North Dakota Geological Survey
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Log-to-Core Cross-Section, Middle Member Bakken Formation, North Dakota

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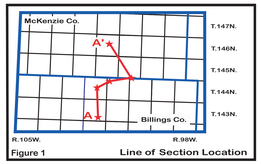


Figure 1 Line of Section Location

Exploration activity is focusing once again on the Bakken Formation in the Williston Basin. The current activity began in Richland County, Montana in 2001. Success in Richland County has resulted in the expansion of the play into North Dakota. Over the past several months, companies have been acquiring acreage throughout the western portion of the state. Horizontal drilling of the shales was the focus of the Bakken play in the late 1980's and early 1990's. New activity is pursuing the middle member. Although highly productive in Canada, this interval has had only limited production in the U. S. portion of the basin, which has so far been confined to vertical wells along the northern Nesson Anticline.

Many questions about the Bakken Formation remain unanswered. This poster session will show some preliminary results from an on-going study of the middle member, and will present representative logs and photos of core, and relate some of the problems associated with both.

The Bakken Formation, as traditionally understood, consists of a lower organic-rich black shale, a middle siltstone member, and an upper organic-rich black shale, all in an onlap relationship. Core data show the actual lithologic succession to be more complex. Additional organic-rich black shales occur locally in the upper Three Forks Formation and middle Bakken member. Also problematic is the presence of the "Sanish Sand", a productive lithology generally associated with the Three Forks Formation; it occurs in core above the third (lowest) Bakken shale.

It may be more appropriate to refer to the Bakken Formation as a nearly isolated source system, extending from the uppermost portion of the Three Forks Formation to the lowermost portion of the Lodgepole Formation. Extensive oil analyses suggest that there has been very little migration of oil from the formation. Oil migration from the Bakken has been documented at only one location, the Dickinson Lodgepole mounds. Even in the Dickinson area the migration is minimal, as the mounds are immediately adjacent to or close to the contact with the Bakken Formation. Lack of evidence for large scale expulsion from the Bakken shales and the presence of extremely tight overlying and underlying rocks suggests that oil generated within the Bakken remains in the Bakken (Price and LeFever, 1994)

The cross-section (Figure 1) is oriented in a roughly north-south direction across the depositional limit of the middle member and extends from McKenzie to Billings Counties. The corresponding well logs have been digitized and are displayed in Cross-section A-A'. Where possible all of the log types are displayed. All of the wells selected have been cored through the middle member of the Bakken Formation. Representative samples for each of the lithofacies present are displayed in the corresponding core section. This section is intended for illustrative purposes only and does not depict the actual thickness of the lithofacies.

The middle member of the Bakken Formation reaches a maximum thickness of 140 feet just to the east of the Nesson Anticline. It consists of a sequence of highly argillaceous, well-cemented siltstones and sandstones. Seven lithofacies can be recognized in this sequence in North Dakota (Figure 2), and can be traced throughout the entire Williston Basin in core. Local variations to these lithofacies occur. Determining the areal extent and thickness of the facies based on log signatures is more problematic because the section is highly argillaceous. Although Lithofacies 3, a cleaner sandstone/siltstone section, is easily identified on wireline logs, the rest of the lithofacies require frequent log-to-core correlation.

The lowest lithology of interest in the log section is the "Sanish Sand", which occurs at the top of the Three Forks section, and is a prolific producer on the Antelope structure. The sand is similar to that of the middle member and may belong more appropriately to the Bakken Formation than the Three Forks. The sand is distinctly different from the underlying Three Forks Formation, and where the contact is present in the core there is generally an abrupt shift from tan sand to an interbedded sequence of well-cemented apple-green and tan shales and siltstones. It has a more limited areal distribution than the Bakken and appears to be tied to dissolution of the Prairie Salt. Along the southern limit of the Bakken, near the current edge of the Prairie, the Sanish can be seen to thicken and thin in response to the dissolution. There is an additional Bakken Shale (third shale) section present below the sand in one core from Billings County. The very fine-grained sandstone is highly burrowed and contains porosity and permeability similar to the middle Bakken section. The lithologic characterisitics and the areas of proven Sanish production suggest this may be an additional pay in the section. However, care needs to be taken when tracking this section on wireline logs. The log character changes depending on the adjacent rock type. The most reliable method discovered for determining the presence of the "Sanish Sand" is to correlate upward from the top of the Birdbear. Additional section on top of the three cycles of the Three Forks is "Sanish Sand".

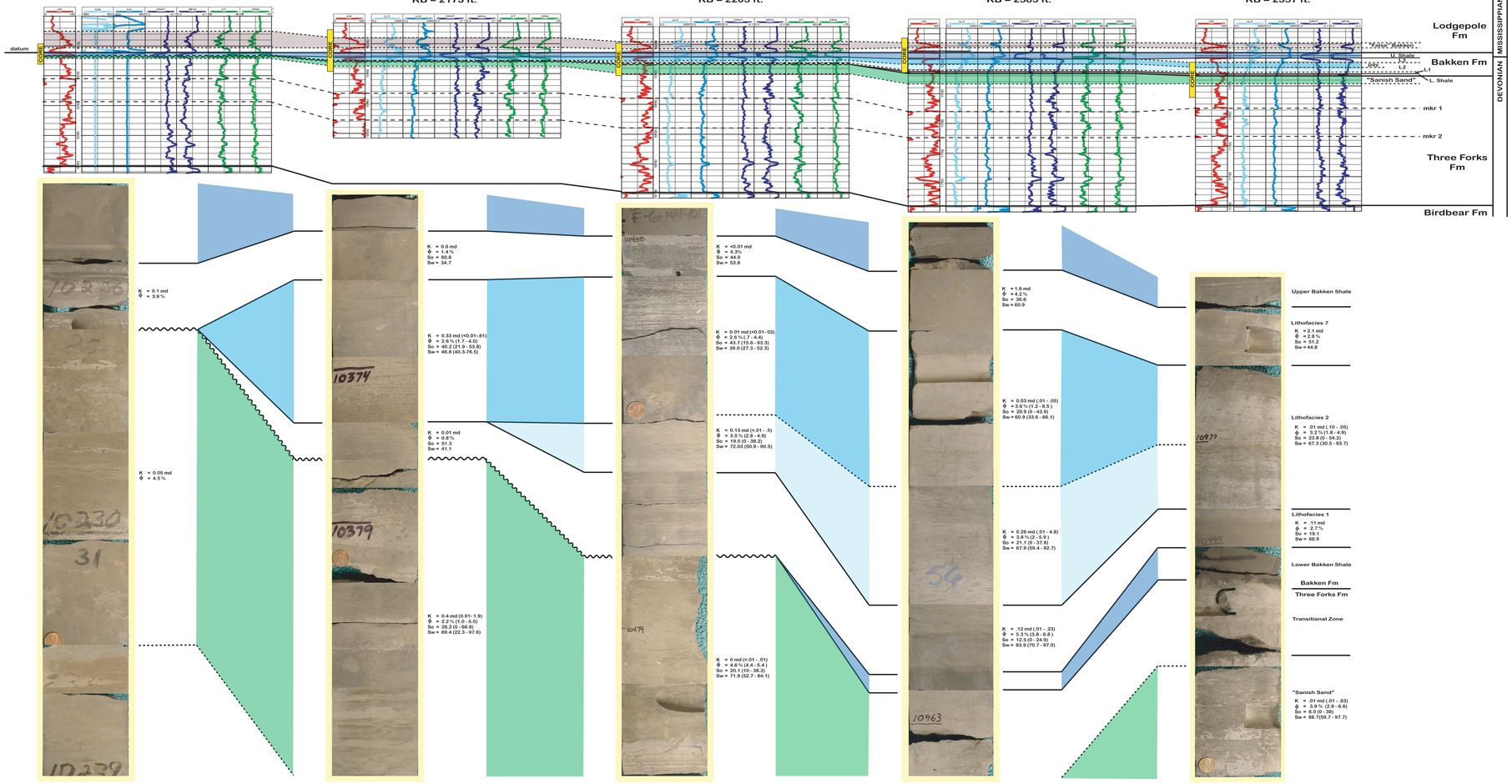
Middle member lithofacies 1 and 7 occur throughout the basin. The facies are thin (1-4 ft), immediately above or below the contact with the shales and are characterized by an increase in organic matter towards the shale contact, abundant disseminated pyrite, and no fossils. Lithofacies 1 is transitional from the lower Bakken shale, and lithofacies 7 is transitional to the upper Bakken shale. Lithofacies 2 overlies lithofacies 1 and is present throughout the basin. Within the study area it consists of two parts, a lower siltstone with abundant clay drapes and an upper highly burrowed siltstone. The upper portion is equivalent to the pay zone in Richland County, Montana. The burrowed section is cleaner on the gamma-ray curve than the underlying clay drape section, although this depends on the surrounding rock type. Where Lithofacies 3 is present, the entire section appears highly argillaceous. Porosity values measured from wireline logs vary for Lithofacies 2. A comparison of porosities measured from wireline logs, shows the porosity value from the sonic logs to be consistently greater than from the density-neutron logs. This may be due to the high amount of clays within the section. A limited comparison of the cross-plot porosity to porosity values actually measured in core analyses indicate that the value indicated by the density curve is closer to the actual measured value than that based on the sonic logs. Porosity is directly related to the degree of dolomitization of the calcite cement within the rock. The corresponding resistivity values are generally low for the section in producing wells.

The gravity of Bakken oil ranges from 38 to 45 degrees API. Although measured porosity values for the play in Montana are generally low, between 8 and 12 percent, this extremely light oil sandwiched between tight rock within the hydrocarbon window could produce extensive accumulations of oil. There is probably production potential from all of the lithofacies within the middle member.

Price, L.C., and LeFever, J.A., 1994, Dysfunctionalism in the Williston Basin: the Bakken/mid-Madison Petroleum System: Bull. of Canadian Petroleum Geology, vol. 42, no. 2, p. 187-218.

Middle Member Lithofacies Figure 2

	Upper Member
L7	SILTSTONE, massive, dense, mottled, dolomitic, argillaceous, grey-green, fossiliferous, disseminated pyrite, rhythmites up to 15 cm thick in lower half of section (occassionally fossil-rich), slightly bioturbated, contact with upper member sharp.
L5 & L6	PARALLEL INTERBEDS OF DARK GREY SHALE AND BUFF SILTY SANDSTONE, moderately bioturbated, vertical burrows, calcareous, disseminated pyrite, overall coarsening-upward, flame and load structures at base of coarse laminae, rhythmites up to 10 cm thick, upper half may display trough cross-bedded sandstone beds, gradational lower contact with underlying unit.
L3 & L4	SANDSTONE, tripartite division with upper and lower third wavy and flaser bedded silty sandstone gradational to and from the middle coarse-grained sandstone which may be massive and/or bedded (trough and tabular cross-bedding, inclined and horizontal laminae, and swash cross-stratification) with pebble and fossil-rich lags (shale clasts up to 4 cm diameter where B2 overlies the lower member, and feldspar clasts). Mainly quartzose with minor feldspar disseminated pyrite, buff to green, calcareous, slight to no bioturbation.
L2	PARALLEL INTERBEDS OF DARK GREY SHALE AND BUFF SILTY SANDSTONE, moderate to very strong bioturbation disrupting laminae, dolomitic becoming calcareous with depth, disseminated pyrite, fossiliferous, lower contact gradational, upper contact gradational or erosive where channelling, grey-green.
L1	SILTSTONE, massive, dense, mottled, very calcareous, argillaceous, grey-green, highly fossiliferous, random orientation of fossils, disseminated pyrite, lower contact may be either gradational over several centimeters or erosive.
	Lower Member



Core photos are for illustrative purposes and do not depict actual lithofacies thickness.