Oil Production from the Bakken Formation: A Short History

By Julie LeFever

Once again the Bakken Formation is in the news as oil prices rise. Over the years the State of North Dakota has seen several episodes of drilling to try to recover a portion of the immense amount of oil that this formation has generated. Beginning with the initial discovery in 1953, the Bakken has been a significant contributor to the North Dakota economy. Over 44 million barrels of oil have been produced from this formation, and there is a large potential to add to that total with the current oil play.

Although a significant quantity of oil has been produced from the Bakken it is only a fraction of what the Bakken is capable of producing. Long considered to be a premier source rock, science places the oil potential of the Bakken between 10 and 400 billion barrels of oil (L.C. Price, pers. commun.). A comparison of the past drilling activity in the Bakken Formation with the current play provides a new insight into how technology can potentially unlock oil from this virtually untapped resource.

Plays of the Bakken Formation
Pre-1987

Early exploration for Bakken oil was by conventional vertical drilling and began with the discovery of Antelope Field (Fig. 1B). Oil was recovered in Antelope Field from the Bakken Formation in 1953 when an unsuccessful Madison test (Stanolind Oil – #1 Woodrow Starr (SWSE Sec. 21, T152N, R94W)) recovered oil on a drill stem test. The well was completed for 536 barrels of oil (BO) and essentially no water. Offsets to this well were disappointing, so further development did not occur until 1956 when Northern Pump Co. drilled and completed the #1 Ella Many Ribs for 320 barrels of oil per day (BOPD). The majority of the wells for the field were drilled in the 1950's and 60's. During the 1980's, renewed interest in the Antelope structure resulted in the drilling and completion of a number of wells along the southern end of the feature.

Wells were completed in Antelope Field in both the Bakken Formation and underlying thin, highly burrowed porous silty sandstone referred to as the "Sanish Sand". Early wells in the field were drilled with a salt-based mud system; this was later changed to an oil-based mud system to prevent dissolution and the resulting casing collapse of the overlying Madison salt section. Typical completion methods consisted of perforating the well followed by a sand-oil fracture stimulation treatment. The prominent occurrence of natural fractures along the structure enhanced the production.

The field has been highly successful. Fifty-two wells produce or have produced along the structure with an average initial production (IP) of 209 BO. The field produced 67,798 BO in 2003 and has a cumulative total in excess of 12.5 million barrels of oil and 10 billion cubic feet (BCF) of gas.

After the development of Antelope Field, exploration of the Bakken proceeded slowly. The tight, impermeable reservoir of the Bakken required

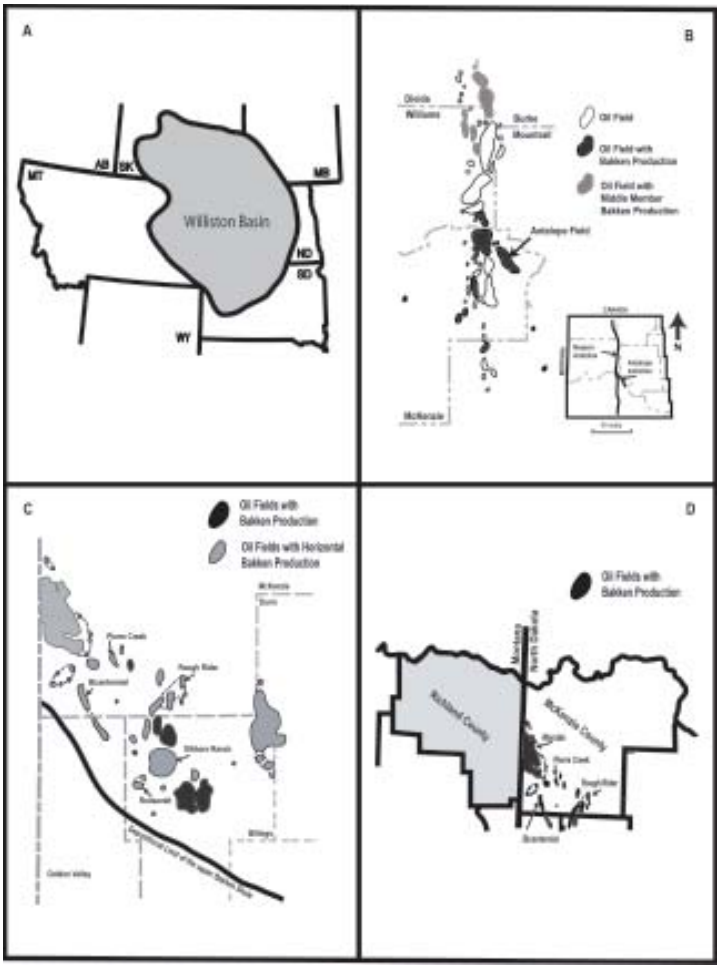

Figure 1. – A) Location map of the Williston basin. B) Fields with production from the Bakken Formation along the Nesson anticline. C) Fields producing from the Bakken along the "Bakken Fairway". D) North Dakota fields with Bakken production adjacent to Richland County, Montana.

natural fractures in order to produce. The next discovery in the formation did not occur until 1961 when Shell Oil Company used seismic methods to discover Elkhorn Ranch Field along the depositional limit in what is now known as the "Bakken Fairway" (Fig. 1C).

This was a typical Williston basin discovery. The well was an Ordovician Red River test that recovered oil on a drill stem test in the Bakken. The Shell Oil Company - #41X-5-1 Government (NENE Sec. 5, T143N, R101W) was subsequently completed and tested 136 BOPD and a trace of water. However, the well was located in a remote area and was often shut-in during inclement weather. It produced an average of 50 BOPD until 1964, when its casing collapsed and the well was plugged and abandoned. Further development of the Bakken did not occur in this area until 1976.

Another notable discovery at this time was along the Nesson anticline. The #1 B.E. Hove (SWNW Sec. 2, T154N, R95W) was drilled by Pan American Petroleum Corporation in Hofflund Field. During its initial test, the well flowed 756 BOPD and 3 barrels of water per day (BWPD). This well was perforated and then treated with 10,000 gallons of acid. Production problems resulted in two workovers with additional acid treatments followed by a water-based fracture stimulation. The well produced for two years with a cumulative production of 62,700 BO. It was plugged in 1969 due to non-commercial production and collapsed casing.

Continued exploration for Bakken oil occurred along the "Bakken Fairway". Wells along the "Bakken Fairway" are not limited to Bakken production. Most of the fields have multiple pays that are associated with structural features such as folds, faults, or both. These features contribute to the fracturing of the Bakken and may enhance the quality of the reservoir. The ability to produce from other formations makes it much more cost effective. The drilling activity in this area began in the late 1970's.

In the "Bakken Fairway", the formation exhibits an on-lapping relationship. The stratigraphy of this area is relatively simple. The Three Forks Formation is overlain by the remaining, stratigraphically higher, members of the Bakken. The Bakken, in turn, is overlain by the carbonates of the Lodgepole Formation. As the Bakken thins, it becomes much more susceptible to fracturing and, as shown by previous drilling, fracturing is necessary for production.

Successful wells were those that encountered natural fractures. Less than successful wells, those not encountering natural fractures, were perforated in the Bakken shale and produced for a while. Oil was collected or diesel was substituted for produced oil and used as part of a sand/oil fracture stimulation treatment. This treatment was necessary for economic reserves.

Successful wells were also drilled with oil-based fluids. The Bakken shale is an oil-wet reservoir and wells that had water introduced to the system had difficulty unloading the water. Introduction of water into the system could be through drilling fluids, acidizing, or fracture stimulation methods. Acidizing Bakken wells also creates additional problems, as the treatment may react with the pyrite present in the shales forming an iron hydroxide precipitate.

The long history of vertically drilling the Bakken set the stage for horizontal drilling. Vertical drilling established that the wells with significant vertical production were draining fractured reservoirs. It also helped to determine the proper methods necessary to successfully complete a Bakken well. The production decline curves display a characteristic rapid drop in production over the first year, followed by steady production with virtually no decline.

Post-1987

Drilling activity along the "Bakken Fairway" changed greatly after Meridian Oil, Inc. drilled and completed the first horizontal well in the Bakken Formation. The #33-11 MOI, was initially drilled vertically. It was cored, logged, and drill stem tested, all of which indicated that the formation was tight. Meridian then backed up the hole and kicked off at 9,782 ft. Horizontal drilling was attained at 10,737 ft (measured depth) with a resulting radius of 630 ft. The well was completed on September 25, 1987 for 258 BOPD and 299 thousand cubic feet (MCF) of gas. The well had a horizontal displacement of 2,603 ft and is now producing in the upper Bakken shale that is 8 ft thick. The decline curve for the #33-11 was remarkably stable for the first two years until additional nearby wells came online. The well has produced 357,671 BO and 6,381 barrels of water (BW) through December 2003.

The success of this well set off the previous notable play dealing with the upper Bakken shale. Operators were eager to use horizontal well technology to encounter more fractures and thus produce more Bakken oil. As in any play, there was a learning curve. The #33-11 MOI took 57 days to drill and complete; 27 days to drill the vertical borehole and 12 days to drill the horizontal section at a cost of $2 million. The third set of ten wells drilled by Meridian, further down the learning curve, had an average cost of $1.08 million and took 35 days to drill. By the end of the play, Meridian Oil, Inc. was touting the fact that they could drill and complete a horizontal Bakken well for essentially the same price as the drilling and completion of a vertical well, around $900,000. Successful wells were capable of producing high volumes of oil (IP's in excess of 1900 BOPD).

The play continued into the early 90's. During the play, 22 operators drilled horizontal wells. Half of these operators were involved in one or two well programs. The early horizontal wells were medium-radius wells with one 2500

to 3500 ft horizontal leg. They were drilled underbalanced or slightly underbalanced with an inverted mud system and completed with slotted liners tied back to casing. It was not uncommon to be stuck in the hole extending the drilling time and the expense of the hole. The wellbore still had the same sensitivity factors to fluids that were encountered in the vertical holes. If the wells did not encounter naturally occurring fractures there was no production and no ability to stimulate the wellbore in an attempt to connect with a regional fracture system.

Another problem occurred with the horizontal Bakken shale play. Interference between wellbores was well documented to extend over a large portion of the Fairway. Horizontal wellbores could have an effect on a vertical wellbore 2500 to 3000 ft away. The large scale regional fractures are highly interconnected, causing pressure and fluid communication to extend over several sections. Interference between wells would not show up immediately, but would generally become apparent after a month of continuous production. Routine maintenance included periodic removal of salts and fines that would accumulate in the bottom of the wellbore.

2001 to Present

The Bakken Formation is once again in the spotlight. The current drilling activity began in 2001 and is largely centered in Richland County, Montana (Fig. 1D). Success is pushing the play to move into North Dakota. Leasing activity within the State has been high over the past several months in anticipation of the play moving across the border. To date, there is one reportable well drilled with numerous permits for additional wells.

Middle Member Bakken Play
Richland County, MT

The stratigraphy of the play area is relatively simple (Fig. 2). It consists of the Bakken Formation onlapping the underlying Devonian Three Forks Formation. Each successively higher member within the Bakken has a greater distribution than the preceding member. The members eventually pinch out against the Three Forks Formation in southern Richland County. In the main play area, only the upper two-thirds of lithofacies 2 and the overlying upper shale member of the Bakken remain. Impermeable rocks of the underlying Three Forks and the overlying Mississippian Lodgepole as well as the pinch out of the facies provide the trapping mechanism.

The Balcron Oil - #44-24 Vaira (SESE Sec. 24, T24N, R54W) has a well defined log characteristic for the porosity zone of interest (Fig. 3). The distinctly cleaner gamma-ray log is typical of the pay zone and is mappable over a large area (Fig. 4). A log porosity of approximately 10% can be calculated for the pay zone.

The Three Forks consists of interbedded tan fine-grained sandstone to siltstone and light brown claystones. Structures include parallel laminations that are locally brecciated (probably due to the dewatering of the sediments) and ripple laminations. The sequence is highly cemented and impermeable, forming a good bottom seal.

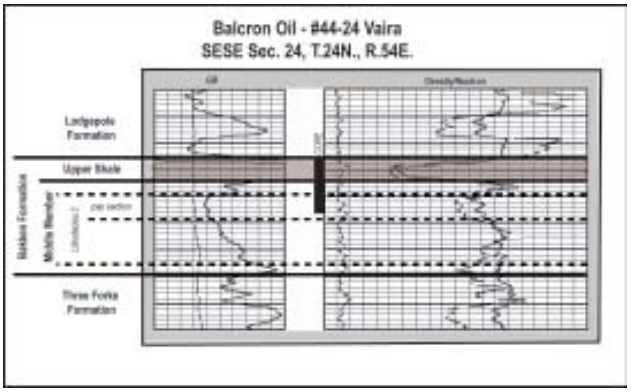

Figure 3. – Typical wireline log from Richland County, Montana. Log shows the pay section that is the horizontal target.

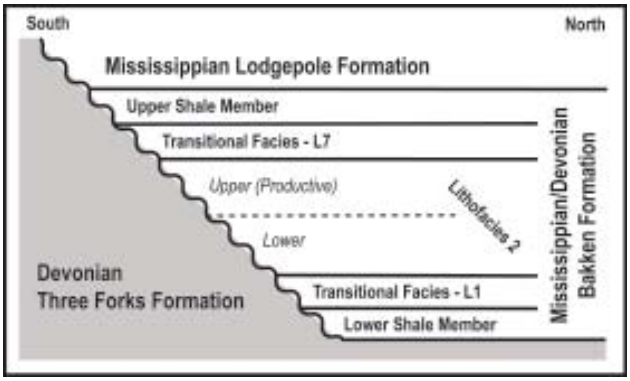

Figure 2. – Stratigraphy of the Bakken Formation in the play area of Richland County, Montana.

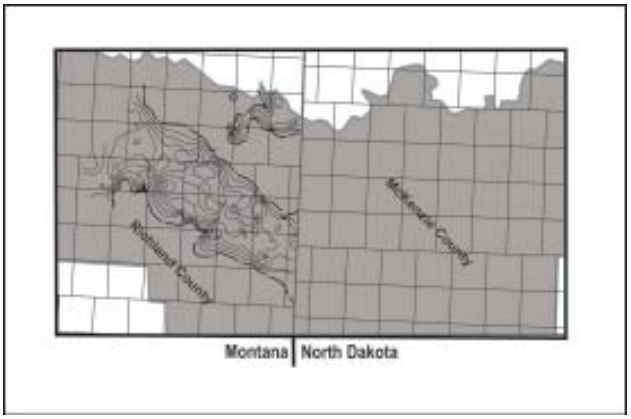

Figure 4. – Isopachous map of the pay zone within Richland County, Montana (CI=2 ft).

The lower Bakken shale is absent over most of the play area in Montana, and the middle member sits unconformably on the underlying Three Forks. It is common to see abundant debris along the contact between the Three Forks and the middle member siltstone. The basal portion of the Bakken middle member consists of a brownish-grey, argillaceous siltstone. Burrowing and small clay drapes are present. Immediately above the clay drape section is a dolomite or an equivalent bioturbated siltstone/sandstone sequence that is the producing zone in Montana. This is then overlain by a thin transitional zone and the upper Bakken shale.

The middle member of the Bakken Formation gradually thickens towards the center of the basin in North Dakota where it attains a maximum thickness of 90 ft (Fig. 5). An isopachous map of pay section in lithofacies 2 shows why the play is where it is (Fig. 4). There is a noticeable trend approximately 2 to 3 townships wide by 72 miles long. Along this trend, the middle member reaches a thickness of 35 feet and then thins somewhat before continuing its gradual thickening towards the center of the basin. The thickness of the producing interval reaches a maximum of 14 feet and has consistent log porosity between 8 and 12%.

The other porosity zone contoured (to the north) is one that occurs within the middle member (Fig. 4). This zone has limited distribution and occurs between the two shales. Facies changes, like this, within the middle member suggest that these may be common and potentially productive. Other additional lithofacies identified in other areas of the basin can be easily mapped and are potentially productive (LeFever et al., 1991).

The other notable feature of the play is the influence of the Devonian Prairie Salt. Indicated by the solid black line on Figure 5, the trend present in Montana appears to be directly related to the dissolution of the underlying salt. The trend that is strongly present in Montana can be traced into North Dakota as far as Mondak field. As the state line is crossed, the edge of the Prairie shifts to the south and locally terminates the trend. The lithofacies is traceable in North Dakota but shifts location due to the presence of the salt.

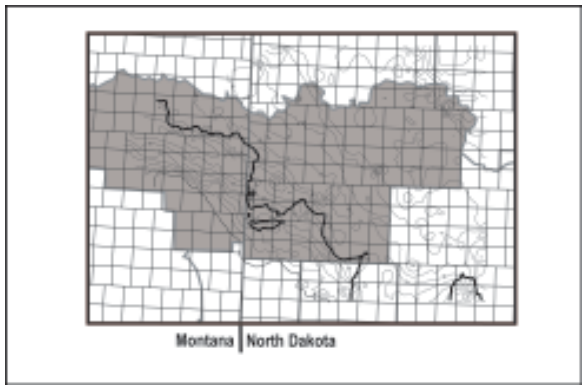

Figure 5. – Isopachous map of the middle member of the Bakken Formation (CI=5 ft). Richland County, Montana and McKenzie County, North Dakota are shaded. Heavy black line represents the edge of the Devonian Prairie Salt.

North Dakota

Production from the middle member of the Bakken is not new to North Dakota. There have been a few wells, primarily along the northern Nesson anticline that have been perforated in and produced from the Bakken middle member (Fig. 1B). The Bakken in these wells was not the primary target; that was deeper usually the Devonian Winnipegosis Formation. Wells producing from the Bakken were perforated because they were reaching their economic limit or had no other production potential. Production from these wells was limited.

Five lithofacies within the middle member of the Bakken Formation have been identified throughout Montana, North Dakota, Saskatchewan and Manitoba (Fig. 6). In ascending order, they are:

1) Lithofacies 1 consists of light grey, greenish-grey, or brownish-grey argillaceous siltstone. It is generally massive, cemented with calcite, and has scattered pyrite nodules and fossils (crinoids and brachiopods). Locally the unit is burrowed. Porosity is intergranular.

2) Lithofacies 2 consists of greenish-grey to brownish-grey, argillaceous siltstone or sandy siltstone to brownish-grey, very fine grained sandstone. Small scale clay drapes are present, as well as burrows.

3) There are three parts to Lithofacies 3. The upper and lower third consists of wavy to flaser bedded, light to medium grey, argillaceous to sandy siltstones and brownish-grey, very fine-grained sandstones with local claystones. The middle third consists of a medium grey, dark grey, or greyish-tan, fine- to medium-grained sandstone that may be massive, cross-bedded, or thinly laminated.

4) Lithofacies 4 consists of alternating medium grey argillaceous siltstones, light to medium grey very fine-grained sandstones and dark grey shale. The unit is thinly laminated, displays planar and ripple laminations, is moderately bioturbated in places, and locally cemented.

5) Lithofacies 5 is a medium to light grey, massive to wispy laminated siltstone that is generally cemented.

Most of the production from the middle member in North Dakota prior to the start of this oil play was from Lithofacies 3. As described above, it is a sandstone-siltstone bed that occurs throughout the northern portion of North Dakota and extends into Saskatchewan and Manitoba. It is highly productive in Saskatchewan with a long production history from Rocanville and Roncott Fields. In North Dakota, production from this facies is marginal and found in 9 fields along the northern Nesson Anticline including Temple, Stoneview and North Tioga (Fig. 1B). It has an easily mappable wireline log characteristic throughout North Dakota with a notably cleaner response on the gamma-ray curve (Fig. 7).

All of the wells producing from Lithofacies 3, with the exception of one, were completed as a bailout zone. This facies is generally less argillaceous, coarser grained and better cemented than the rest of the middle member. Thickness of the pay zone is 12 ft with 7 to 12% porosity. Well completions generally consisted of acidization and a gelled water-sand fracture treatment. It is interesting to note that the best producer in Stoneview underwent the least amount of acid treatment.

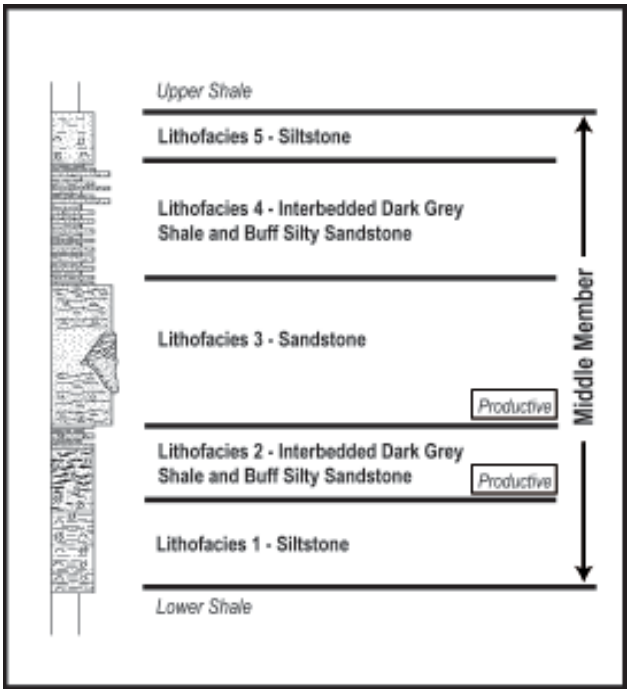

Figure 6. – Diagram showing the lithofacies present in the middle member of the Bakken Formation throughout the Williston basin. Lithofacies 2 is productive in Richland County, Montana. Lithofacies 2 and 3 are productive in North Dakota.

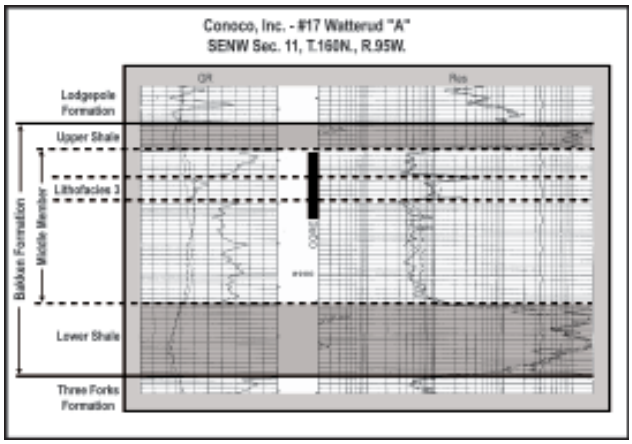

Figure 7. – Typical log of the producing section along the northern Nesson anticline. Lithofacies 3 is the pay section of the Joilette Oil (USA), LLC. - #1-17R Robert Heuer.

Drilling and Completion of Bakken Horizontal Wells

Technology has finally caught up to the Bakken Formation. The ability to fracture stimulate these horizontal wells is what makes this play work. Whereas, in the late 80's-early 90's wells had to rely on encountering natural fractures to supply the oil; the wells in this play create their own fractures.

Wells generally consist of two 4000 to 5000 ft laterals drilled on a 1280-acre spacing unit. Also, unlike the previous play, the middle member is drilled with saturated brine instead of inverted mud. The zone generally has between 7 to 12% porosity, a permeability of .01 to .02 md, and 70 to 80% oil saturation. Once drilled, the well is then treated with a 650,000 to 1 million pound gelled water-sand frac. Due to high gas content, it is common for the wells to flow for quite a while before having to be put on pump.

The per well cost is approximate $2.2 million with the potential for the well to produce 500 to 700 BOPD initially, leveling off at 250 BOPD with virtually no water.

North Dakota

The first horizontal well of this play in North Dakota was drilled and completed on March 3, 2004 in Lithofacies 3. It was a re-entry of a 1981 Madison test in Sadler Field by Joilette Oil, Inc. - #1-17R Robert Heuer (SESE Sec. 17, T161N, R95W). One lateral leg was drilled with a sidetrack. The lateral was then treated with gelled water-sand frac and tested. Reported results for the initial potential test were 87 BOPD, 150 MCF of gas, and 142 BWPD. Cumulative production to date on this well is 14,838 BO, 12,021 MCF of gas and 4,515 BW.

Although results were not like what has been seen in Montana, this is a different facies, which will probably require adjustments to the completion method. This is also the initial well in the play and there is always a learning curve.

Conclusions

The middle member Bakken play is well on its way in Montana. Prior to the start of the play, Richland County had 80 producing fields in the county with 23 producing from the Bakken Formation. Data from the Montana Board of Oil & Gas show that 50 wells produced from the Bakken prior to the current play. By the end of August 2004, 127 wells had production from the Bakken. Ninety-four horizontal wells have been drilled into the Bakken with 92 producers, one PNA (plugged and abandoned), and one dry hole. Additionally, numerous permits have been issued. The impact of the current activity is easy to see based on the total production from Richland County. Production has doubled since 2003, and is still increasing.

The same facies that produce in Montana are present and potentially productive in North Dakota. There may be slight changes in composition, locally rocks may be slightly more silty/sandy or more argillaceous so adjustments may have to be made to drilling or completion techniques.

North Dakota has a thicker section of the Bakken middle member. Additional section may suggest additional targets for horizontal drilling. Production has already been proven from one of the higher lithofacies. There is also an additional section at the base of the Bakken, the "Sanish Sand". This is a significant producer at Antelope Field and occurs throughout the "Bakken Fairway". This highly burrowed sandstone/siltstone facies is probably related to salt collapse and may be productive in the fairway area. Another potential target may be the lower Lodgepole Limestone between the upper Bakken shale and the "False Bakken". Detailed mapping of all the zones will be required to determine the best location to tap into the Bakken resources.

The ability to stimulate horizontal wells is driving the play. Past history has shown that the Bakken doesn't give up its oil easily. It requires some sort of fracture system and in the past nature controlled the system. Now, that fracture system can be artificially generated to open the Bakken up to production. The drilling of these wells with 2 long horizontal legs and stimulating them with a large frac treatment is expensive ($2.2 million) but can lead to a very profitable well especially at current oil prices. The potential for success from horizontally drilling the middle member is great. There will be a learning curve associated with these wells, just as there is in every other play.

References Cited

LeFever, J.A., Martiniuk, C.D., Dancsok, E.F.R., and Mahnic, P.A., 1991, Petroleum potential of the Middle Member, Bakken Formation, Williston Basin, *in* Christopher, J.E. and Haidl, F.M., eds., Sixth International Williston Basin Symposium: Saskatchewan Geological Society Special Publication No. 11, p. 74-94.