STATE OF NORTH DAKOTA
BAKKEN FORMATION RESOURCE STUDY PROJECT

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This paper presents the results and methodology of a project by the North Dakota Department of Mineral Resources (DMR) Oil and Gas Division (OGD) and Geological Survey (NDGS) to estimate the original oil in place (OOIP) and recoverable reserves in the Bakken Formation within the State of North Dakota.

The original oil in place in the Bakken Formation within the thermally mature portion of the State of North Dakota is estimated to be **149.2 billion barrels**. The estimates are presented by County and separated into the total Bakken Formation, upper Bakken shale member, middle Bakken member, and lower Bakken shale member to make them more useful for resource evaluation and planning (Tables 1-4) and (Figures 3-6).

OOIP is defined as the total hydrocarbon content of an oil reservoir and refers to the oil in place before the commencement of production. OOIP is measured in stock tank barrels, meaning the volume of oil is corrected for shrinkage that occurs when the oil is brought to the surface to be sold at standard pressure and temperature. OOIP must not be confused with *oil reserves* which are the technically and/or economically recoverable portion of the oil volume in the reservoir and is referred to in this publication as estimated ultimate recovery (EUR).

The estimates of Bakken Formation OOIP and EUR provided in this publication are valuable for economic forecasting and infrastructure planning. These estimates also highlight the enormous potential for increasing recovery through continued development and deployment of new technology.

Previous publications on the Bakken Formation from Dow (1974) to Flannery and Kraus (2006) focused on the potential of the formation as a source rock. These investigators made estimates of the volume of oil that the Bakken Formation has generated ranging from 10 to 500 billion barrels. This paper differs from those publications in that it uses a wealth of public geology and engineering data generated since 2004 to estimate OOIP in the Bakken Formation. This estimate validates the highest oil generation estimates of Price (unpublished) and Flannery and Kraus (2006).

The Bakken Formation EUR using current drilling and completion practices within the thermally mature portion of the state of North Dakota has also been estimated. The estimated ultimate recovery is approximately **1.4%** of original oil in place, which is equal to **2.1 billion barrels.** The estimated recovery factors are also presented by county to show the high degree of variability in the geology and productivity of the Bakken Formation (Table 1). Note the recovery factors range from a low of 0.7% in Divide County to a high of 3.7% in Billings County.

The process of estimating Bakken Formation OOIP began with the compiling of a database containing all rock property, oil property, EUR, well cost, and well performance data presented to the Industrial Commission as expert testimony from June 2004 through December 2007. This database contains the geological and engineering data from 496 cases representing over 2,100 square miles of the Bakken resource broadly distributed across the state and is included as an Excel™ spreadsheet on the CD version of this publication. The data was sorted by county and evaluated using standard statistical methods to eliminate outliers and to determine mean, minimum, and maximum values. Well performance and economic data was also included and can be analyzed to evaluate the effectiveness of variations in well spacing and well bore geometry.

The rock properties in the case exhibit database yield statistically representative porosity and oil saturation values for the middle Bakken member for each county within the thermally mature region of the Bakken in western North Dakota. Additional data was required to evaluate the upper and lower Bakken shale members. A total of 601 core derived porosity analyses from the Bakken Formation are included in OGD well files (data is included as an Excel™ spreadsheet on the CD). The average effective porosity from the entire Bakken Formation was found to be approximately 5.5%. The upper Bakken shale member and lower Bakken shale member were found to contain an average effective porosity of 7% based on 60 analyses from seven wells in the upper Bakken shale member and 104 analyses from 13 wells in the lower Bakken shale member. Plug analyses of the middle member obtained from 437 samples from sixteen wells yielded an average effective porosity of 5.4%. A water saturation of 30% was selected for the mean value because it represents irreducible saturation and reflects the typically water free production from the Bakken shales. Minimum and maximum values of 20% and 40% were selected a representative of the same range above and below the mean as the middle Bakken member water saturation data.

The rock volume in each County was determined by using Petra™ software to planimeter isopach maps developed by Lefever (2008) as NDGS publication GI-59. Only the rock volume within the thermally mature region as determined through Time Temperature Index (TTI) mapping by Nordeng (2008) as NDGS publication GI-61, was included in this analysis (Figure 1). The TTI mapping was confirmed by comparison with a recent update of the work of Schmoker and Hester (1989). In this study it was proposed by that the eastward limits where the upper and lower members of the Bakken Formation in North Dakota are thermally mature can be determined from resistivity measurements. Neset (2007) evaluated resistivity measurements of wells drilled after 1989 using resistivity logs obtained from the OGD website to evaluate and confirm or modify the thermal maturity boundaries of the Bakken Formation. Logs with a geometric average deep resistivity reading of 35 ohm-m or greater were classified as thermally mature and those with a reading less than 35 ohm-m were classified as thermally immature. Neset's results confirm Schmoker and Hester's previous maturity boundary and extended it to the south and west (figure 2).

We estimate that additional resources of **10.5-17.6 billion barrels** OOIP have migrated from thermally mature areas into areas of the Bakken Formation that are not thermally mature. This is evidenced by significant production from the upper Three Forks Formation in the Sinclair Field located in southwestern Manitoba more than 70 miles from the leading edge of oil generation in the Bakken Formation. Possible migration pathways include major lineament trends such as the Brockton-Froid or through Bakken Formation "thicks" associated with sub-basins in southern Renville and central Bottineau Counties. OOIP was calculated for the area that is not thermally mature using rock volume, average porosity, and tight sand irreducible oil saturation estimates for the Bakken Formation Middle member only. This resource volume is estimated separately because it represents an unconventional tight formation oil play that requires oil migration together with structural or stratigraphic trapping mechanisms. The uncertainty of encountering accumulations of this resource is much greater than for the unconventional resource play within the thermally mature Bakken Formation region. There is currently no data from which to estimate EUR for this migrated resource.

Figure 1 – Thermally Mature Bakken Formation in North Dakota

Figure 2 - 35 ohm-m Contours Indicate Eastward Limits of Thermally Mature upper and lower Bakken shales

Figure 3 – Williston Basin with major structural features and modern Bakken / Three Forks production areas.

Table 1 & Figure 4 – Thermally Mature Total Bakken OOIP, EUR, and Recovery Factor.

Table 2 & Figure 5 – Thermally Mature upper Bakken shale member acres, acre-feet, porosity, Water Saturation (Sw), Formation Volume Factor (Bo), and OOIP

Table 3 & Figure 6 – Thermally Mature middle Bakken member acres, acre-feet, porosity, Sw, Bo, and OOIP

Table 4 & Figure 7 – Thermally Mature lower Bakken shale member acres, acre-feet, porosity, Sw, Bo, and OOIP

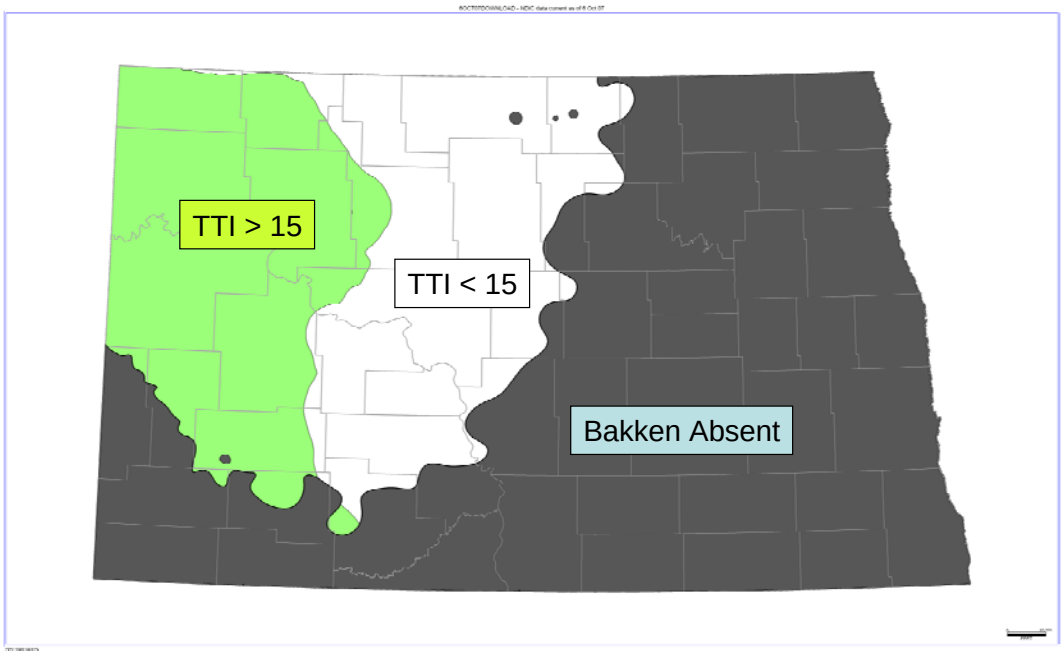

Figure 1 – Thermally Mature Area (green area TTI > 15) of the Bakken Formation, Nordeng(2008) used a TTI of 15 as the limit for the onset of oil generation. TTI < 15 indicates the area of potential migrated oil potential in North Dakota.

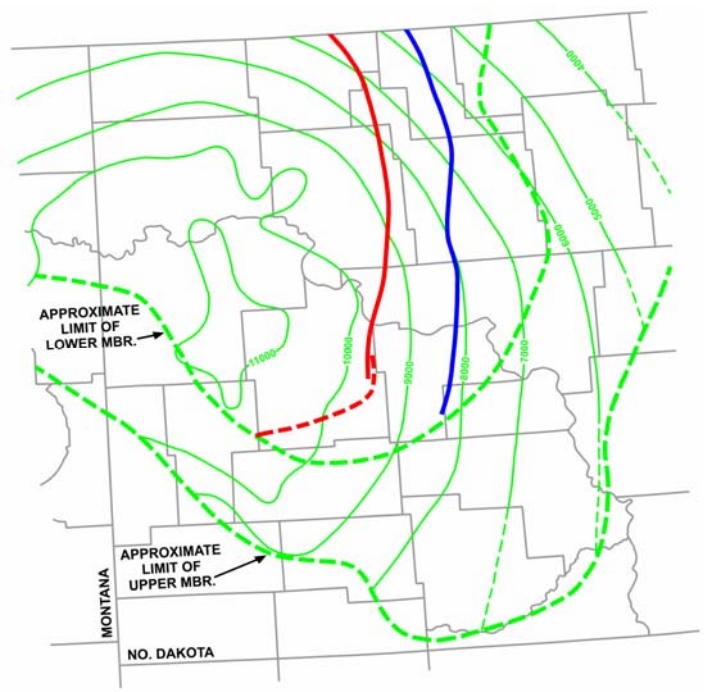

Figure 2. 35 ohm-m contours indicate the eastward limits where the upper and lower members of the Bakken Formation are thermally mature. The red line indicates the lower shale boundary and the blue line indicates the upper shale boundary. The red dashed line is the extension from data collected during the Neset study (modified from Neset, 2007).

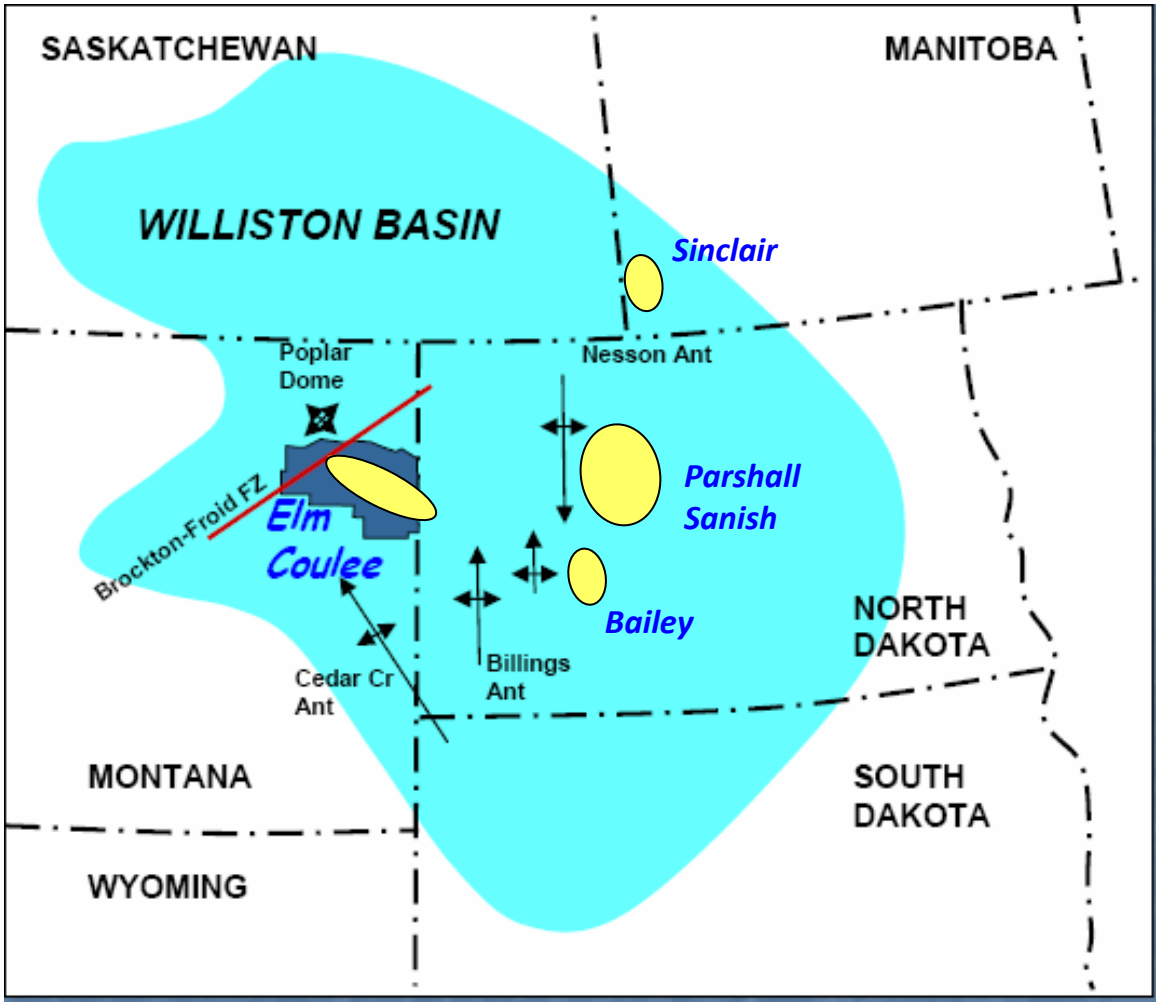

Figure 3 – Williston Basin with major structural features and modern Bakken / Three Forks production areas.