorn (shale). Note the NW-SE trend that is coincident with the depositional edge of the Devonian Prairie salt and Heart River Fault.



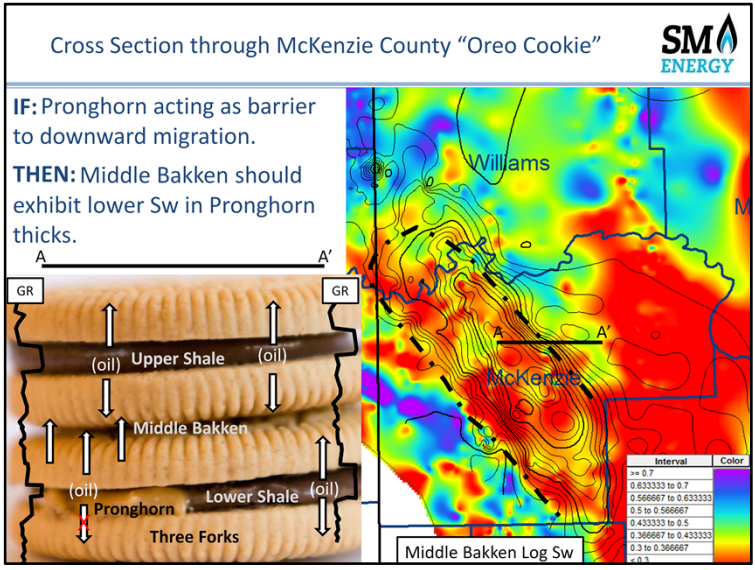
Presenter’s notes: Upper Pronghorn thickness map with colors removed.



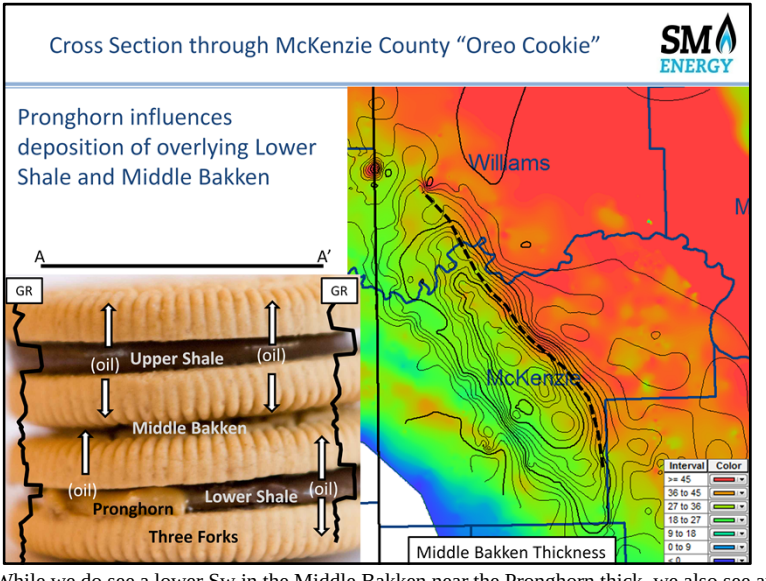
Presenter's notes: The upper Pronghorn thickness contour map in the previous slide was overlain on the upper Three Forks Sw map. Note the correlation between thickness of upper Pronghorn and water saturation of underlying upper Three Forks.



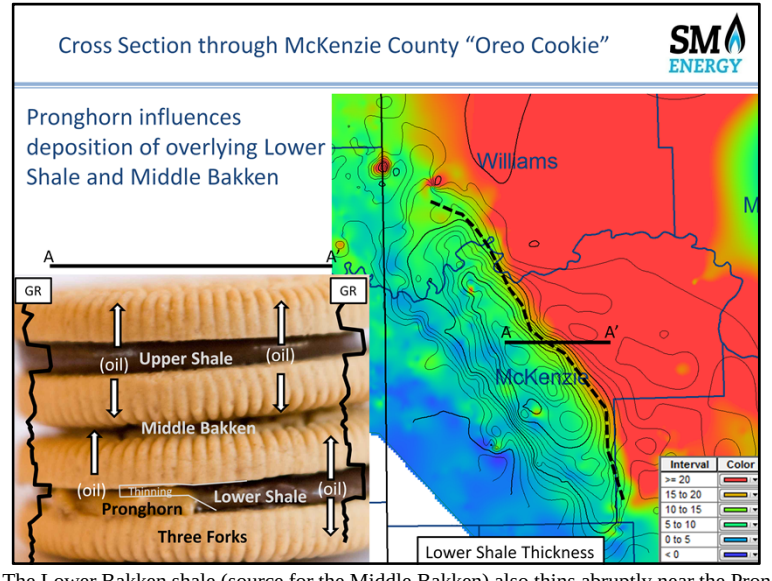
Presenter’s notes: This juxtaposition of the two maps led to the hypothesis that the high clay content in the pronghorn was impeding oil migration into the Three Forks. Note cookie cross section showing impedance of oil migration from the lower Shale into the underlying Three Forks where the Pronghorn is present. This also has another implication. It suggests that in the basin center oil does not migrate laterally for long distances within the upper Three Forks (because the Three Forks where the Pronghorn is present updip has lower oil saturations.



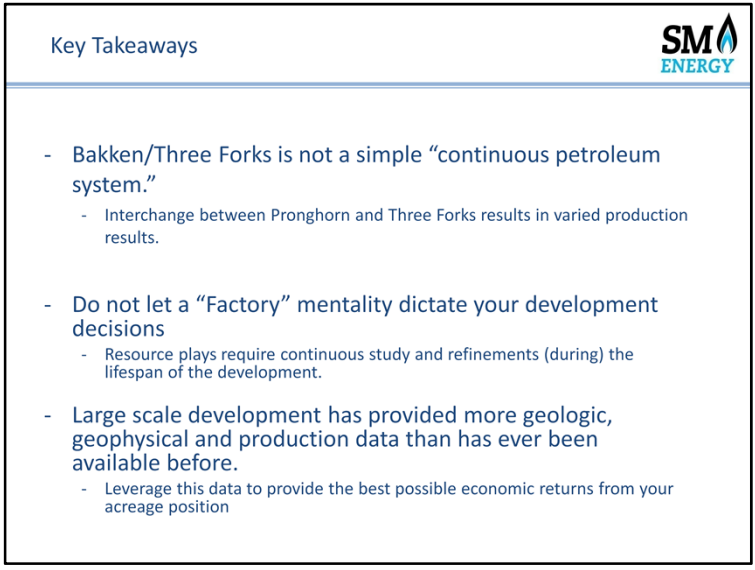
Presenter’s notes: To further test the concept that the Pronghorn is acting as a barrier to downward oil migration in the Three Forks we tested the hypothesis that “if the Pronghorn is acting as a barrier to downward migration, we should see lower Sw in the Middle Bakken in areas of thickening Pronghorn.” The map on the right is a calculated Sw map for the Middle Bakken. Note the slightly lower Sw aligned with the Pronghorn thick. With this in mind, logic would tell you that wells in the area of the Pronghorn thick should target the Middle Bakken. This concept is further explored in the next two slides.



Presenter’s notes: While we do see a lower Sw in the Middle Bakken near the Pronghorn thick, we also see an abrupt thinning of the Middle Bakken reservoir. Coupled with the thinning is a decrease in reservoir quality in the Middle Bakken.



Presenter’s notes: The Lower Bakken shale (source for the Middle Bakken) also thins abruptly near the Pronghorn, resulting in less oil being generated to source the Middle Bakken in this area.



Presenter’s notes: The interaction between the Pronghorn and Upper Three Forks, and resultant effect on well results in the central part of McKenzie County provides a great example of where detailed geologic work can significantly affect development plans, and allow operators to make more informed decisions. As an industry, we must strive to not let a “Well Factory” mentality dictate our development decisions.

Acknowledgments

Thank you to SM Energy Staff and Management

Please attend my talk at the RMR AAPG and UrTec in Denver 2014:

–Utilizing Hydrocarbon Yield Determinations to Evaluate Source/Reservoir Relationships in the Bakken/Three Forks of the Williston Basin, ND

-Mark Millard (SM Energy) and Tim Ruble (Weatherford)