Examination of middle Three Forks (2nd Bench) Hydrocarbon Charge and Production

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Introduction

Beginning in 2012, various operators in the Bakken-Three Forks play began testing and examining the middle to lower portions of the Three Forks Formation as a prospective unconventional reservoir (fig. 1) (Petroleum News, 2012; Gaswirth and Marra, 2015). The prospective Three Forks reservoir horizons were informally subdivided into four benches, numbered 1 to 4 in descending order (fig. 1). Prior to that time, drilling and production was primarily focused on the Middle Bakken and upper Three Forks (1st bench). Beginning in early 2015, approximately 2 years after commencement of initial drilling and testing of the middle to lower Three Forks, the North Dakota Oil and Gas Division began tracking the specific target interval of horizontal Three Forks wells. Since that time, over 180 horizontal wells have been drilled

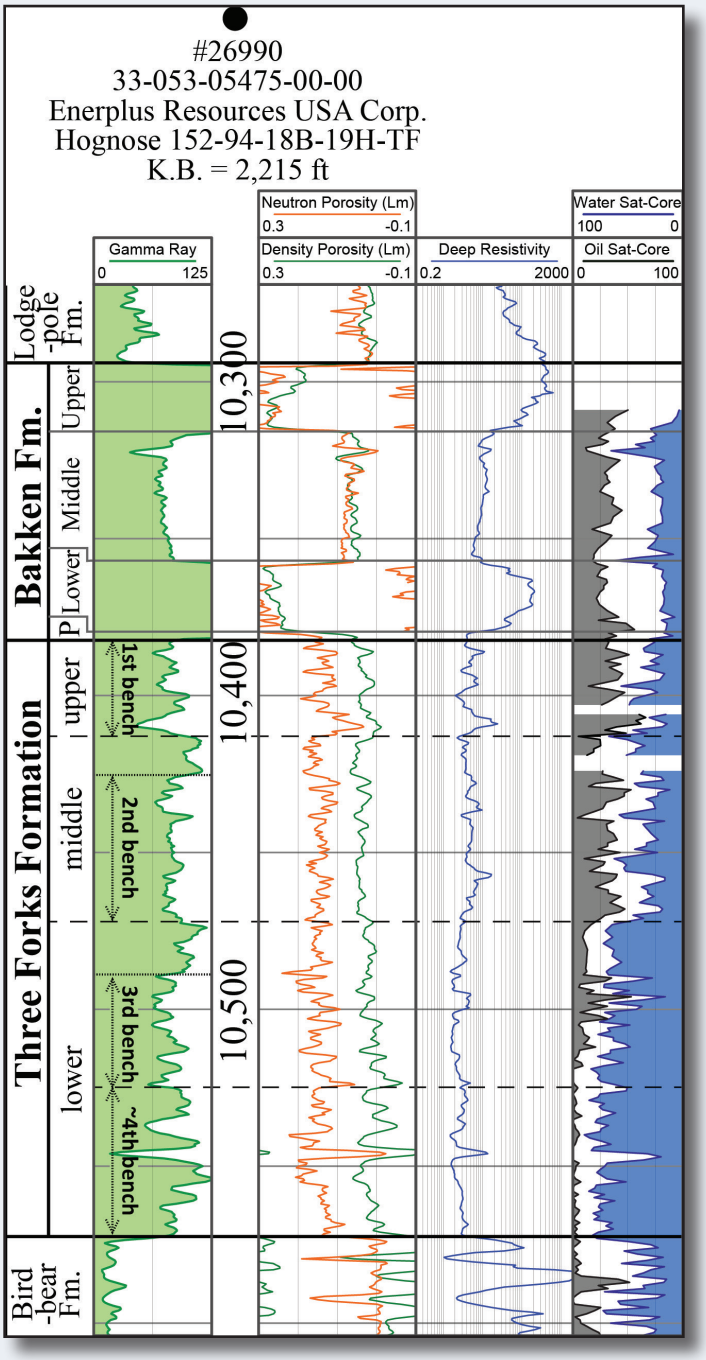

Figure 1. Wireline log example of the Bakken and Three Forks Formations with core plug oil and water saturation data (right side). Note the consistent oil saturations (typically 25-50%) that extend from the Bakken down through the base of the middle Three Forks (2nd bench). P = Pronghorn. Depths are in feet below surface.

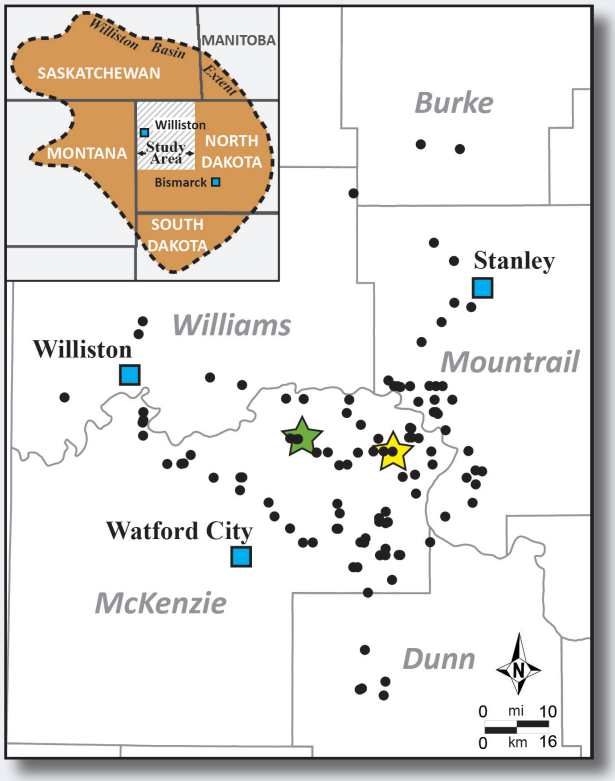

Figure 2. Production map showing the distribution of productive horizontal oil wells (black circles) that have been drilled and completed within the middle Three Forks (2nd bench). The yellow star depicts the location of well #26990 (fig. 1), and the green star the location of well #22388 (figs. 3 and 4). The light grey lines represent county outlines. A basin-scale reference map is provided in the top left corner.

and completed in the middle to lower Three Forks Formation, which have cumulatively produced nearly 20 million barrels of oil to date (fig. 2). The majority (~80%) of those wells targeted the middle Three Forks (2nd bench). A significant number of additional, pre-2015 middle to lower Three Forks wells are also present, but the number of those earlier wells and their cumulative production volumes have yet to be determined.

There is currently limited geological information available regarding the petroleum geology and economic importance of the middle to lower Three Forks. Resource assessments of the Three Forks Formation have ranged from approximately 2 to 4 billion barrels of recoverable oil, but these assessments have been limited to the upper Three Forks (Nordeng and Helms, 2010; Gaswirth et al., 2013). This article reports the preliminary findings of a recently initiated study on the origin and distribution of oil saturations within the middle Three Forks. It also reviews the present production footprint of 2nd bench horizontal oil wells and projects their potential future distribution. In addition, I am examining oil saturations and hydrocarbon production in the lower Three Forks (3rd and 4th benches).

Geology

The Three Forks Formation was deposited during the Upper Devonian (385 to 359 million years before present) and directly underlies the Bakken Formation (Murphy et al., 2009). Hydrocarbons present within the Three Forks are believed to be sourced from the overlying lower Bakken shale, which is considered to be a world class petroleum source rock.

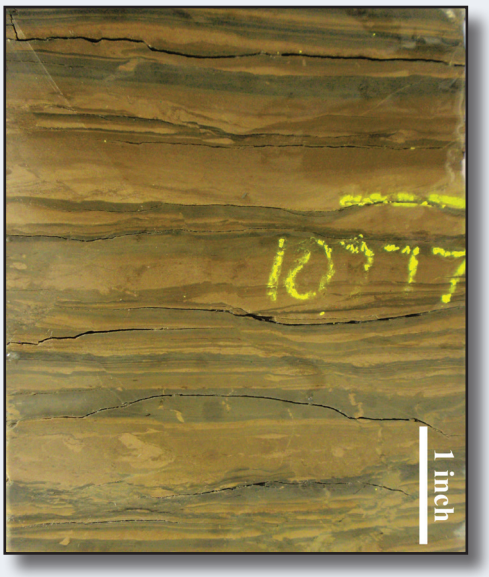

Figure 3. Core photograph example of the middle Three Forks from Whiting's Skaar Federal 41-3-3H (NDIC: #22388, API: 33-053-03979-00-00, Sec. 3, T152N, R97W). The tan colored layers of the core consist of dolomite silt while the grey-green portions are more clay-rich.

Figure 4. Core photograph example of the middle Three Forks from Whiting's Skaar Federal 41-3-3H (NDIC: #22388, API: 33-053-03979-00-00, Sec. 3, T152N, R97W) that displays sand to pebble sized clasts of dolostone suspended in the silt to mud matrix. This is an example of the interpreted debris flow facies common of the middle Three Forks (2nd bench).

Previous studies have sub-divided the Three Forks in different schemes, including 1) six sub-units ranging from unit 1 to unit 6 in ascending stratigraphic order (e.g. Christopher, 1961), and 2) more simplistic upper, middle, and lower members (e.g. Bottjer et al., 2011) which is utilized in this article. A number of oil and gas companies have also adopted an informal "bench" terminology system which refers to the various Three Forks reservoir intervals as bench 1 to bench 4 in descending stratigraphic order (e.g. fig. 1).

The middle Three Forks (2nd bench) contains similar lithofacies (rock types) to the prolific upper Three Forks (1st bench) including beds of tan silty dolostone intercalated with grey to green claystone, which have been interpreted to represent intertidal to tidal flat deposits (fig. 3). In addition, the middle Three Forks is also comprised partly of siltstone to mudstone beds containing variable amounts of pebble-sized dolostone clasts interpreted as debris flows (fig. 4) (Droege, 2014).

Middle Three Forks (2nd Bench) Oil Saturations

Oil and water saturation data measured from middle Three Forks core samples were compiled and examined from over 50 wells (fig. 5). The fluid saturation averages indicate that the middle Three Forks can be subdivided into three areas based primarily on oil saturations and secondarily on water saturations. Fluid saturations were found to be nearly indistinguishable between the upper and middle Three Forks (e.g. fig. 1) within the 1st tier area (highest oil saturations), which extends across northeastern McKenzie to southeastern Dunn and southwestern Mountrail counties (dashed outlined area - fig. 5). There is also a larger, 2nd tier area where water saturations are higher in the middle Three Forks, but notable oil saturations are still present (dotted outline area – fig. 5). Moving laterally outward from beyond the 1st and 2nd tier oil saturation areas, the 3rd tier area merely represents where core plug water saturations continue to increase overall while oil saturation values decrease to <10% (fig. 5).

Lower Bakken Shale Thermal Maturity

The low porosity and permeability throughout the Bakken-Three Forks section leads to the understanding that most of the oil in place has been locally generated (minimal lateral migration). The source rock in closest stratigraphic proximity to the middle Three Forks is the lower Bakken shale (e.g. fig. 1). Examining the lower shale, most of the high oil saturation (1st tier) area correlates with where the lower Bakken shale is both >20 feet thick and has reached the greatest level of thermal maturity with respect to oil generation (fig. 6). The 2nd tier,

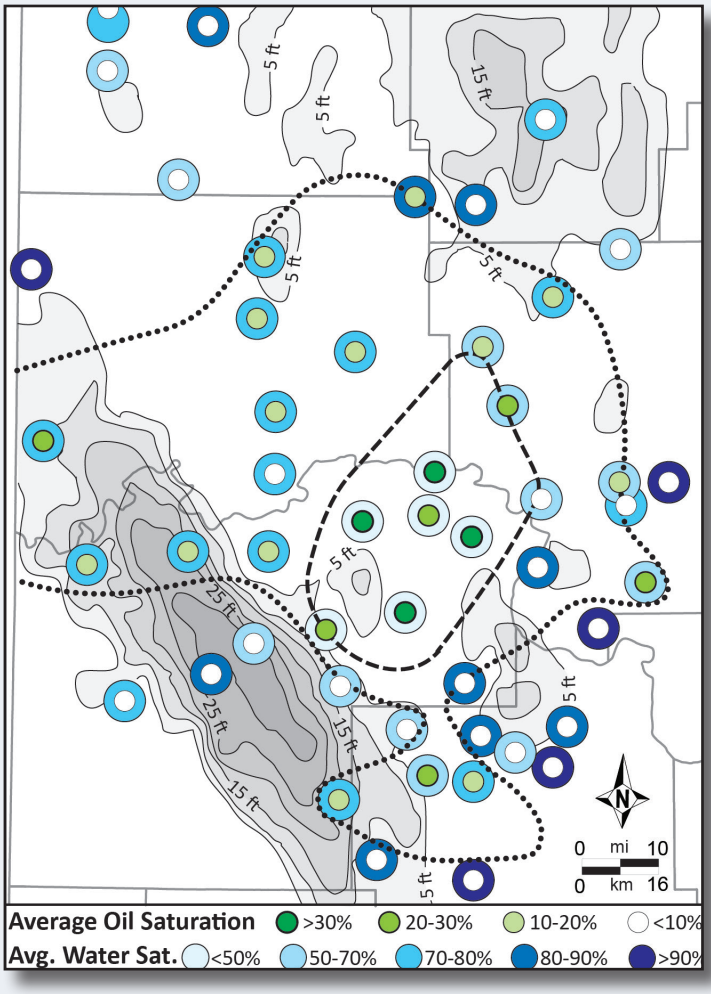

Figure 5. Fluid saturation map showing the average oil (white-green dots) and water (blue circles) saturations of the middle Three Forks from core plug analysis data. The thick dashed outline depicts where the middle Three Forks averages the highest oil (20-40%) and lowest water (<50%) saturations. The dotted outline depicts where the middle Three Forks typically contains intermediate oil (10-30%) and water (50-80%) saturations. Beyond the intermediate oil saturation area, the middle Three Forks commonly averages 70-90% core plug water saturation with <10% oil. The grey-colored contours represent the thickness of the Pronghorn Member of the Bakken Formation, which appears to inhibit hydrocarbon charge from the lower Bakken shale to the Three Forks Formation (Millard and Brinkerhoff, 2016).

intermediate oil saturation area reflects where either the lower Bakken shale has thinned and/or is less thermally mature, but still within the peak oil generation window. Therefore, oil saturations of the middle Three Forks appear to be primarily a function of both the thickness and thermal maturity of the lower Bakken shale. The greater the volume of oil generated from the lower shale, the further hydrocarbons are forced downwards into the underlying Three Forks Formation.

Middle Three Forks Current and Future Footprint

The majority of middle Three Forks wells permitted and/or drilled and completed since early 2015 have been proximal to the area of highest core plug oil saturation (fig. 7). This timeframe correlates with the beginning of depressed oil prices. Oil saturations likely correlate with oil production to some degree, where drilling and completing wells in areas with higher oil saturations result in better well performance. The immediate future of drilling activity in the middle Three Forks will likely continue to focus on the area with highest oil saturations (1st tier area). Over the course of time, middle Three Forks development will likely extend more into the 2nd tier intermediate oil saturation area through a combination of commodity price changes, technological advances, and/or continued drilling-completion cost reductions.

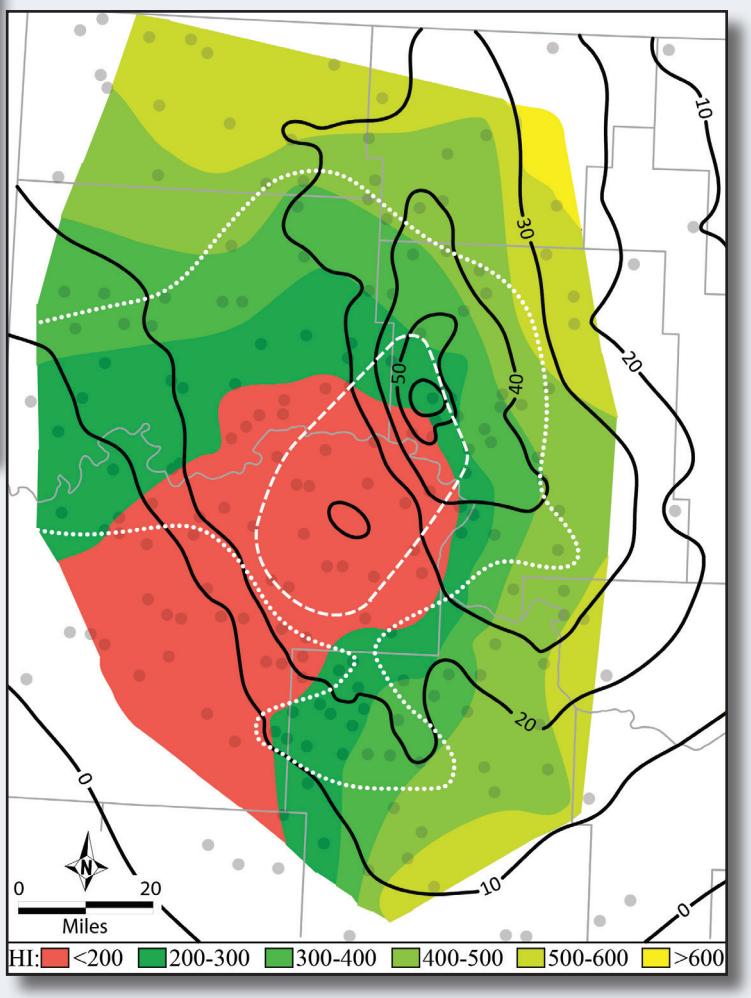

Figure 6. Thermal maturity (hydrogen index = HI) and isopach (thickness) map of the lower Bakken shale. The colored HI contours reflect the thermal maturity of the lower Bakken shale, where red is the most thermally mature area with respect to oil generation and the light green to yellow is the least thermally mature. The thick black lines are isopach (thickness) contours of the lower Bakken shale in feet. The dashed white line depicts where the middle Three Forks contains the highest average core plug oil saturations and the dotted line the area with low to intermediate average oil saturations.

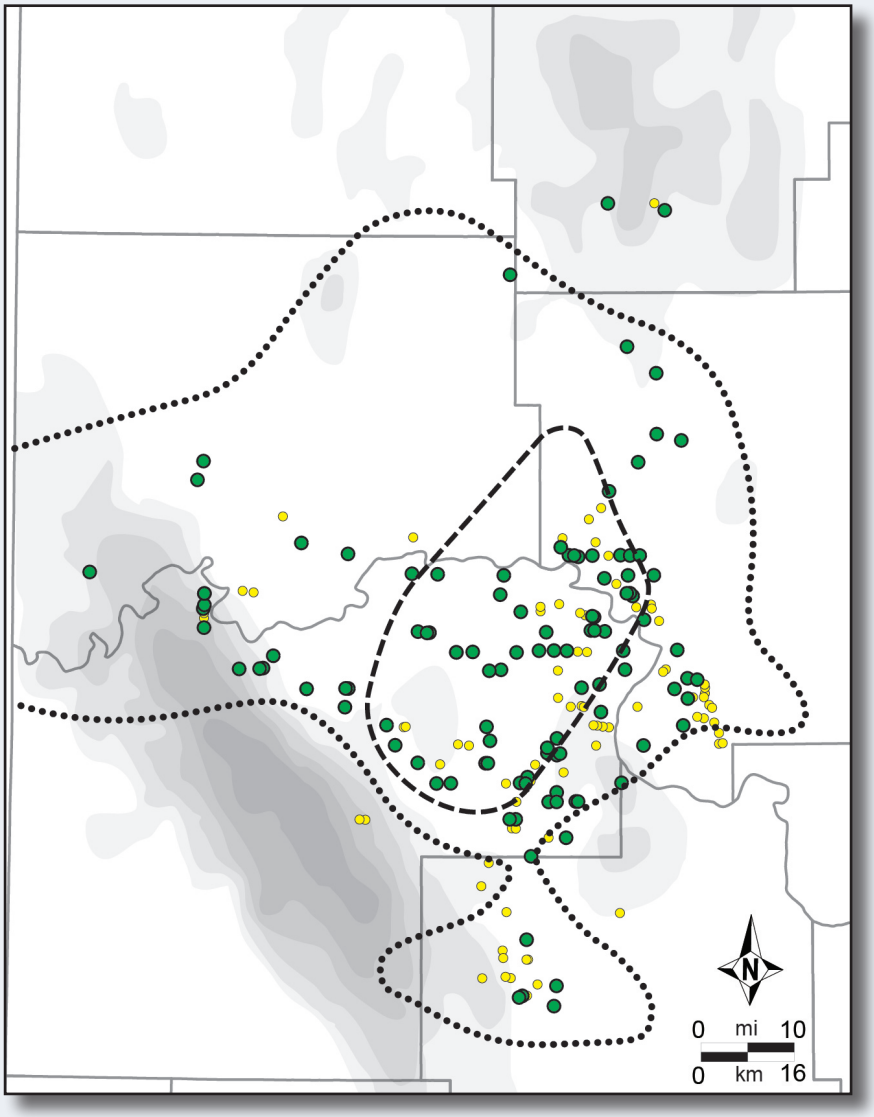

Figure 7. Middle Three Forks production map with outline of 1st tier/high oil saturation area (dashed line) and 2nd tier/intermediate oil saturation area (dotted line). Green circles show the distribution of middle Three Forks horizontal oil well and the yellow circles are undrilled, permitted well locations. Note how over 95% of the middle Three Forks wells are presently located within the intermediate oil saturation area, the majority of which are positioned within or close to the high oil saturation area. Grey shading depicts the thickness (isopach) of the Pronghorn Member of the Bakken Formation with contouring ranging from 5 to 30 feet in 5 foot contour intervals.

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