Technology-Based Oil and Natural Gas Plays:
Shale Shock! Could There Be Billions in the Bakken?

This report presents information about the Bakken Formation of the Williston Basin: its location, production, geology, resources, proved reserves, and the technology being used for development. This is the first in a series intending to share information about technology-based oil and natural gas plays. Questions or comments on the contents of this report should be directed to Steven G. Grape at steven.grape@eia.doe.gov or (214) 720-6174.

Through the use of technology, U.S. oil and natural gas operators are converting previously uneconomic oil and natural gas resources into proved reserves and production.

The Bakken Formation of the Williston Basin is a success story of horizontal drilling, fracturing, and completion technologies. The recent, highly productive oil field discoveries within the Bakken Formation did not come from venturing out into deep uncharted waters heretofore untapped by man, nor from blazing a trail into pristine environs never open to drilling before. Instead, success came from analysis of geologic data on a decades-old producing area, identification of uptapped resources, and application of the new drilling and completion technology necessary to exploit them. In short, it came from using technology to convert unconventional resources into reserves.

Figure 1. The Williston Basin

Location

The Williston Basin is in the north central United States, underlying much of North Dakota, eastern Montana, northwestern South Dakota, and southern Saskatchewan and Manitoba, Canada (Figure 1).

The Bakken Formation can be encountered throughout the Williston Basin. It is 11,000 feet deep in the depocenter (see Glossary) of the basin in the southwest corner of North Dakota. The depth of the Bakken rises to 4,500 feet deep on the eastern edge of the basin, and up to 3,100 feet deep (950 meters) on the northern edge, across the Canadian border in Manitoba and Saskatchewan.

The Bakken Formation was formally described (named) by geologist J.W. Nordquist in 1953. His samples came from the Amerada Petroleum - H.O. Bakken #1 well on the Nesson Anticline in Williams County, North Dakota. Henry Bakken was the surface owner where the well was drilled.[1]

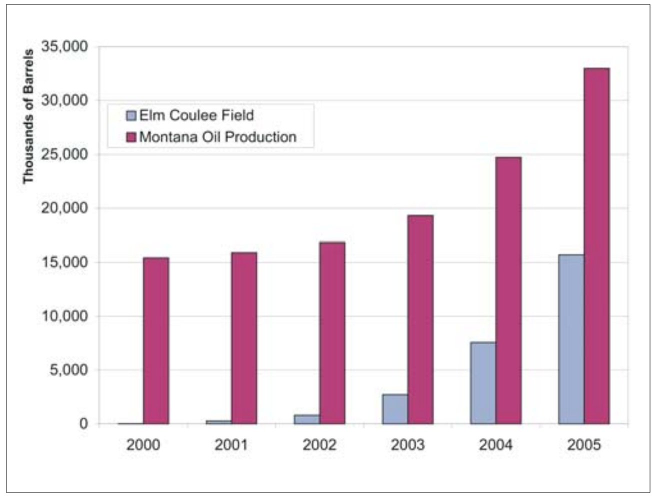
The current U.S. development activity in the Bakken Formation is located in Richland County, Montana, and McKenzie, Golden Valley, and Billings Counties, North Dakota. The largest discovery to date within the Bakken Formation is the Elm Coulee Field of Richland County, Montana.

Booming Bakken Production

Montana reports that the Elm Coulee Field, which is completed in the middle member of the Bakken Formation, has doubled its oil production for the third year in a row in 2005.[2]

Discovered in 2000 and now grown to 529 square miles, the Elm Coulee Field produced 15 million barrels of oil in 2005. It now accounts for almost 50,000 barrels of oil per day, about half of Montana's crude oil production (Figure 2). This level of production would not have been attained without application of the most recent horizontal drilling and completion techniques.

Figure 2. Montana & Elm Coulee Field Oil Production



Source: Montana Department of Natural Resources[2]

Resources

The resources of the Bakken Formation are defined by the United States Geological Survey (USGS) as unconventional "continuous-type" oil resources. This means the hydrocarbons within the Bakken have not accumulated into discrete reservoirs of limited areal extent. Other examples of "continuous-type" oil or natural gas resources are from low-permeability (tight) formations (e.g. Austin Chalk), shales, and coalbeds.

The success of horizontal drilling and fracturing efforts in Montana are prompting reevaluation of earlier resource assessments for this play. The 1995 USGS Assessment of Resources estimated that the Bakken Fairway, Bakken Intermediate, and Bakken Outlying plays (combined) resources were large, but estimated that only 151 million barrels (mean estimate) were technically recoverable.[3] The Bakken Intermediate (8,185 square miles) included the area of the Elm Coulee Field.

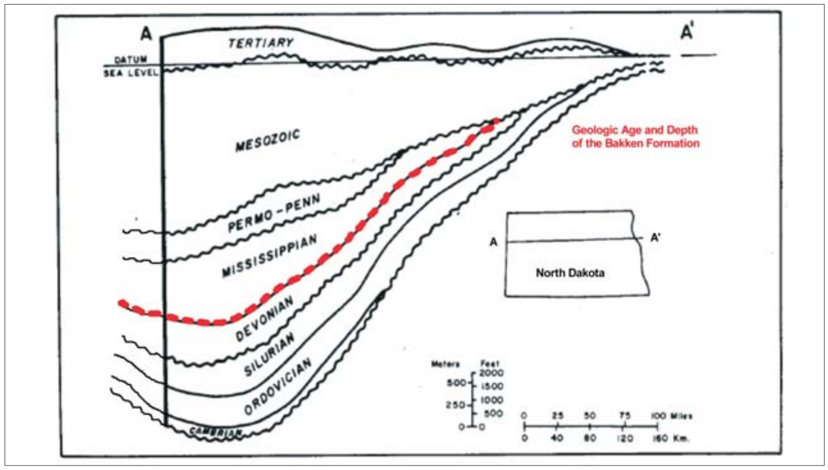
In contrast to the older USGS estimate, Headington Oil Company, one of the two largest operators in the Elm Coulee Field, now estimates that the in-place resources of the Elm Coulee Field area are 5 million barrels per square mile.[4] With an assumed 10-percent average recovery factor, Headington estimates primary oil recovery could be 270 million barrels from the Elm Coulee Field.[5]

With new horizontal drilling and completion technology taken into account, the technically recoverable resource base for the entire Bakken Formation is potentially much larger. A draft study by the late organic geochemist Leigh Price[6] provides estimates ranging from 271 to 503 billion barrels (mean of 413 billion) of potential resources in place. The study represents Dr. Price's work as it stood at the time of his death in August 2000. It was conducted while he was working for the USGS, but it did not receive a complete scientific peer review by the USGS and was not published as a USGS product. A new assessment of the entire basin, due out in about a year, will provide an updated USGS estimate of the technically recoverable oil resources in the Bakken Formation. If the formation's potential bears out, this could (depending on recovery factors) increase the estimate of technically recoverable crude oil resources in the United States by billions of barrels. For perspective, consider that the current estimate of all technically recoverable crude oil resources in the United States, not including Bakken oil resources, is 174.67 billion barrels.

Geology

The Bakken Formation was deposited during the Upper Devonian Period and Lower Mississippian Period, some 417 to 350 million years ago (Figure 3).

Figure 3. Geologic Age and Depth of the Bakken Formation



Sources: American Association of Petroleum Geologists.[7] EIA, Office of Oil and Gas.

The stratigraphy of the Bakken Formation has been extensively researched and documented by North Dakota geologist Julie A. LeFever. Throughout most of the Williston Basin, the Bakken Formation has three members:

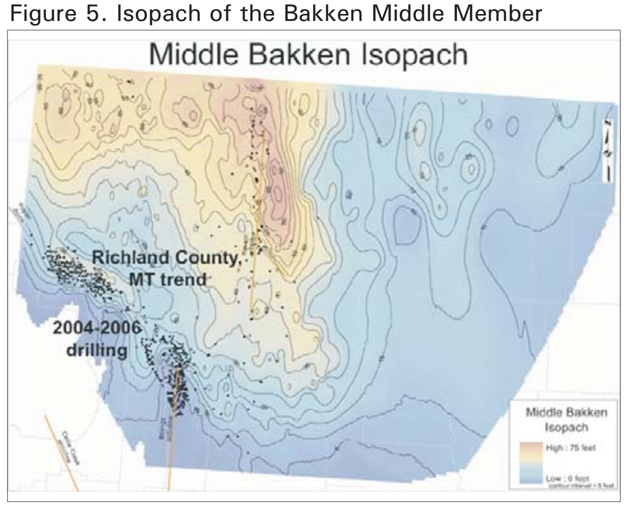
- The Upper Member, a 23-foot thick black marine shale;
- The Middle Member, an 85-foot thick interbedded layer of limestone, siltstone, dolomite, and sandstone; and
- The Lower Member, a 50-foot thick black marine shale.

Figure 4. Bakken Stratigraphy in North Dakota

Source: North Dakota Geological Survey[8]

The shale members are notable for their high organic carbon content. Both contain a high concentration of type II kerogen – an organic source rock material that converts to oil and natural gas when thermally mature. Early Bakken production efforts focused on the shale members, but had very limited success. Current efforts are now focused on the Middle Member of the Bakken Formation, which has more porosity and permeability than the adjacent shales. The North Dakota Geological survey identified five separate lithofacies (see Glossary) within the Middle Member in North Dakota (Figure 4). Not all of these facies are present throughout the Middle Member, which is thinner on its southwestern edge (Figure 5). Despite being thinner, the southwestern edge of the Bakken Middle Member is being targeted for development, because it contains a higher porosity dolomite facies, an excellent reservoir rock.

Figure 5. Isopach of the Bakken Middle Member



Source: American Association of Petroleum Geologists[9]

The Bakken Formation is located between two tight formations: the overlying 900-foot thick

Lodgepole Limestone and the underlying 250-foot thick Three Forks Formation. As the Williston Basin subsided these massive low-permeability carbonates acted as seals around the Bakken Formation. The increased temperatures and pressures that accompanied subsidence thermally converted the kerogen content of the shales into petroleum. Sealed with no conduit or high-permeability formation adjacent to the Bakken Formation to allow the petroleum to escape, the internal fluid pressure within the shales rose and eventually fractured the shales and the Middle Member from within.

The result is that, in areas where it is thermally mature, the Bakken Formation is an overpressured, often oil-wet, formation with 41 degree API gravity crude oil resident in its natural fractures that is capable of producing at high production rates.

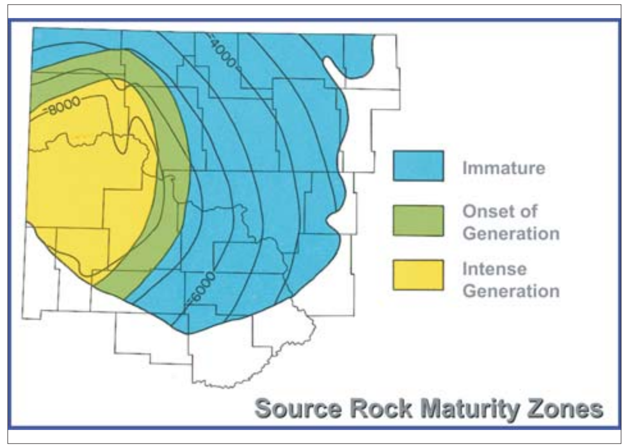
Not all of the Bakken Formation is predicted to be thermally mature at this time (Figures 6 and 7). The general assumption for the kerogen within the Bakken shales is that it thermally matures at a temperature of 100 degrees Celsius, which corresponds to a burial depth of 8,500 feet or deeper in this portion of the Williston Basin.

Proved Reserves

The proved reserves of Montana and North Dakota have increased significantly since the discovery of the Elm Coulee Field in 2000.

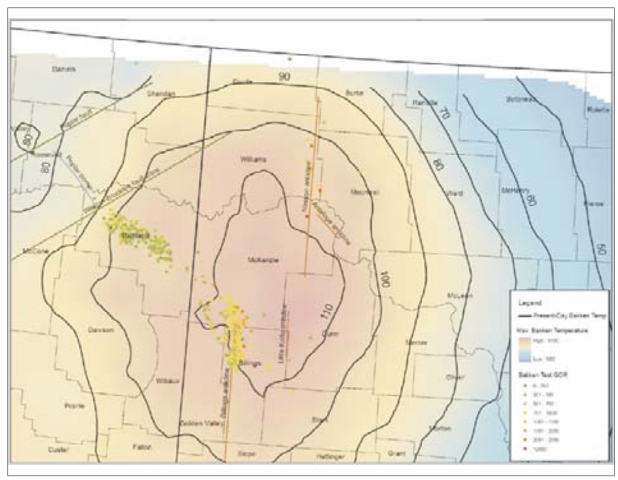
Comparing 2005 to 1999 crude oil proved reserves volumes, the proved reserves of Montana have increased 106 percent, and the proved reserves of North Dakota have increased 59 percent (Figure 8). These production and reserves increases were almost exclusively from the development of Bakken Formation fields and the Ordovician Red River Formation sands of the Cedar Creek anticline. Proved reserves are expected to continue to increase as development of these resources continues and operators increase their knowledge and experience completing wells in the Bakken.

Figure 6. An Estimate of Source Rock Maturity in ND



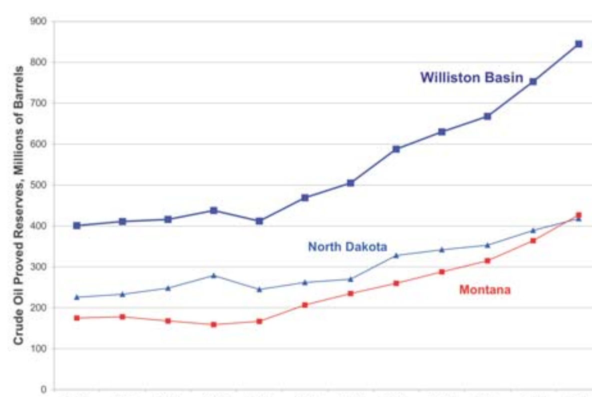
Source: North Dakota Geological Survey[8]

Figure 7. Present Day Bakken Temperature



Source: American Association of Petroleum Geologists[9]

Figure 8: Proved Reserves of Montana & North Dakota



Source: EIA, Reserves and Production Division

Producing Bakken Oil

Although operators and the USGS have known about the resource potential of the Bakken Formation for many years, several factors made it very difficult to produce these resources.

Early drilling in the Bakken Formation targeted the shale members. Success in these efforts hinged on connecting conventional vertical wellbores with an existing natural fracture system while not ruining the wellbore in the process with introduced drilling fluids. The shale itself is highly reactive with water and swells when exposed to it, which can seal off a productive fracture system. Also, the Bakken Formation contains iron pyrite within its sediments. This mineral forms an iron hydroxide precipitate (Figure 9) when exposed to hydrochloric acid, and there are reported cases of this phenomenon causing irreparable well damage. These challenges reduced the likelihood of success and discouraged most operators from trying to produce oil from the Bakken.

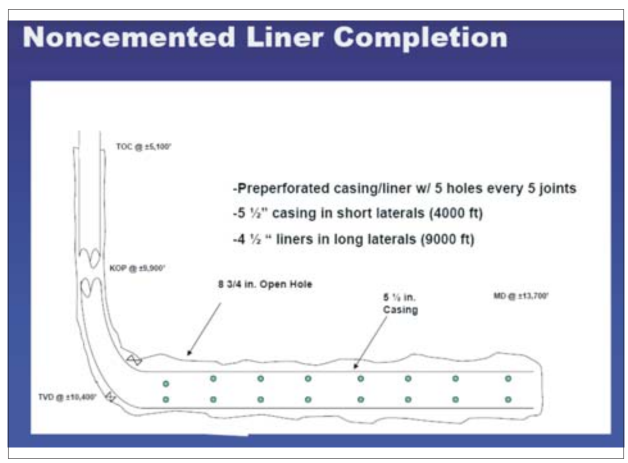
Science and technology are now unlocking more of the resources in the Bakken Formation. Hydraulic fracturing techniques have been used to stimulate production in the oil field since the 1920s in cased, vertical wells. In recent years, techniques have been developed to allow operators to apply this technology to horizontal well laterals.

This new horizontal fracturing technology is now being very effectively used to fracture stimulate horizontal laterals in the Bakken Formation's Middle Member. Lyco Energy Corporation and Halliburton have published a paper on fracture stimulation projects in the Bakken Formation[8]. Their technique calls for aligning the wellbore such that induced fractures have longitudinal orientation to the wellbore. The formation is fractured and produces back through an uncemented pre-perforated liner (Figures 10 and 11).

Figure 9. Iron Hydroxide Precipitate

Source: American Chemical Society

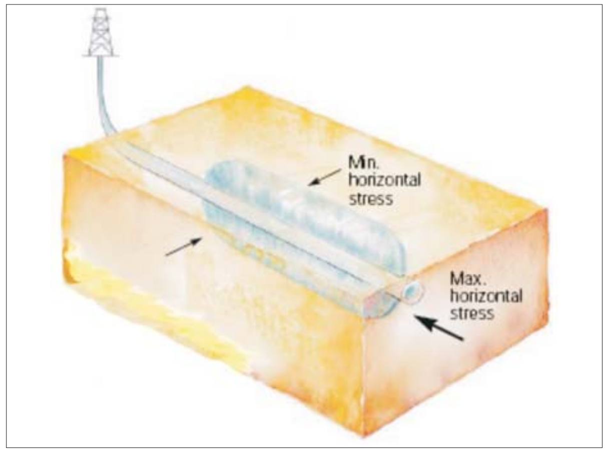
Figure 10. Horizontal Well Completion Design



Source: Society of Petroleum Engineers[10]

Completing a “frac job” in the Bakken Formation has its own associated challenges. Because the formation is overpressured, the frac pumps need to overcome both overburden stress and bottom hole reservoir fluid pressure. Once a fracture is created, closing stresses can be greater than 8,000 pounds per square inch, a force powerful enough to crush normal sand proppant (see Glossary). Crushing of the proppant reduces or eliminates conductivity from the fracture treatment, and creates problems when crushed sand fines are produced back into the wellbore. Stronger proppants have more crush resistance, but are more expensive than ordinary frac sand.

Figure 11. Theory of Longitudinal Fracture Design[9]



Source: Oilfield Review [11]

Refining and Transport Capacity Issue Looms Over Bakken Development

Price and pipeline capacity issues could hinder continued acceleration in the development of the Bakken Formation. As production in Montana and North Dakota increases, the existing transportation system is becoming a bottleneck. The existing pipeline system for the Williston Basin area, which is also used for movement of imported Canadian tar sand oil, is fully utilized. Rather than sell oil at a discounted price to get it into the pipeline, some U.S. operators have announced shut-ins and postponements of drilling.

The States of Montana and North Dakota are both actively working with operators and pipeline companies to address the issue of capacity shortages. In May 2006, Gov. John Hoeven of North Dakota hosted a summit with legislators, oil industry officials from both the United States and Canada, pipeline companies, producers, and railroad officials to help address the challenge of increasing oil pipeline capacity in western North Dakota.

“We’re producing more oil, and we need to be able to get it to market so our producers and mineral owners do not suffer unfair discounts,” Hoeven said. “We’re developing more pipeline capacity and taking other steps (i.e., investigating transportation via railroad tank cars) to solve the problem. More supply is also how we get the price down at the pump to help consumers.”

Crude oil shipped from the Williston Basin in North Dakota and Montana has incurred discounts because of competition for pipeline space. Reduced capacity is attributed to an increase in production, combined with limited pipeline space and a temporary reduction in refinery capacity. In April 2006, the pipeline system was about 15,000 barrels per day short of needed capacity in western North Dakota. As of May 2006, about 6,000 barrels per day were restricted by capacity.[12]

On September 21, 2006, the North Dakota Public Service Commission approved the site of a 52-mile oil pipeline that parallels a stretch of existing oil pipeline in Williams County in northwestern North Dakota. Enbridge Pipelines North Dakota LLC already has approval to install larger pumps along the existing line. Enbridge is hoping to increase its pipeline carrying capacity in the region by at least 30,000 barrels per day by the fall of 2007. The new facilities may be able to take up to 45,000 extra barrels daily.[13]

Figure 12. Location of all known fields of the Williston Basin at the Montana - North Dakota border.

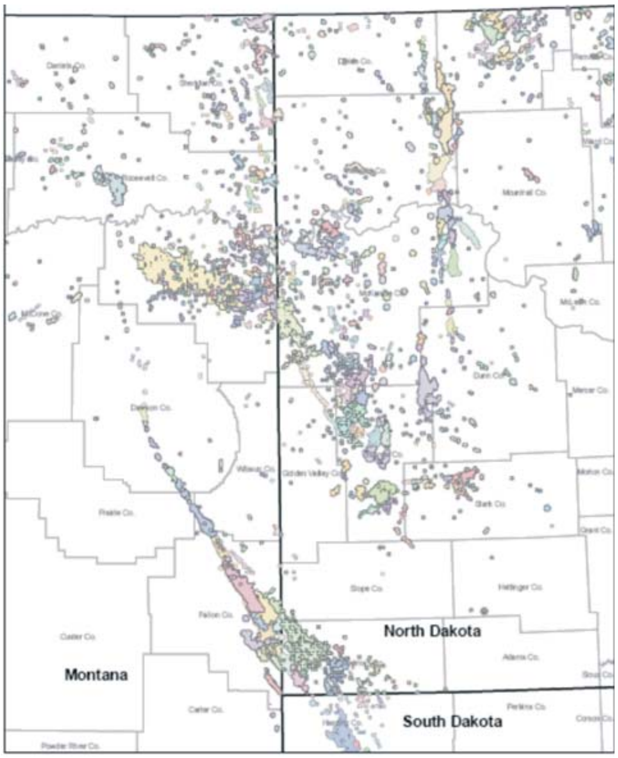
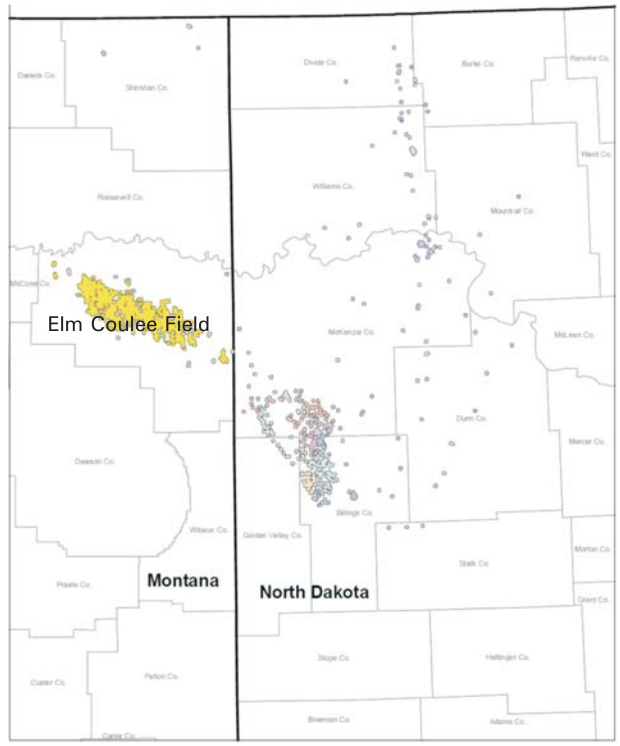


Figure 13. Location of all known fields of the Williston Basin with Bakken listed as a reservoir.



Source: Energy Information Administration, Reserves and Production Division

Conclusion

Oil and natural gas have been produced for decades in the Williston Basin (Figure 12). Producers of oil from the Bakken Formation (Figure 13) have been able to identify a previously overlooked resource and refined their technology and techniques in order to develop it, with great success. There are challenges to overcome, but the outlook is very good for energy development in that part of our Nation called "The Badlands".

EIA has updated its crude oil resource assumptions for the Bakken Formation in the Oil and Gas Supply Module of the National Energy Modeling System (NEMS). NEMS oil and natural gas projections and accompanying assumptions will be published in the *Annual Energy Outlook 2007*, DOE/EIA-0383(2007).

It is likely that other energy resources also await discovery or rebirth in the United States as new technology allows us to locate, define, interpret, and extract them economically. This report is first in a series intending to share information about these technology-based oil and natural gas plays.

References

1. “Mississippian stratigraphy of northern Montana”, Nordquist, J.W., Billings Geological Society, 4th Annual Field Conference Guidebook, p. 68-82, 1953.

2. “Montana Oil & Gas Annual Review 2004”, Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, 2005.

3. U.S.G.S. National Assessment of Oil and Gas Resources, 1995.

4. “Elm Coulee Field, Richland County, MT” , presentation by Bill Walker, Headington Oil Company, Fourteenth Williston Basin Petroleum Conference & Prospect Expo, Minot, ND, May 2006.

5. The primary recovery estimate was corrected to 270 million barrels after clarifying followup discussions with Bill Walker, Headington Oil Company. November 2006.

6. “Origins and characteristics of the basin-centered continuous-reservoir unconventional oil-resource base of the Bakken Source System, Williston Basin”, Price, Leigh C., 2006. http://www.undeerc.org/price

7. “Petroleum Potential of North Dakota”, Ashmore, Herman T., American Association of Petroleum Geologists, Dec. 5, 1969.

8. “Montana-North Dakota Middle Member Bakken Play”, LeFever, Julie A., North Dakota Geological Survey, 2005.

9. “Integrated Analysis of the Bakken Petroleum System, U.S. Williston Basin”, Flannery, Jack; Kraus, Jeff. American Association of Petroleum Geologists Annual Convention, Houston , TX. Poster Session Presentation. Search and Discovery Article #10105. April 10-12, 2006. http://www.searchanddiscovery.net

10. “Improved horizontal well stimulations in the Bakken Formation, Williston Basin Montana” Wiley, Charles; Eberhard, Mike; Barree, Bob; Lantz, Tom; SPE 90697, October 2004.

11. “Cracking Rock: Progress in Fracture Treatment Design” Brady, Barry; Elbel, Jack; Mack, Mark; Morales, Hugo; Nolte, Ken; Poe, Bobby. Oilfield Review, October 1992.

12. Press Release, May 15, 2006. Office of the Governor of North Dakota.

13. “North Dakota regulators approve site of oil pipeline”, Wetzel, Dale, The Bismark Tribune, September 21, 2006.

14. “Bakken Crude Oil Resource of the Williston Basin”, David J. Bardin, December 2005.

Glossary

Anticline: A fold with strata sloping downward on both sides from a common crest.

"Continuous-type" Accumulation: Unlike conventional oil and natural gas accumulations, continuous–type accumulations do not occur in discrete reservoirs of limited areal extent. They include accumulations in low–permeability (tight) sandstones, shales, and chalks, and those in coal beds.

Depocenter: A site of maximum deposition.

Dolomite: A sedimentary rock composed largely of calcium magnesium carbonate ($CaMg(CO_3)_2$).

Kerogen: Complex mixture of compounds with large molecules containing mainly hydrogen and carbon but also oxygen, nitrogen, and sulfur. Kerogen is a precursor of petroleum and the organic component of oil shales. It is waxy and insoluble in water; upon heating, it breaks down into recoverable gaseous and liquid substances resembling petroleum. It is the most abundant form of organic carbon on Earth—about 1000 times more abundant than coal. Types of Kerogen (e.g. I, II, III, or IV) are defined by the hydrogen-to-carbon and oxygen-to-carbon ratios in its compounds.

Limestone: A common sedimentary rock consisting mostly of calcium carbonate, $CaCO_3$, used as a building stone and in the manufacture of lime, carbon dioxide, and cement.

Lithofacies: Rocks with a group of characteristics that imply a certain origin or history.

Permeability: Ability of rock to transmit fluids through pore spaces.

Proppant: A granular substance that is carried into the formation by the fracturing fluid and helps keep the cracks open after a fracture treatment. Crush resistance and size distribution are two measurements to select a proppant. Commonly used proppants include Ottawa (White) Sand, Brady (Brown) Sand, Sintered Bauxite, or a Resin-coated sand.

Proved Reserves: Proved reserves are the estimated quantities of hydrocarbons which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions.

Sandstone: A sedimentary rock formed by the consolidation and compaction of sand and held together by a natural cement, such as silica.

Shale: A class of fine-grained clastic sedimentary rocks with a mean grain size of less than 0.0625 mm (0.0025 in.), including siltstone, mudstone, and claystone. One-half to two-thirds of all sedimentary rocks are shales. The small size of pores in shale relative to those in sandstone causes shale permeability to be much lower than sandstone permeability.