Activity Update for Bakken Petroleum System, Williston Basin

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Introduction

Assessments performed by the United States Geological Survey (USGS) and the North Dakota Department of Mineral Resources in 2008 demonstrated that significant reserves were present in the Bakken Petroleum System in the entire Williston Basin (Pollastro et al., 2008; Bohrer et al., 2008; Nordeng and Helms, 2010). The area was re-assessed in 2013 owing to an increase in the number of wells, longer production histories on existing wells, and new technologies and completion techniques (Gaswirth and Marra, 2015). Once again the assessment increased the undiscovered technically recoverable reserves to 3.65 billion barrels for the Bakken and 3.73 billion barrels for the Three Forks formations of the U.S. Williston Basin.

Petroleum within the Bakken is properly considered a continuous petroleum accumulation for the following reasons:

1. The Bakken is a regionally extensive, organic-rich source rock;
2. The Bakken has a burial history that has resulted in temperatures sufficient to convert organic matter into petroleum;
3. The overlying and underlying rocks are sufficiently thick, widespread and impermeable so as to isolate the accumulation;
4. There are overlying and/or underlying rocks that are sufficiently permeable and porous to accumulate economic quantities of oil or gas. (i.e. Bakken Petroleum System which includes the middle member of the Bakken Formation, Three Forks Formation, and the Lodgepole Formation; Price and LeFever, 1994); and,
5. Abnormally high formation pressures indicate that petroleum has been injected into these rocks and that the "charge" has not escaped through permeable zones, fractures or faults.

Petroleum accumulations, such as the Bakken, cover large areas with poorly defined margins. Virtually every study of the Bakken Petroleum System has concluded that the resource is enormous with total in-place volumes of oil that are in the range of tens to hundreds of billions of barrels.

Bakken exploration spans over 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 the formation. Of particular importance are the dual developments of precise directional drilling technologies that result in the modern horizontal well bore and advances in well stimulation technologies. The significance of this is that artificially fractured horizontal well bores open up much larger sections of an oil-bearing formation, and by virtue of increasing the collection capacity of a single well, allows for larger volumes of oil to be produced. This is especially important when attempting to produce oil from formations such as the Bakken and Three Forks in which matrix permeabilities are in the microdarcy range. A comprehensive history of the early exploration and development of the Bakken is covered in several papers including LeFever (1991) and Nordeng (2010).

Antelope Field

Oil production from the Bakken was first established on the Antelope Anticline in 1953 when Stanolind Oil and Gas Corp. drilled and completed the #1 Woodrow Starr (SWSE Sec. 21, T152N, R94W). The majority of the 44 wells in Antelope Field were drilled during the 1950s and 1960s. Oil production from the first wells in the Antelope Field is restricted to structurally induced fracture systems. The recognition that pervasive fracture systems are a necessary component of a successful Bakken well became the dominant exploration model until the mid-1990s.

1960 - 1975

Between 1960 and 1975 production outside of the Antelope Field was established in a few wells. The #41X-5-1 Government well drilled by Shell Oil in 1961 in Billings County (NENE Sec. 5, T143N, R101W) demonstrated that oil production outside of the Antelope Field was possible. The initial production (IP) rate was reported to be 136 barrels of 43.4° API gravity oil with a gas to oil ratio (GOR) of 1,230 cubic feet of gas per barrel of oil. Seven months later the well was hydro-fraced with 20,000 gallons of acid and 9,000 pounds of sand. Production following stimulation was reported to be 48 barrels of oil per day (BOPD). The well was abandoned in August 1964 after producing 57,840 barrels of oil.

Late in the 1970s, additional vertical production developed along the southwestern depositional limit of the Bakken Formation. Along this trend, known as the "Bakken Fairway," only the upper Bakken is present. The "Fairway" is some 200 miles long and 30 miles wide and lies along the updip feather edge of the upper shale. At least 26 fields were established along structural features over which the Bakken thinned and apparently fractured. Producing wells not encountering natural fractures were routinely fracture stimulated.

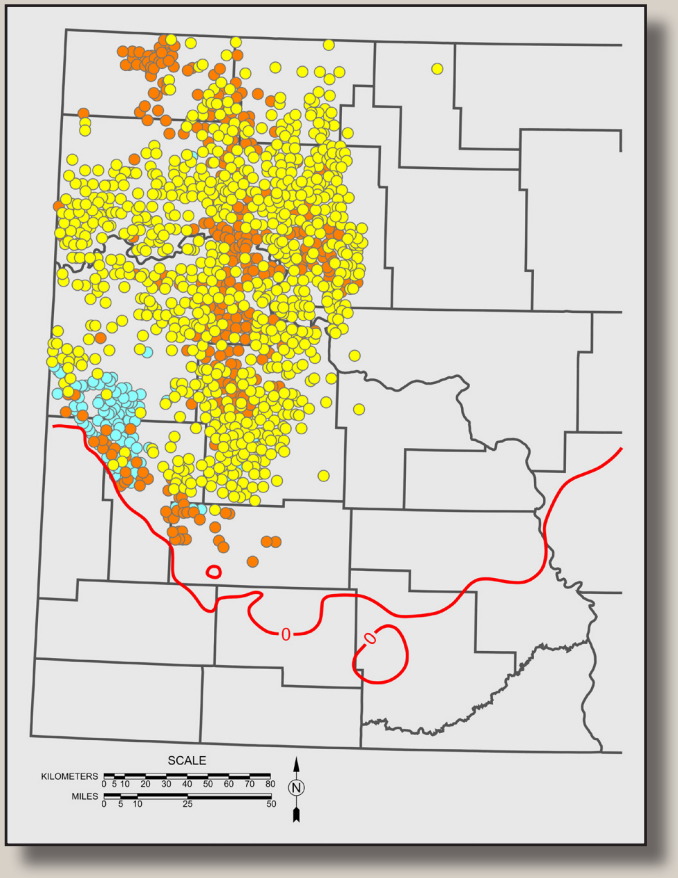

Figure 1. Map of western North Dakota showing the limit of the Bakken in red. Distribution of the production is as follows: Middle Member of the Bakken is indicated in yellow, production from the Pronghorn Member of the Bakken is in blue, production from the Three Forks Formation indicated in orange.

1st Horizontal Play

Drilling methods in the Bakken Fairway changed significantly in 1987 after Meridian Oil, Inc. drilled the first horizontal Bakken well. Meridian drilled and completed a vertical well in March 1986 for 217 BOPD (#21-11 MOI-Elkhorn; NWSE Sec. 11, T143N, R102W). This well established the presence of a fracture trend that was exploited with the first horizontal well into the Bakken. A 2,600-foot-long lateral was drilled from the vertical well into an 8-foot-thick section of the upper Bakken shale. Initial production from the completed lateral was 258 BOPD and 299 MCF of gas (LeFever, 1991). Horizontal drilling along the Bakken Fairway peaked in 1992 before slowing late in the 1990s and essentially ending by 2000 (LeFever, 2000).

Elm Coulee

Development of the Elm Coulee Field in 1996 resulted from the first significant oil production from the Middle Member of the Bakken Formation. Production was established in the Kelly/Prospector #2-33 Albin FLB following an unsuccessful test of the deeper Birdbear (Nisku) Formation. Subsequent porosity mapping outlined a northwest-southeast trending stratigraphic interval containing an unusually thick dolomitized carbonate shoal complex within the Middle Member. Horizontal wells drilled through this shoal complex in 2000 resulted in the discovery of the giant Elm Coulee Field in eastern Montana. 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. The reservoir is overpressured and laterals are routinely stimulated by a variety of sand-, gel- and water-fracturing methods. Initial production from these wells is between 200 and 1,900 BOPD (Sonnenberg and Pramudito, 2009). Since its discovery, more than 1,100 horizontal wells have been drilled in the 450-square-mile field from which more than 169 million barrels of oil have been recovered.

North Dakota

The Bakken Middle Member play moved across the line into North Dakota in 2004. Prior to the discovery of the Parshall Field, 52 wells had been drilled on the North Dakota side of the basin and only nine were economic wells. The play changed when Michael Johnson noted that wireline logs of the Bakken Formation along the eastern limb of the Williston Basin in Mountrail County, North Dakota resembled those from Elm Coulee. Even though the kerogen within the Bakken shales appeared immature and thus might not be generating oil, free oil in DSTs and some minor Bakken production encouraged Johnson to pursue a Bakken play in Mountrail County (Durham, 2009). In 2005, EOG Resources demonstrated with the #1-24H Nelson-Farms (SESE Sec. 24, T156N, R92W) that horizontal drilling coupled with large scale

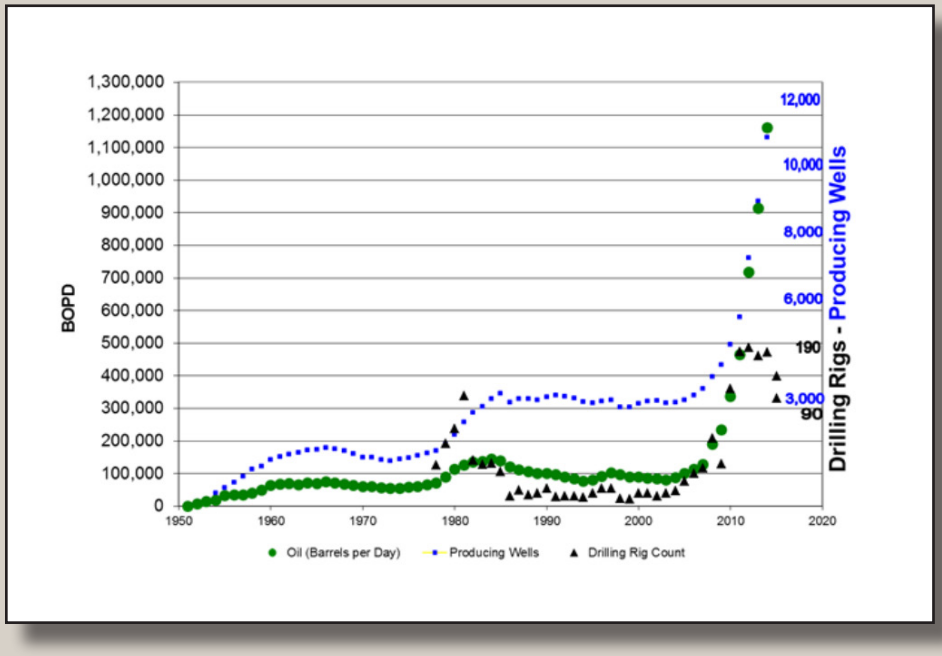

Figure 2. Graph showing Bakken and Three Forks production from 9,208 unconventional wells (Helms, 2015).

hydraulic fracture stimulation of the middle Bakken Formation could successfully tap significant oil reserves along the eastern flank of the Williston Basin. In the following year, EOG Resources drilled the #1-36 Parshall and #2-36 Parshall which resulted in wells with initial production rates in excess of 500 BOPD. Subsequent horizontal drilling in the Parshall Field coupled with staged fracture stimulation has resulted in wells with IP's in excess of 1,000 BOPD. The field's production reached 1 million barrels per month from 73 wells in August 2008. Sanish Field, adjacent to Parshall, followed reaching 1 million barrels of oil per month in March 2010 from 117 wells.

Stimulation of the early wells typically involved large single-stage fracture stimulations using over 2 million pounds of proppant and over a million gallons of water. More recently, the single stage method has been replaced by multistage fracture stimulations that stimulate the lateral with about the same amount of material distributed over 10 to 30 or more separate stages instead of one. In a few instances, different laterals in the same well and laterals in adjacent wells are stimulated at the same time. Whiting Oil installed a microseismic array in the Sanish Field in 2009 in order to better visualize the real-time generation of induced fractures during stimulation.

2010 – 2015

Subsequent horizontal drilling in the Bakken coupled with staged fracture stimulation has resulted in wells with large IP's and faster payouts. Stable oil prices allowed for companies to further refine the methods used in extracting oil from the Bakken Formation. The success rates translated into an increase in the number of producing wells in the state from 4,628 (January 2010) to 12,181 (January 2015) (Helms, 2010-2015). Over 903 million barrels of oil have been recovered from 6,140 wells in the 81 middle Bakken producing fields put into service since 2004.

Information obtained from extensive drilling in the state resulted in the definition of an additional member of the Bakken Formation called the Pronghorn. Additionally, the original members have been formalized to conform to the adjoining states and provinces. New standard subsurface reference sections have also been designated. The Bakken Formation now consists of four members: Upper, Middle, Lower, and Pronghorn.

Cores have played an important role in the understanding to this unconventional source system-play (Durham, 2012). There have been 167 cores cut on the North Dakota portion of the basin since the start of this play. Exploratory cores from the start of the play with extensive oil saturations have encouraged operators to drill, core, and produce from deeper portions of the source system. Production has been established from three separate horizons within the Three Forks Formation as well as the Middle Member of the Bakken. Thirty cores cut the complete Three Forks section adding to the understanding of a formation previously considered to be a trap, now considered to be a reservoir.

The 2,987 horizontal wells drilled into the Three Forks Formation since 2006 have produced 309 million barrels of oil. Currently there are 107 fields with Three Forks production. Thirty-five wells have been completed in both the Bakken and Three Forks Formations. The majority of these wells were drilled in 2010.

As the play moves into the production phase, multiple wells are now drilled from single pads with a closed mud system to minimize the footprint. Also, there has been an increase in the number of acquisitions (ex: Denbury's Bakken holdings by Exxon-Mobil Corp.; Kodiak's holdings by Whiting Petroleum Corp.).

The large single-stage fracture stimulations of the early wells have evolved into multistage treatments averaging 30 to 40 stages on the 10,000-foot laterals with a 50-50 split on plug- and perf- versus ball and sleeve (R. Suggs, 2015, Pers. Comm.). Fluid volumes range from 20,000 to 450,000 barrels with proppant amounts ranging from 80,000 to 3,500,000 lbs. Exceptions exist with laterals having 60 or more separate stages and proppant amounts as high as 10,000,000 lbs. The combination of horizontal drilling coupled with staged fracture stimulation has resulted in wells with IPs averaging in excess of 1,100 BOPD per lateral. With the changes in completions, well costs have risen, early wells at the start the play cost $2.2 M to drill and complete. Current wells cost $8 to $13M.

After an all-time high of 218 rigs running on May 29, 2012, the rig count has decreased along with the drop in the price of oil. Eighty-four rigs are currently running in the core areas of the North Dakota Williston Basin. The decrease in oil prices has also directed the drilling towards the low-risk Bakken Formation.

Currently in the Bakken-Three Forks play there are 9,208 unconventional wells producing 1.1 million barrels per day with cumulative production of 1.2 billion barrels and 900 wells waiting for completion (Helms, 2015). As would be expected, transportation of the crude oil to market continues to be a problem.

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Julie LeFever Receives AAPG Award

Sue Cluff, President of the Rocky Mountain Section of the American Association of Petroleum Geologists (right) presents the John D. Haun Landmark Publication Award to Julie LeFever during the 2015 annual meeting of AAPG.

At the American Association of Petroleum Geologists (AAPG) annual meeting in April, the Rocky Mountain Section of AAPG awarded the 2015 John D. Haun Landmark Publication Award to Leigh C. Price (deceased) and Julie A. LeFever for their 1992 paper entitled: Does Bakken horizontal drilling imply a huge oil-reservoir base in fractured shales?, *in* J. W. Schmoker, E. B. Coalson, and C. A. Brown, eds., Geological Studies Relevant to Horizontal Drilling: Examples from Western North America: Denver, Colorado, Rocky Mountain Association of Geologists, p. 199-214. The following was obtained from the Rocky Mountain Section website "This award, newly named after Dr. John D. Haun, longtime Rocky Mountain geologist and past president of the AAPG and AIPG, recognizes the authors or editors of a book, guidebook or other publication that over the past decade has had exceptional influence on developing new hydrocarbon plays or deeper understanding of fundamental geology within the Rocky Mountain region. As noted in the nomination, this article is “an exceptionally data-rich and well-reasoned paper published a decade before the shale gas and shale oil ‘boom’ started. Price and LeFever make the case for the exceptionally large, but at that time untested, oil potential of the Bakken Formation in the Williston Basin. With uncanny accuracy, they predict the essential characteristics of the Bakken shale oil play and the utility of horizontal wells. It took a full decade for fracture completion technology in horizontal wells to be developed and tested in the formation, thereby proving their prediction. To support their case, the authors draw comparison of the Bakken Formation with other self-sourced, fractured shale reservoirs that at the time were producing oil commercially. Now it is the Bakken Shale that is the industry gold-standard, the model for shale resource play exploration globally.”