

A Brief History of Oil Production from the Bakken Formation in the Williston Basin

by Stephan Nordeng

Oil and gas production from the Bakken Formation provides an excellent case study of the successful development of a significant natural resource through the application of ever more sophisticated drilling and stimulation technologies. The history of Bakken development (fig. 1) spans almost 60 years and is witness to several important advances in drilling, completion and stimulation techniques. Each of these advances has significantly increased the productive acreage and value of this formation.

However, horizontal wellbores alone are frequently inadequate to allow for oil to be produced at rates that justify the cost of drilling and completing a well. This problem is often overcome by increasing the natural seepage of oil by inducing fractures in the rock. This is done by pumping a water and sand slurry into the formation at pressures high enough to cause the oil-bearing rock to fracture. The increased flow of oil through this newly created network of fractures can substantially increase oil production.

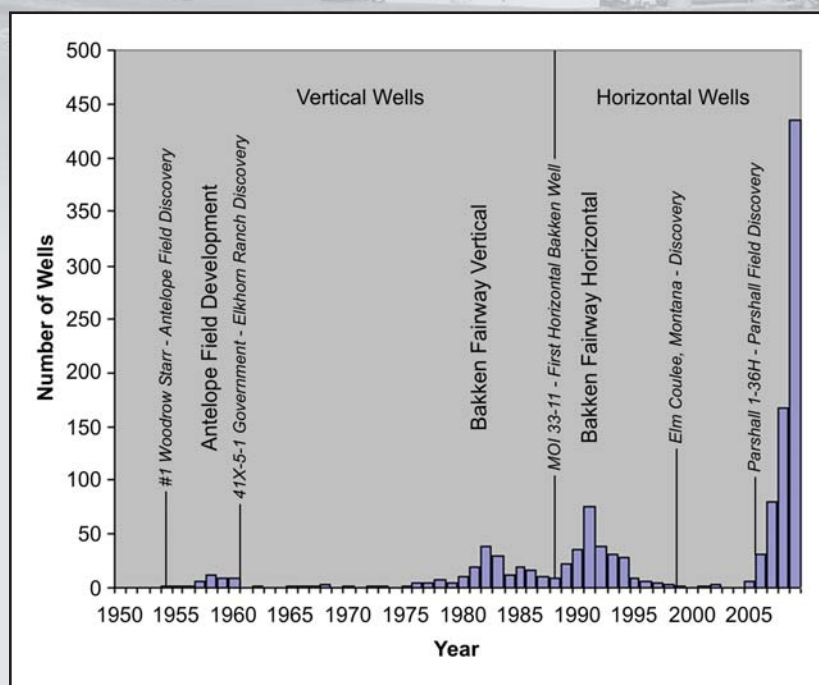
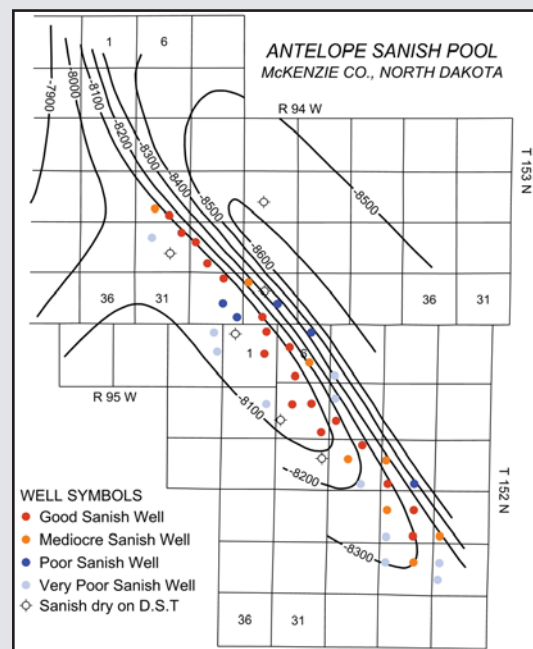


Figure 1. Historic distribution of Bakken tests, significant discoveries and technologic advances in the Williston Basin.

Probably the most conspicuous advance in drilling came with the development of tools that enable precise directional drilling resulting in the modern horizontal wellbore. This technology allows a larger section of an oil bearing formation to be in contact with the well thereby increasing the collection capacity and productivity of a single well. This is especially important when attempting to produce oil from formations such as the Bakken and Three Forks in which oil naturally seeps into the wellbore at very slow rates.

The technique of hydrofracturing to stimulate well production has been used since the earliest days of Bakken production. However, over time and with the introduction of horizontal drilling, the size and complexity of these stimulation efforts has increased dramatically. Increasing the size of the fracture stimulation produces more fractures, which substantially increases well productivity. More recently, very large fracture stimulation efforts have been joined by stimulation efforts that include multiple stages of hydrofracturing. In the staged fracture method, sections of the horizontal wellbore are isolated and individually fractured on a

Figure 2. Structure map of Antelope Field with wells and relative production indicated (modified from Murray, 1968).



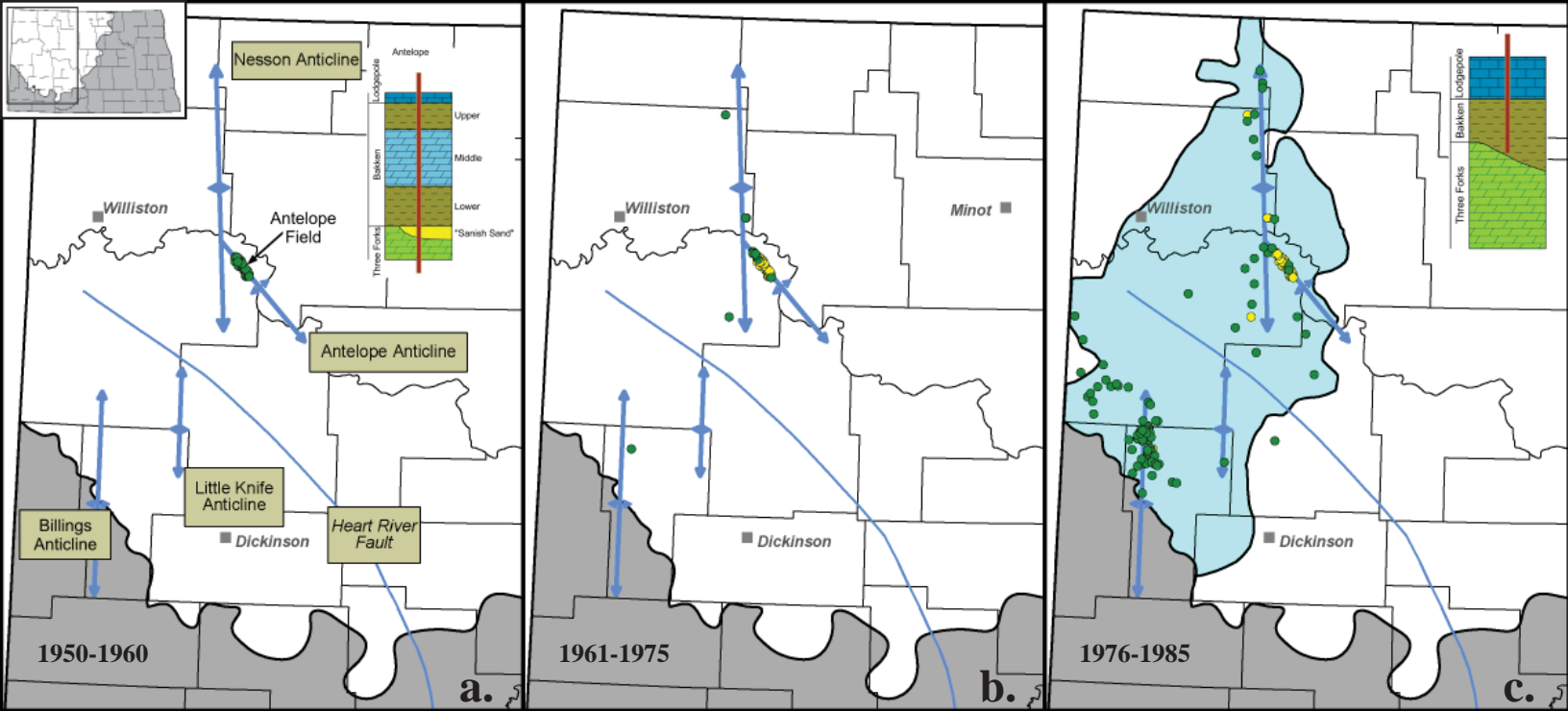


Figure 3. Bakken/Sanish producing wells drilled between 1950 and 2010. Wells drilled during the time period indicated by each map are shown in green; wells depicted on preceding maps are shown in yellow. The inset (top left) shows the area represented by the maps. (a) Producing wells drilled between 1950 and 1960 in the Antelope Field. (b) Bakken producers drilled between 1961 and 1975 proving that Bakken production was possible outside of the Antelope Field. (c) Vertical Bakken producing wells drilled between 1976 and 1985.

section by section basis. This generally reduces the length of wellbore that is fractured at any given time to 1,000 feet or less. This allows for better control and results in a more uniform distribution of fractures along the horizontal wellbore.

Discovery - Antelope Field

Oil production from the Bakken was first established on the Antelope Anticline (fig. 2) in 1953 when Stanolind Oil and Gas Corp. drilled and completed the #1 Woodrow Starr (SW ¼ SE ¼ Sec. 21, T152N, R94W). The well was drilled to a total depth of 12,460 feet, plugged back and cased to 10,675 feet. The well was perforated between the depths of 10,528 to 10,556 feet and stimulated with 4,900 pounds of sand and 120 barrels of crude oil. The well came on line on December 6, 1953 at a rate of 536 barrels of 44° API (American Petroleum Institute) gravity oil and 770 cubic feet of gas per barrel per day. Casing problems in the #1 Woodrow Starr forced the well to be plugged and abandoned after 55 months of production during which 279,254 barrels of oil (bbls) and 108 barrels of water were produced. Most of the wells in Antelope Field were drilled during the 1950s and 1960s (figs. 3a and 3b). During that time, 44 vertical wells were drilled with an average initial production (IP) of 217 barrels of oil, with one well producing as much as 890 barrels (LeFever, 1991).

The success of wells drilled in the Antelope Field depended upon natural fracture networks in the Bakken and Three Forks (Sanish) Formations to supply enough oil to the wellbore to be economic. Murray (1968) found that production from the Bakken/Sanish pool in the Antelope Field is strongly influenced by tectonic fractures. These fractures probably opened through tensile failure along the most tightly flexed portion of the steeply dipping northeastern limb of the Antelope Anticline (fig. 2). Natural fracturing stimulated by the relatively small hydrofracturing technology of the era appears

to have allowed for the otherwise “tight” reservoir rock in this field to yield oil and gas at commercial rates. Original formation pressures in this field were significantly above the usual near hydrostatic trend present in other reservoirs in the Williston Basin. Meissner (1978) considered oil maturation and subsequent source rock compaction to be the primary cause of the abnormally high pressures generally found in the Bakken.

Oil production from vertical wells in the Antelope Field is restricted to a localized set of geologic conditions that resulted in the formation of natural fracture systems. The recognition that structurally related fracture systems are a necessary component of a successful Bakken well became the dominant exploration model until the mid-1990s.

Expansion

Between 1960 and 1975 production outside of the Antelope Field was established in a few wells. Of particular significance was the discovery of the Bakken/Three Forks Pool in the Elkhorn Ranch Field on the eastern flank of the Billings Anticline. This discovery was made in 1961 after Shell Oil drilled the Government 41X-5-1 well in Billings County (NE ¼ NE ¼, Sec. 5, T143N, R101W). The well was drilled to a total depth of 13,018 feet and was plugged back to a depth of 10,738 feet. A drill stem test that included 109 feet of the lower Lodgepole, Bakken and Three Forks Formations recovered gas and heavily oil cut mud with shut-in pressures of about 6,600 pounds per square inch (psi). The well was perforated in the upper Bakken shale and upper Three Forks between 10,705 and 10,715 feet depth. Four thousand gallons of acid were used to stimulate the well. The initial production rate was reported to be 136 barrels of 43.4° API gravity oil per day with a gas to oil ratio (GOR) of 1,230 cubic feet of gas per barrel of oil. Seven months later the well was hydrofraced with 20,000 gallons of acid

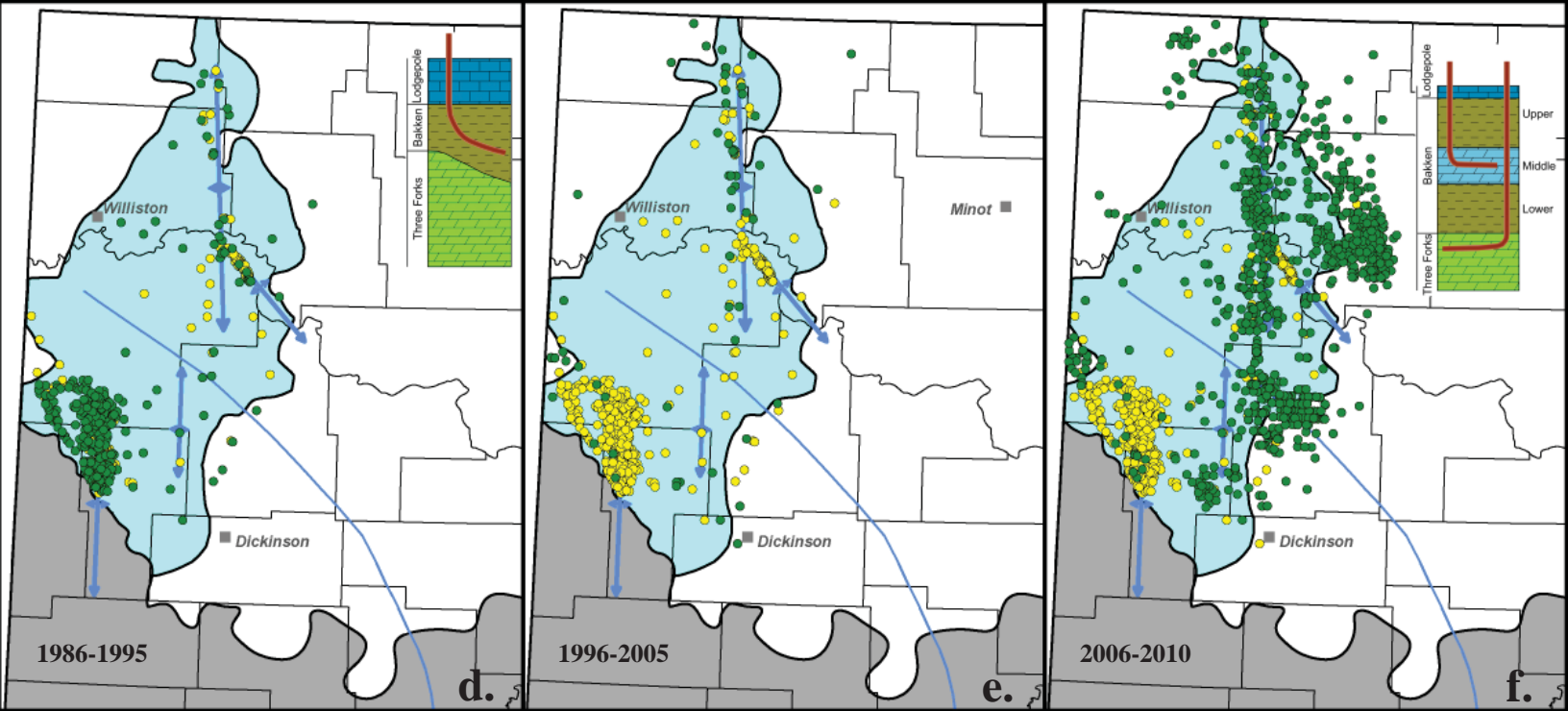


Figure 3 (continued). Most of the production was found in the “Bakken Fairway” near the southwestern limit of the Bakken Formation along the Billings Anticline. The light blue area is the portion of the Bakken that is considered “mature” on the basis of Rock Eval® data (Nordeng and LeFever, 2009). (d) Bakken producers drilled between 1986 and 1995. (e) Bakken producing wells drilled between 1996 and 2005. (f) Bakken producers drilled since 2005.

and 9,000 pounds of sand. Production following stimulation was reported to be 48 barrels of oil per day. The well was plugged and abandoned in August of 1964 after producing 57,840 barrels of oil.

Bakken Fairway

The second phase of Bakken activity occurred in the late 1970s and early 1980s (fig. 3c) along the depositional limit of the Bakken Formation. Only the upper Bakken is present along this trend.

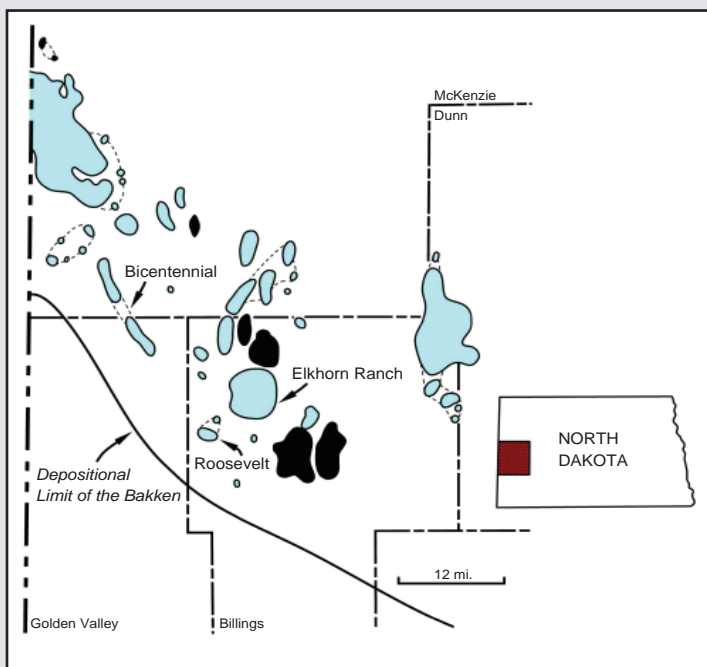


Figure 4. Map of western North Dakota showing the location of the “Bakken Fairway”. Major Bakken producing fields in blue, others in black.

Drilling concentrated on structural features over which the upper Bakken had thinned. Enhanced natural fracturing of the shale was expected in these settings based on the idea that the fracture density in thinner units is usually greater than in thicker units (Sperr, 1991). At least 26 fields have been established along this trend that extends from the Estes/Mondak area to Little Knife (fig. 4). Most of the fields have multiple pays associated with structure such as folds, faults, or a combination of the two.

During this same period of time ideas concerning the productive potential of oil-prone shales began to emerge (Schmoker and Hester, 1983; Price et al., 1984). One of the principal ideas that influenced exploration was the notion that organic-rich shales such as the Bakken only generate oil after reaching a level of “maturity” that is dictated by the heating history of that shale (Wood, 1988). Maps of shale maturity were used to evaluate the productive potential of the Bakken and were believed to be capable of differentiating between potentially productive and nonproductive portions of the basin. As a result, exploration in the Bakken Formation was almost exclusively limited to those portions of the basin in which the Bakken was deemed “mature.”

Horizontal Drilling

Drilling methods changed radically following Meridian Oil’s first horizontal Bakken well drilled in 1987. Meridian drilled and completed a vertical well in March 1986 for 217 barrels of oil per day (#33-11 MOI-Elkhorn in the NW¼ SE¼, Sec. 11, T143N, R102W). This well established the presence of a fracture trend that was exploited with the first horizontal well into the Bakken. As noted, the #33-11 MOI-Elkhorn was originally drilled vertically. Later, a 2,600 foot lateral was drilled from this well into an eight-foot-thick section of the upper Bakken shale and was completed for 258 barrels of oil per day and 299,000 cubic feet of gas

(LeFever, 1991). Horizontal drilling continued along a 200-mile-long by 30-mile-wide strip of land referred to as the “Bakken Fairway.” The “Fairway” is a northwest-southeast trending band along the updip feather edge of the upper shale. The Bakken Formation typically thins over structures along the “Fairway” and production is in close proximity to these structures. Structure-enhanced, natural fracturing of the upper shale is believed to be the primary factor controlling Bakken production within the “Fairway” (Sperr, 1991).

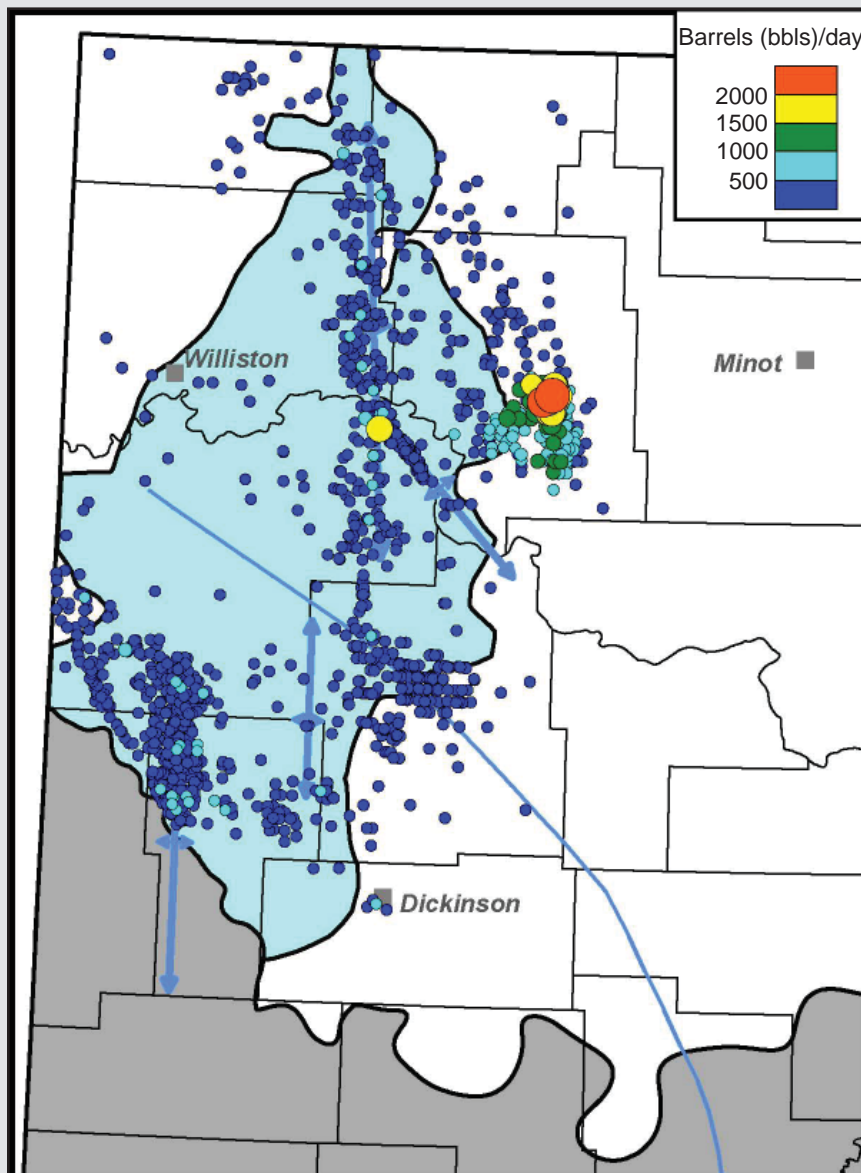
A number of wells in other portions of the Williston Basin attempted to utilize the drilling strategy employed along the “Fairway” by targeting the upper shale with horizontal wellbores. Horizontal drilling along the Bakken Fairway peaked in 1992. Drilling activity slowed for the remainder of the 1990s and essentially ended by 2000.

Elm Coulee Field, Montana

Development of the Elm Coulee Field in eastern Montana began after Dick Findley found porosity trends in the middle Bakken that suggested the presence of a significant reservoir. Horizontal

drilling in 1996 demonstrated for the first time that oil generated in the Bakken shales could accumulate within the middle member and that significant production could be established (Brown, 2006). Production from the middle member was established in the Kelly/Prospector 2-33 Albin FLB following an unsuccessful test of the deeper Birdbear Formation. Findley’s porosity maps outlined a northwest-southeast trending stratigraphic interval containing an unusually thick dolomitized carbonate shoal complex within the middle member of the Bakken Formation (Brown, 2006). As with the previous Bakken producing fields, production at Elm Coulee depends on fracturing, but in this case the productive fractures are found in the middle member of the formation. This is a significant development in exploration thinking because the porosity trends in Elm Coulee field depend to a large degree on the depositional and diagenetic history of Bakken Formation. The knowledge gained in the Elm Coulee Field marked a significant advance in the development of the Bakken.

Since the Elm Coulee discovery, more than 600 horizontal wells have been drilled in the 450-square-mile field from which more than 90 million barrels of oil have been recovered. The productive portions of the reservoir contain between 3 and 9 percent porosity with an average permeability of 0.04 millidarcies. A pressure gradient of 0.53 pounds per square inch/foot is present in the Bakken indicating that the reservoir is slightly overpressured. Stimulation of the laterals is routinely used and includes sand-, gel- and water-fracturing methods. Initial production from these wells ranged between 200 and 1,900 barrels of oil per day (Sonnenberg and Pramudito, 2009).



Parshall Field

Michael Johnson noticed that wireline logs of the middle Bakken in Mountrail County resembled those from the Elm Coulee Field in Montana. Even though the organic matter in the Bakken shales appeared incapable of oil generation, the recovery of free oil in drill stem tests and some minor production led Johnson to pursue a Bakken play in Mountrail County (Durham, 2009). In 2005, EOG Resources demonstrated with the Nelson Farms 1-24H (Sec. 24, T156N, R92W) that horizontal drilling coupled with large hydraulic fracture stimulation of the middle Bakken Formation could recover significant oil reserves along the eastern flank of the Williston Basin in Mountrail County. The following year, EOG Resources drilled the Parshall 1-36 and Parshall 2-36, which resulted in wells with initial production rates in excess of 500 barrels of oil per

Figure 5. Bakken producers in which the relative initial production rates are scaled to the size and color of the circle that shows the wells location. The initial production rate shown here is the average daily production rate obtained from no fewer than 60 days and no more than 90 days of production. The Parshall Field is located where the cluster of large orange circles (2,000+ barrels per day) are plotted in eastern Mountrail County.

Figure 6. Monthly oil production from the Parshall Field, Mountrail County, North Dakota. Data from the North Dakota Industrial Commission.

day. Subsequent horizontal drilling in the Parshall Field coupled with large fracture stimulation has resulted in several wells with initial production in excess of 1,000 barrels of oil per day (fig. 5). Most of the laterals drilled in Mountrail County are on the order of 5,000 feet in length and are fracture stimulated with at least a single stage or in many cases 10 to 12 individual stages. In general, the hydrofracing stimulation uses between 2 and 3 million pounds of sand and 500,000 to a million gallons of slick, gelled water.

Currently, the field is producing an average of about a million barrels of oil per month from 127 wells (fig. 6). This discovery has focused significant attention not only on the oil potential of the Bakken Formation in this part of the Williston Basin, but also on the Bakken Formation throughout the Williston Basin.

Probably the most compelling evidence as to how changing exploration strategies and technologies are altering our perceptions of the oil and gas potential of the Williston Basin is found by comparing the technically recoverable reserves estimated by the North Dakota Department of Mineral Resources (DMR) in 2005 with those in the 2008 assessment (Bohrer et al.). In 2005, the DMR estimated that just under 14 million barrels of oil were recoverable from the Bakken with the technology of that time. Three years later, changing technology places the reserves at 2.089 billion barrels of recoverable oil. Even though the Bakken itself has not changed, our ability to extract oil from it has, so that as technology advances our ideas concerning the future possibilities of this resource must as well.

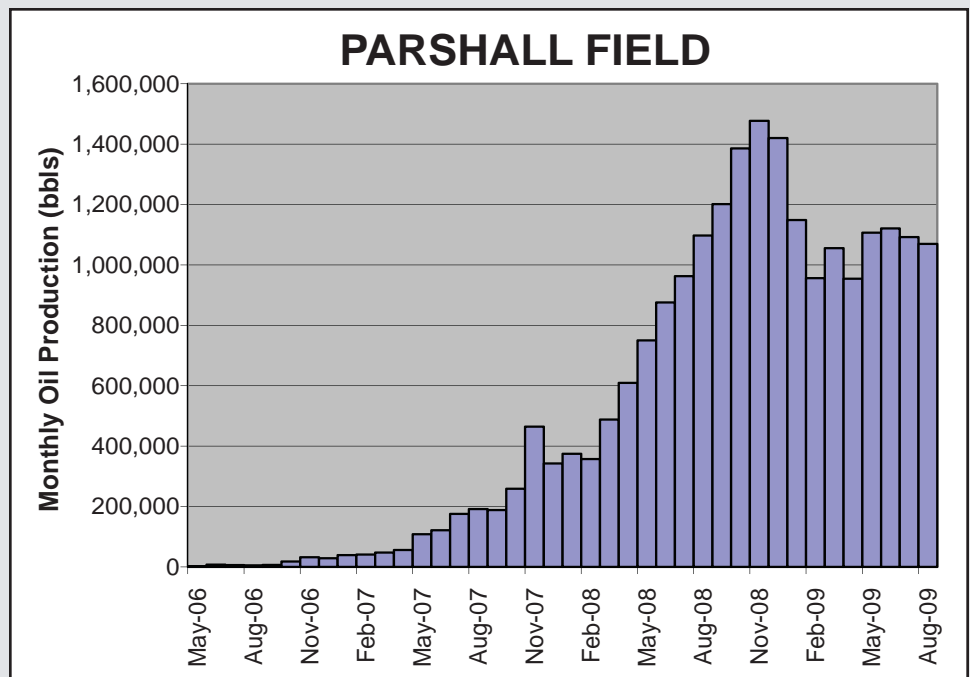
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