[PS]Lithostratigraphy and Depositional Systems of the Bakken Formation in the Williston Basin, North Dakota*

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Search and Discovery Article #50392 (2011)
Posted March 15, 2011

*Adapted from poster presentation at AAPG Eastern Section Meeting, Kalamazoo, Michigan, September 25-29, 2010

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Abstract

The Late Devonian to Early Mississippian Bakken Formation in the Williston Basin of North Dakota is a large emerging, unconventional oil play. This unconventional gas reservoir is widespread across the intracratonic basin with an estimated 3.7 billion barrels of undiscovered, recoverable oil and has significant economic potential in portions of North Dakota, South Dakota, Montana, Saskatchewan and Manitoba. Although the Bakken interval is being drilled throughout the basin, several uncertainties remain including the environment and distribution of depositional facies, generation and migration of hydrocarbons, and controls on production. The Bakken Formation consists of a middle member bounded by two black, organic-rich shale units. Generally, the upper and lower shale members are considered to have been deposited under relatively deep marine anoxic conditions (>200 meters depth). However, the underlying Sanish sand unit and the middle member of the Bakken have been interpreted as deposited in an epicontinental sea under shallow-water high-energy conditions (< 10 meters depth). The middle member of the Bakken is a complex stacked interval of dolomitic siltstone, and oolitic or calcareous sandstone. To evaluate the inferred rapid changes in base level and the influence on depositional environments and production, log characteristics were statistically tied to core. Isopach maps of units and petrofacies of the Bakken and associated units were used to better define lithostratigraphic boundaries and petrofacies in several hundred wells distributed across a 1,000 square mile study area in northwest North Dakota. The result is an improved understanding of deposition and basin evolution for the Bakken interval.

Selected References

Meissner, F.F., 1978, Petroleum Geology of the Bakken Formation, Williston Basin, North Dakota, and Montana: MGS Twenty-Fourth Annual Conference: 1978 Williston Basin Symposium: The Economic Geology of Williston Basin, p. 207-227.

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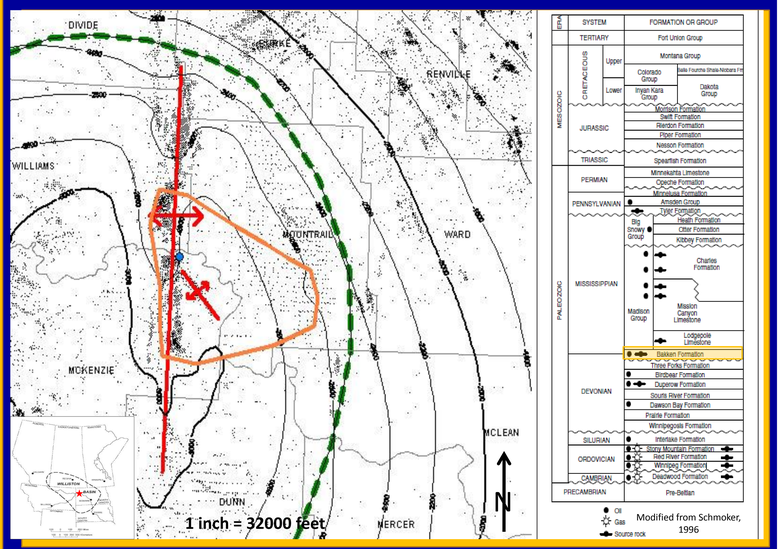
Abstract

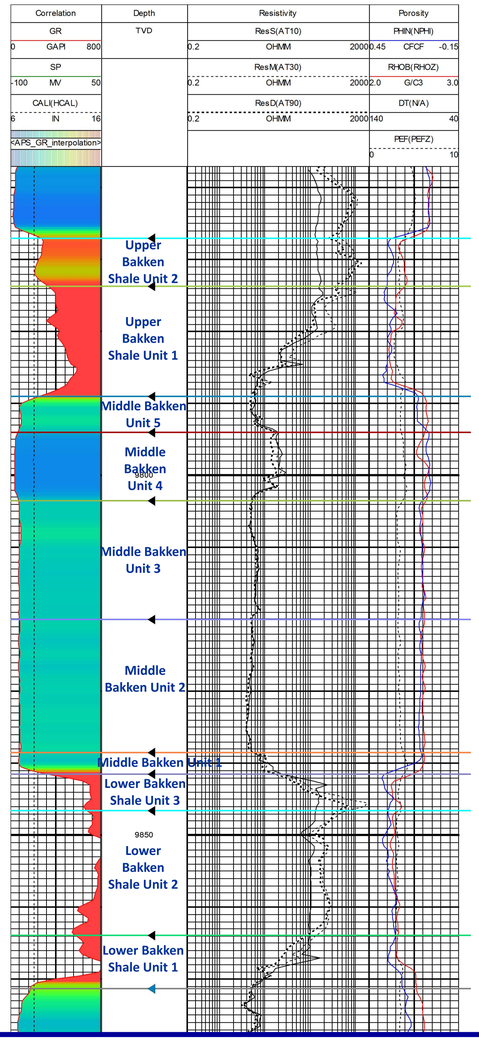
The Late Devonian to Early Mississippian Bakken Formation in the Williston Basin of North Dakota is a large emerging unconventional oil play. This unconventional oil reservoir is widespread across the intracratonic basin with an estimated 3.7 billion barrels of undiscovered, recoverable oil, and has significant economic potential in portions of North Dakota, South Dakota, Montana, Saskatchewan, and Manitoba. Although the Bakken interval is being drilled throughout the basin, several uncertainties remain including the environment and distribution of depositional facies, generation and migration of hydrocarbons, and controls on production. The Bakken Formation consists of a middle member bounded by two black, organic-rich shale units. Generally, the upper and lower shale members are considered to have been deposited under relatively deep marine anoxic conditions (>200 meters depth). However, the underlying Sanish sand unit and the middle member of the Bakken have been interpreted as deposited in an epicontinental sea under shallow-water high-energy conditions (< 10 meters depth). The middle member of the Bakken is a complex stacked interval of dolomitic siltstone, and oolitic or calcareous sandstone. To evaluate the inferred rapid changes in base level, and the influence on depositional environments and production, log characteristics were statistically tied to core. In addition log based solutions were used to generate RHOmaa Umaa cross plots and lithology composition graphs. The result is an improved understanding of depositional patterns and basin evolution for the entire Bakken interval.

Study Area & Stratigraphic Column



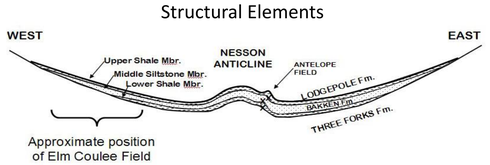
The map above displays the top of the Bakken Structure with the study area (~ 975 square miles) outlined in orange and the study well, the Sakakawea 13X-35, highlighted with a blue dot. In addition the Bakken thermal maturity boundary is depicted with a green dashed line and the Nesson and Antelope structural feature s are represented with red anticline symbols. The North Dakota portion of the Williston Basin is characterized by a semi-circular structure and is one of two depocenters which formed during the Late Devonian. Orogenic activity during the Devonian resulted in the formation of this intracratonic basin which experienced changes in base level, fluctuation of clastic input and episodic adjustment of interior platforms (Smith & Bustin, 2000).

Sakakawea Federal 13X-35
XTO Energy Inc.
Well ID: 33053028580000

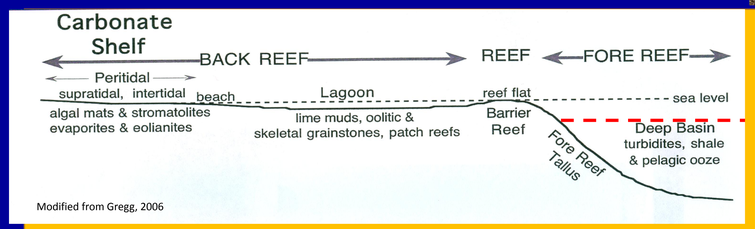


A complete Paleozoic stratigraphic section exists in the deepest portion of the Williston basin and is characterized by thick intervals of shale and carbonates. The Early Mississippian and Late Devonian Bakken Formation consists of upper and lower shale units binding a middle member which is composed of a mixed lithology of dolomitic siltstone and interbedded gray shale and calcareous sandstone. The petrofacies in the Middle Bakken have been defined by previous authors including Julie LaFever, Leigh Price and others. However the Upper and Lower Shale intervals have not received as much attention. The petrofacies in the Lower and Upper Bakken Shale were picked using a combination of well log characteristics including Gamma Ray, Neutron and Bulk density and Photoelectric curves as well as mineral matrix cross plots and lithology composition plots. A depositional model is shown below emphasizing that the Bakken shale units were deposited in a relatively deep water environment. The Middle Bakken reservoir interval was deposited during a drop in sea level and a subsequent shallower water setting.

Structural Elements



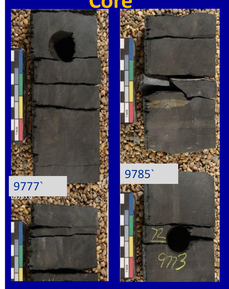
Modified from Meissner, 1978



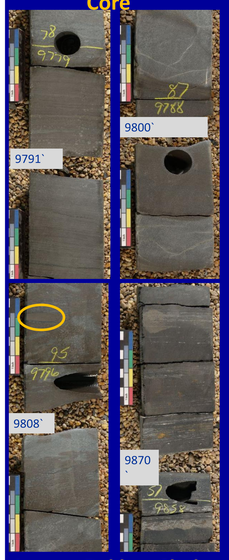
Modified from Gregg, 2006

The Lower Bakken is a very organic-rich (Gamma Ray >700 API), finely laminated shale which is very similar in lithology to the Upper Shale. Several pyrite nodules and pyrite thin beds are recognized in core. The pyrite was formed from the decomposition of organic matter in bacterial sulphate reduction. Depositional conditions for both shale intervals can be defined by restricted water circulation and little to no clastic sedimentation. In core the Middle Bakken appears to be a mixed lithology of dolomitic siltstone and calcareous sandstone. The lithofacies and sedimentary structures recognized in core suggest this interval was deposited in a far shore to carbonate shelf-like depositional setting where water depth was no greater than 10 meters and wave action was common. The Upper Bakken is an organic-rich (Gamma Ray 200-600 API), finely laminated shale with several pyrite nodules recognized in core.

Upper Bakken Shale Core



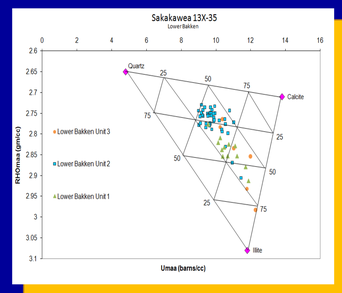
Middle Bakken Core



Lower Bakken Shale Core

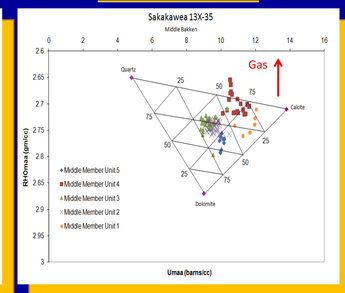
RHOmaa Umaa Plots

Lower Bakken Shale



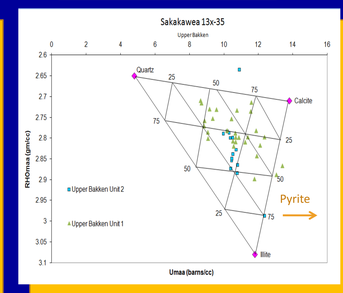
Three petrofacies of the Lower Bakken (LB) are shown in this RHOmmaa Umaa plot. LB Unit 1 is characterized by almost equal amounts of illite, calcite and quartz. LB Unit 2 is very quartz rich (~75%) and the points for this interval are nicely clustered. LB Unit 3 shows a very similar mineral matrix to LB Unit 1 which shows about 30-40% of illite, calcite and quartz.

Middle Bakken



In this RHOmaa Umaa plot MB Unit 1 is the most calcareous of the facies reading over 75% calcite and about 25-30% dolomite. MB Unit 2 reads about 40% for both calcite and quartz with about 20% dolomite. MB Unit 3 shows a similar mineral matrix as MB Unit 2 but is slightly more quartz rich. MB Unit 4 shows the cleanest lithology of mostly calcite and quartz and shows a gas affect. MB Unit 5 reveals the most dolomite (~ 50%) out of all the facies.

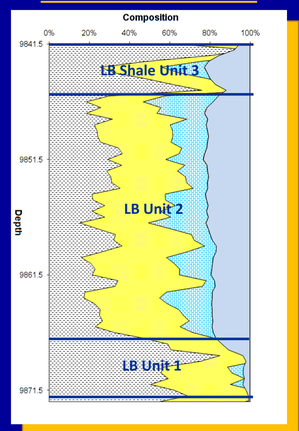
Upper Bakken Shale



The two separate petrofacies identified in the Upper Bakken (UB) Shale are shown in this RHOmaa Umaa plot. UB Unit 1 appears to have a lower clay content (< 30%) and greater amounts of calcite (~50%) and quartz (~ 20%). UB Unit 2 reveals it is more clay-rich (~50-60%) Points plotting outside of the triangle are reading a high iron content from the pyrite commonly found organic-rich shale.

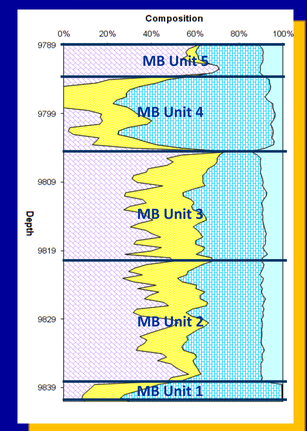
Lithology Composition Plots

Lower Bakken Shale



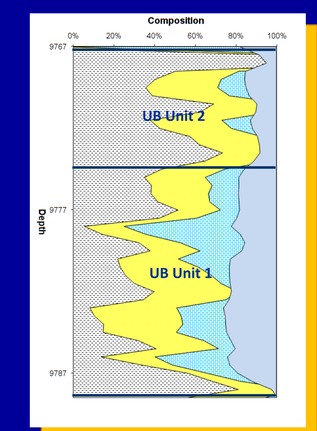
The lithology composition plot for the Lower Bakken Shale shows clay composition to be relatively high (60-70%) for LB unit 1 and 3 and rather low (20-30%) for LB Unit 2. LB Unit 2 appears to have the highest percentage of quartz (~30%) and calcite (~15-20%).

Middle Bakken



The lithology composition plot for the Middle reveals that MB Unit 1 and 4 have e dolomite and seem to be quartz te rich in comparison to the other ies. MB Units 2, 3 and 5 appear to 50-60% dolomite component and e quartz and calcite.

Upper Bakken Shale



The lithology composition plot for the Upper Bakken Shale shows UB Unit 1 to be less clay rich than UB Unit 2. Clay percentage is as high as 70-80% in UB Unit 2. UB Unit 1 shows a large abundance of calcite (20-30%) and quartz (30-40%).

Conclusions & Future Work

- The use of RHOmma Unaa cross plots and lithology composition plots provide further insight to the variations in mineral matrix and lithology of the entire Bakken interval without limitation to the Middle Bakken
- Isopach maps of the petrofacies of the Bakken and associated units will be used to better define lithostratigraphic boundaries
- Further investigate water depth at the time of deposition for the Upper and Lower Shale Units
- Sedimentary structures and natural fractures are able to be identified in cored intervals

Acknowledgements

- United States Department of Energy provides funding for this research
- The North Dakota Oil and Gas Commission provided data for the project including the digital and raster logs as well as core photos
- TGS well log services provided several smart rasters

References

Meissner, 1978, Petroleum Geology of the Bakken Formation, Williston Basin, North Dakota and Montana
Pitman, Price, & LaFever, 2001, Diagenesis and Fracture Development in the Bakken Formation, Williston Basin: Implications for Reservoir Quality in the Middle Member
Smith & Bustin, 2000, Late Devonian and Early Mississippian Bakken and Exshaw Black Shale Source Rocks, Western Canada Sedimentary Basin: A Sequence Stratigraphic Interpretation