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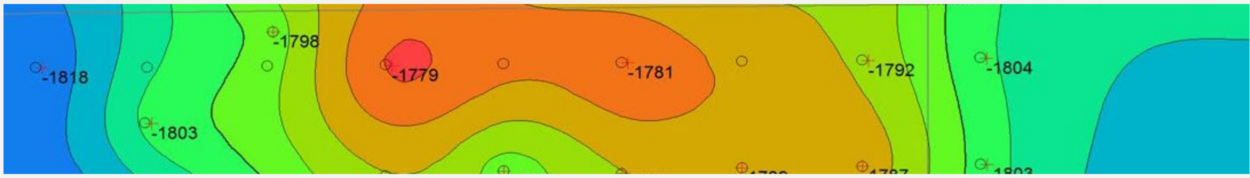

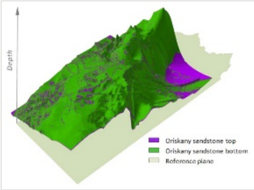

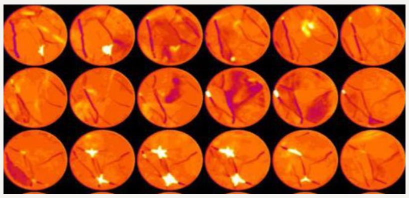

Bakken Shale Basin Study

June 26, 2019

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Gary Covatch

DOE Contract Number DE-FE0025912

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TABLE OF CONTENTS

LIST OF EXHIBITS

ACRONYMS AND ABBREVIATIONS

API	American Petroleum Institute
ARI	Advanced Resources International
Bbl/B	Barrel
CO_2	Carbon dioxide
DOE	Department of Energy
EERC	Energy & Environmental Research Center
ft	Foot, Feet
GOR	Gas-oil ratio
Hz	Horizontal
MBbl	Thousand barrels
MBOED	Thousand Barrels Oil Equivalent per Day
Mcf	Thousand cubic feet
Mcf/bbl	Thousand cubic feet per barrel
MESA	Mission Execution and Strategic Analysis
mi^2	Square mile
MM	Million
MMB/D	Million barrels per day
MMB/mi^2	Million barrels per day per square mile
MMcfd	Million Cubic Feet per Day
N_2	Nitrogen
NETL	National Energy Technology Laboratory
OOIP	Original oil in-place
psi	Pounds per square inch
pst/ft	Pounds per square inch per foot
PVT	Pressure volume temperature
RB/STB	Reservoir barrels/stock tank barrels
Ro	Vitrinite reflectance
TOC	Total Organic Carbon
U.S.	United States
°F	Degrees Fahrenheit

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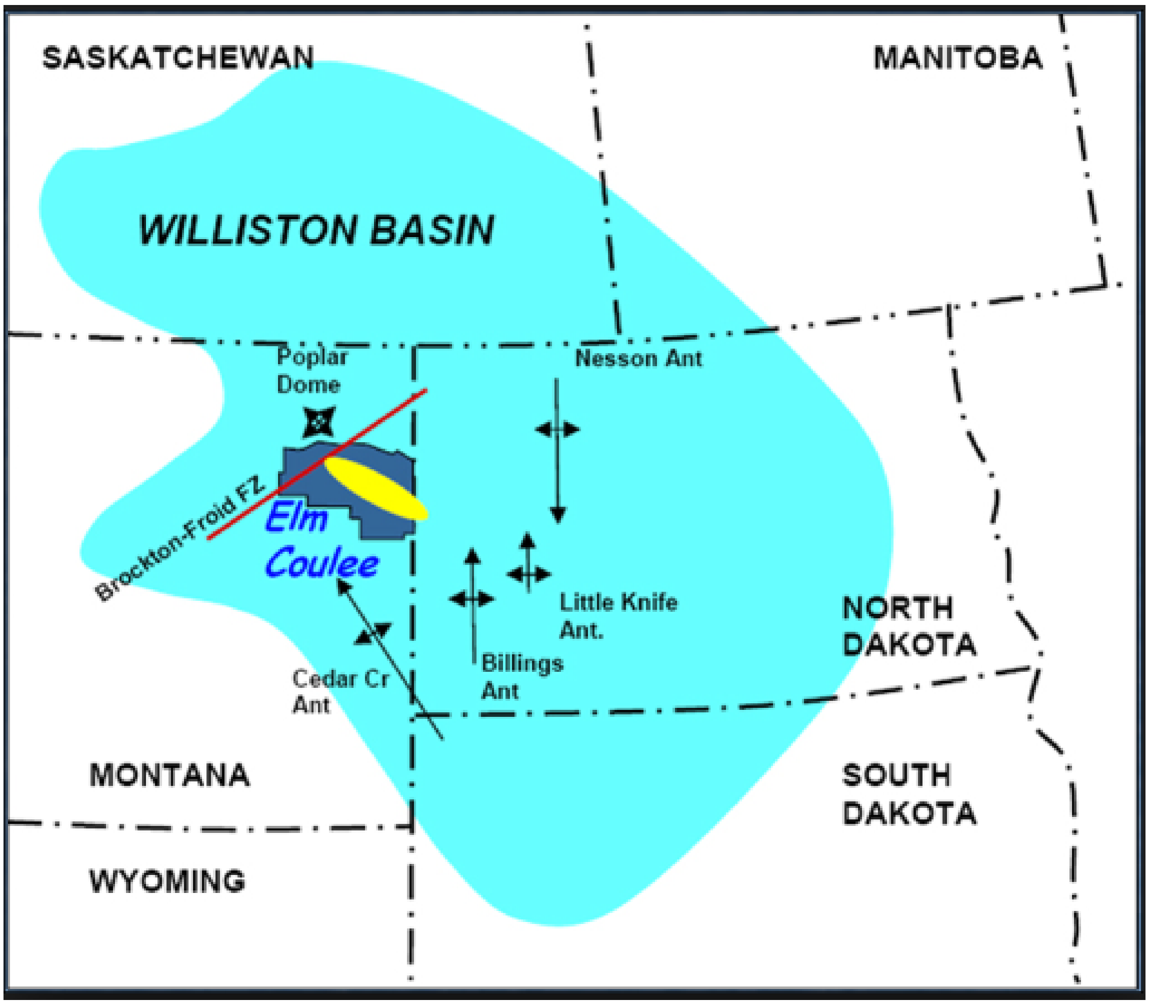
1 INTRODUCTION

The Bakken Shale extends across an 18,400 square mile (mi^2) area in the United States (U.S.) portion of the Williston Basin in North Dakota and Montana, plus considerable additional area in the Canadian portion of the Williston Basin in Saskatchewan and Manitoba, Exhibit 1-1. The pinch-out of the Bakken Shale interval defines the areal extent of this shale deposit. The continuous and fully charged oil saturation area in the central, thermally mature portion of the Bakken Shale is the target of most interest to Bakken operators.

Exhibit 1-1 Williston Basin Location Map



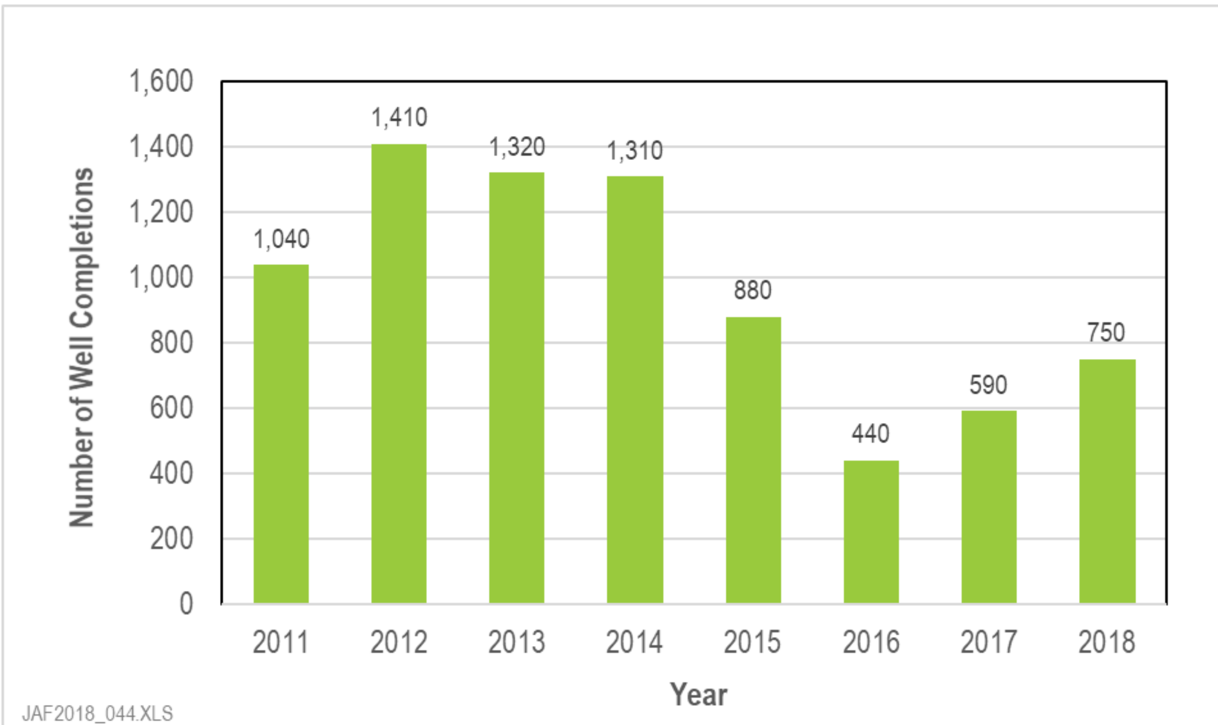
Source: Heck et al., 2004

Initial Bakken Shale activity was in the Elm Coulee Field in southeastern Montana. This was followed by intensive development of the Bakken Shale in North Dakota. As of the end of 2018, nearly 13,000 vertical and horizontal (Hz) wells have been drilled and completed in the Bakken Shale, with the bulk of these wells placed online in the Basin Center area of Mountrail, McKenzie, Dunn and Williams counties.

2 DEVELOPMENT ACTIVITY

Following the drilling of resource characterization wells in the late 1990's, significant pursuit of the Bakken Shale started in 2004, following the drilling and completion of 105 Hz wells. With a steady increase in rigs, Hz well completions reached a peak of 1,410 Hz wells in 2012 and remained close to this level for the next 2 years. Following the drop in oil prices, Hz well completions declined, first to 880 in 2015 and then further to a modern-day low of 440 in 2016. Higher oil prices, along with recent improvements in well performance, supported the rebound in well completions to 590 in 2017, with additional growth to 750 Hz well completions in 2018, displayed in Exhibit 2-1.

Exhibit 2-1 Bakken Shale Hz Well Completions, 2011-2018



Source: Advanced Resources International's Tight Oil Database, 2018; Drilling Info, 2018

Today, the Bakken Shale is an increasingly mature tight oil play. As such, some of the more productive areas of the Bakken Shale have become highly drilled. For example, the Nesson Anticline area of Mountrail County now has 2,100 well completions, consuming nearly 60 percent of the potentially available Bakken Shale Hz well locations in this county.

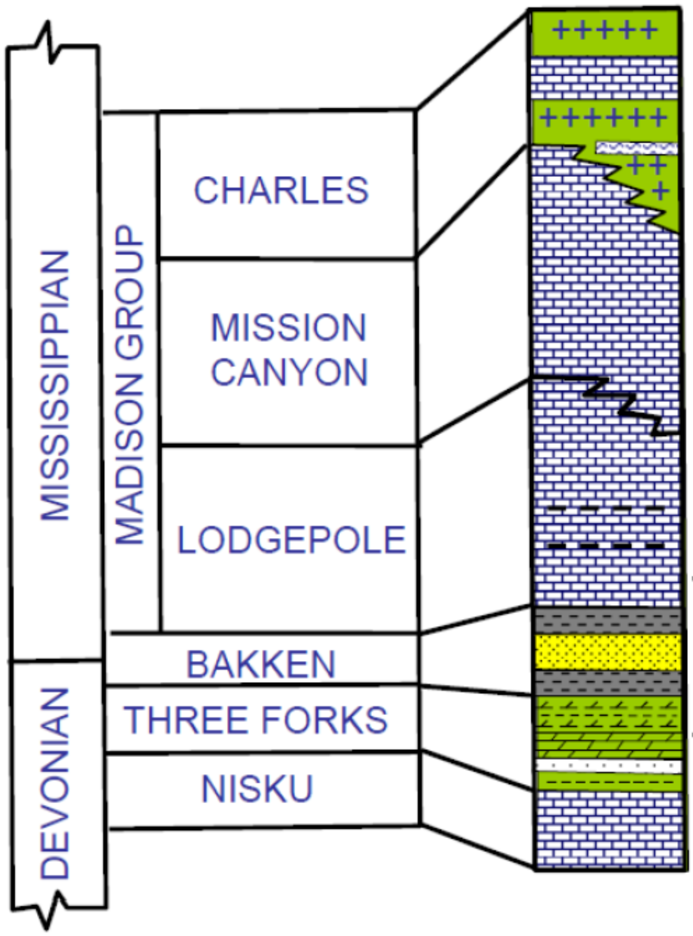
As a result, much of the recent well drilling has moved to adjoining counties of Williams, McKenzie, and Dunn. In addition, several cyclic gas injection pilot projects have been recently initiated to improve the oil recovery efficiency of the Bakken Shale.

3 Geologic Setting

3.1 Stratigraphic Column

The Mississippian Bakken Shale lies above the Devonian Three Forks Shale and is overlain by the Lodgepole Formation of the Madison Group, Exhibit 3-1.

Exhibit 3-1 Bakken Shale Stratigraphic Column



Source: Jin and Sonnenberg, 2013

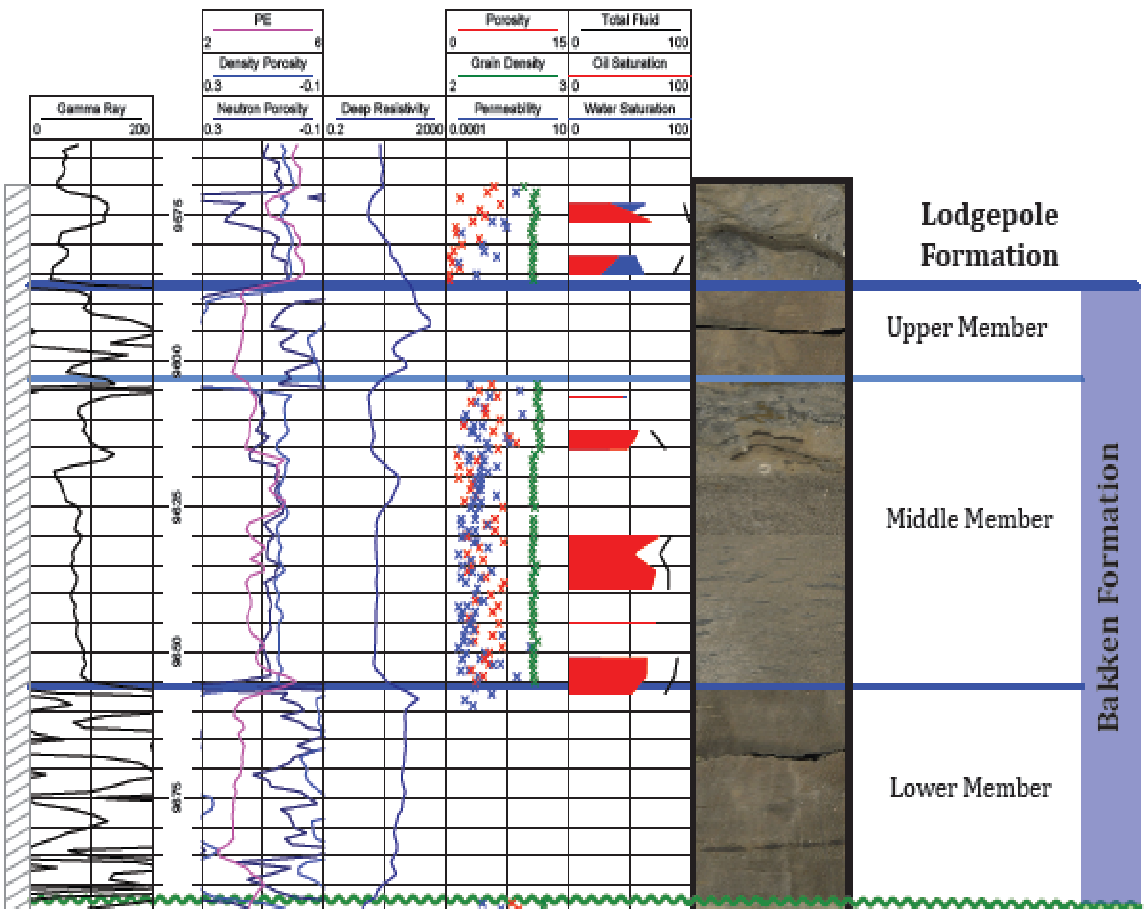
Below the Bakken Shale is an equally attractive shale formation called the Three Forks Shale (not addressed in this Bakken Shale study) that has become notably active in the recent years. Along with increasing production of tight oil, the Bakken Shale also produces substantial volumes of associated wet gas and natural gas liquids.

3.2 SHALE INTERVAL

The Bakken Shale contains three members, as shown on log EOG #2-11 Liberty in southern Mountrail County, Exhibit 3-2.

- The Upper Member consists of organic-rich, finely laminated shales deposited in a restricted marine setting.
- The Middle Member is a dolomitic siltstone to fine-grained sandstone, containing a network of microfractures.
- The Lower Member is similar to the Upper Member, an organic-rich shale.

Exhibit 3-2 Typical Bakken Well Log

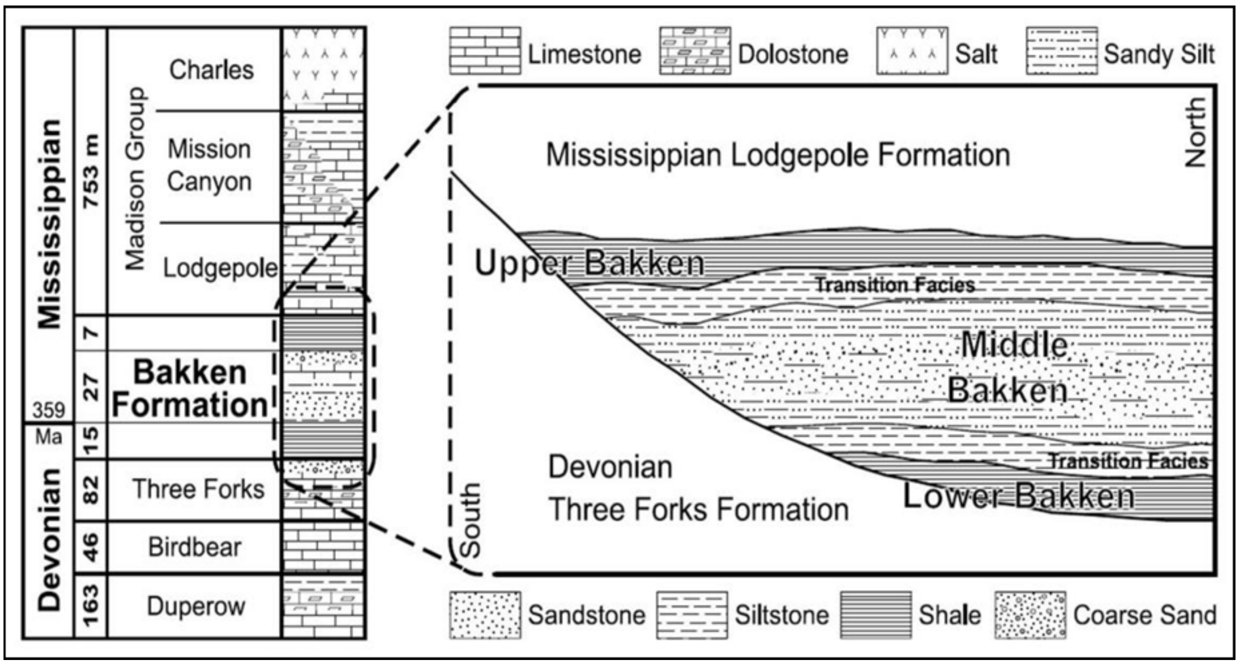


Source: LeFever, et al. 2013

3.3 BAKKEN FORMATION DEPOSITION

Within the Williston Basin, the Mississippian Bakken Shale overlies the Devonian Three Forks Formation and, in turn, is conformably overlain by the Mississippian Lodgepole Formation, which acts as an effective vertical barrier to hydraulic fracturing, as shown in Exhibit 3-3. The Upper and Lower Bakken shales are organic-rich black shales that were deposited in anoxic marine environments and sourced the Middle Bakken oil reservoir. The Middle Bakken consists mainly of silty dolostone and fine-grained sandstone characterized by moderately low permeability (Grau and Sterling, 2011).

Exhibit 3-3 Deposition of the Bakken Formation

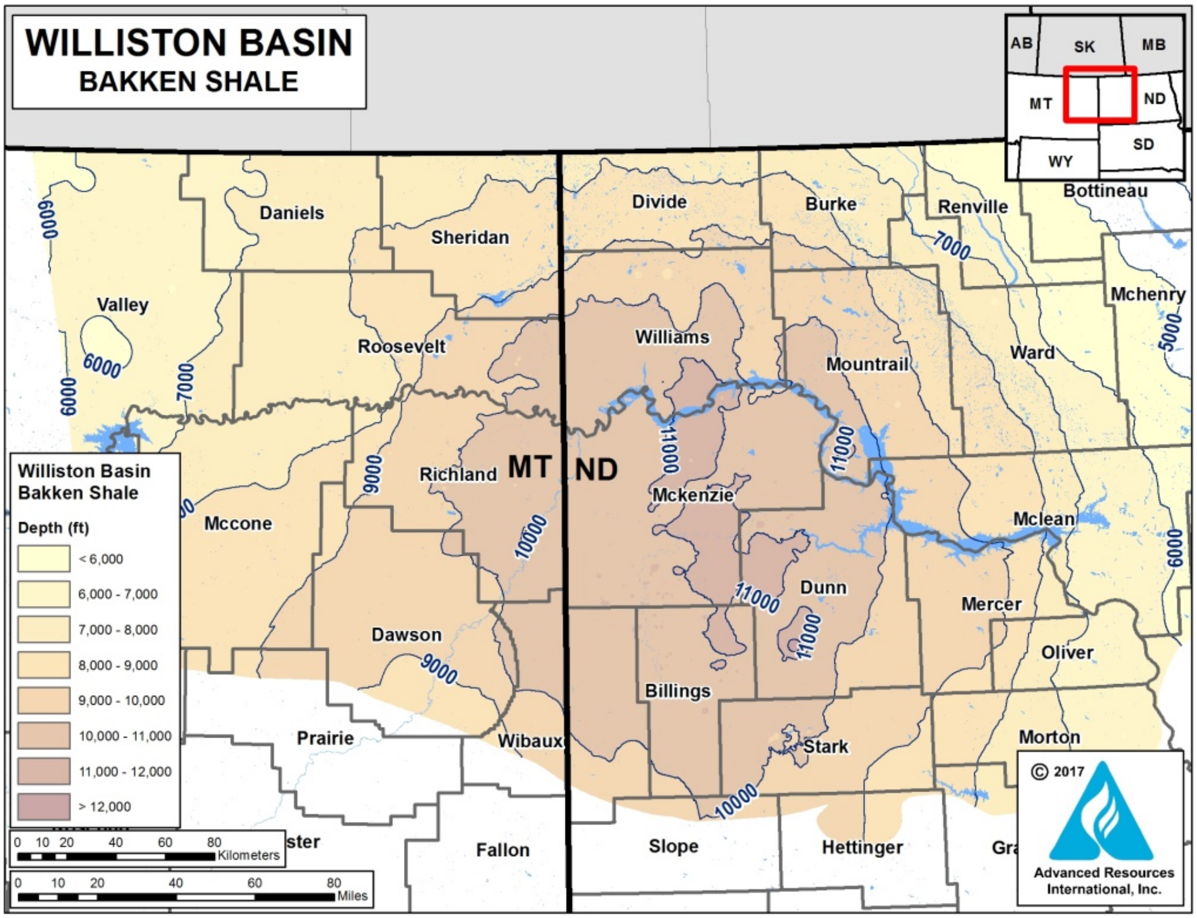


Source: Kuhn et al., 2012.

3.4 Shale Depth

From a depth of about 8,000 feet (ft) at the basin margins, the Bakken Shale reaches a depth of over 11,000 ft in the heart of the basin's hydrocarbon "kitchen" in west-central North Dakota, as shown in Exhibit 3-4.

Exhibit 3-4 Bakken Shale (Middle Member) Shale Depth



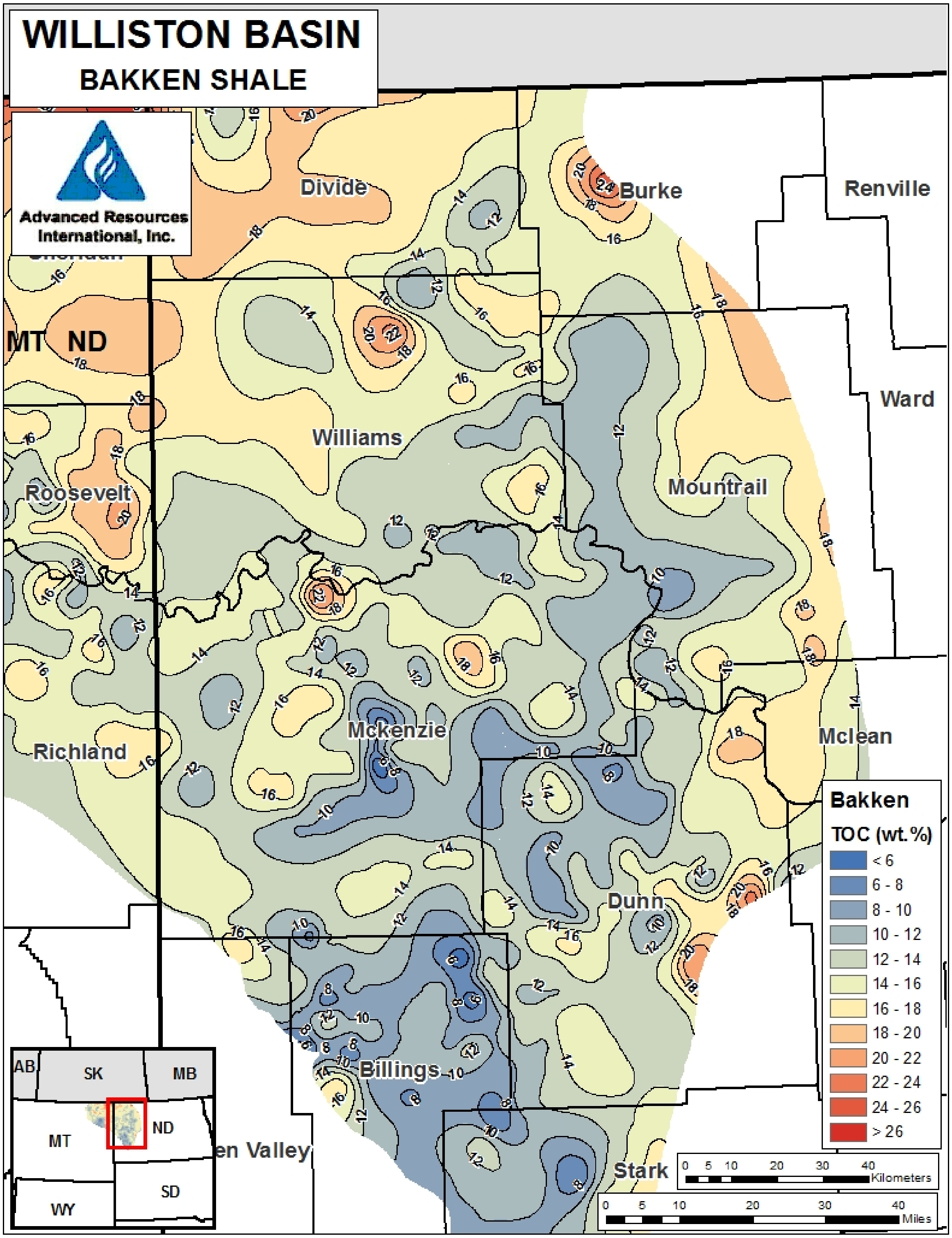
Source: Advanced Resources International, 2018

3.5 Bakken Shale TOC

Total organic carbon (TOC) in the Bakken Shale is highly variable across the basin, ranging from less than 6 percent to over 20 percent, as shown in Exhibit 3-5. The average TOC generally ranges from 10 percent to 15 percent and is quite variable stratigraphically (vertically) within the Bakken Formation.

Detailed core analysis from a Bakken Shale well in Mountrail County shows TOC in the Upper and Lower Bakken Shale to range from 10 percent to 18 percent (Zhang et al., 2013).

Exhibit 3-5 Upper Bakken Shale Total Organic Carbon (TOC) Map



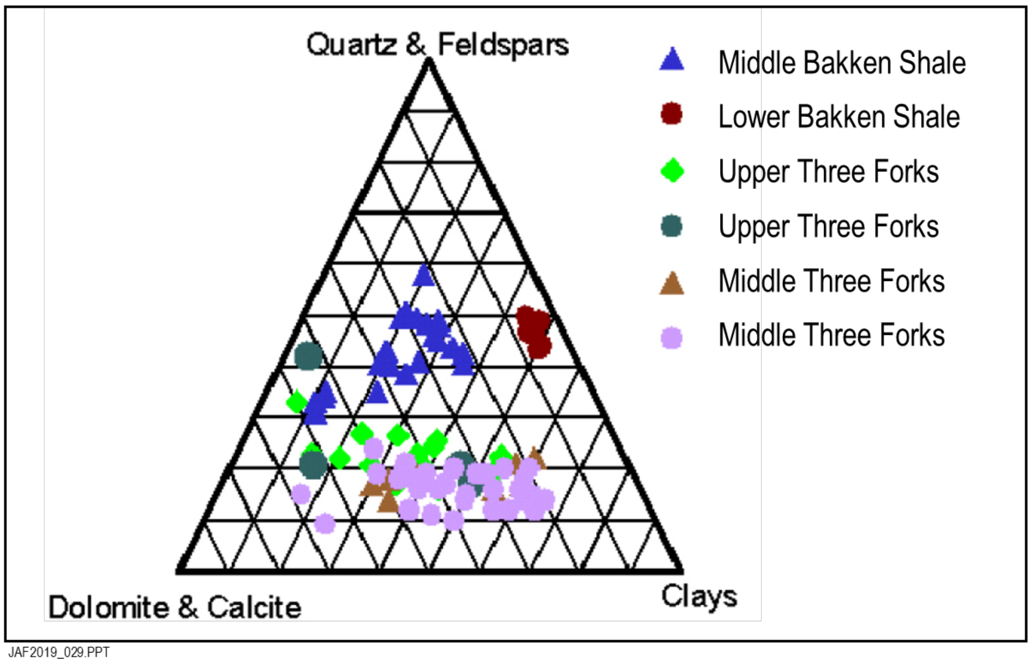
Source: Advanced Resources International, 2019

3.6 Shale Mineralogy

ConocoPhillips provided data from core of the Middle and Lower Bakken as well as for four benches within the Three Forks Formation, displayed in Exhibit 3-6 (Mitchell, 2013).

- The Upper and Lower Bakken Members consists of organic-rich, finely laminated shales from a restricted marine setting.
- The Middle Bakken Member consists of quartz, feldspar, and carbonate with little clay.
- The higher volumes of quartz and carbonate, along with little clay, create a brittle rock favorable for hydraulic stimulation.

Exhibit 3-6 Middle/Lower Bakken and Three Forks Mineralogy



Source: Mitchell,2013

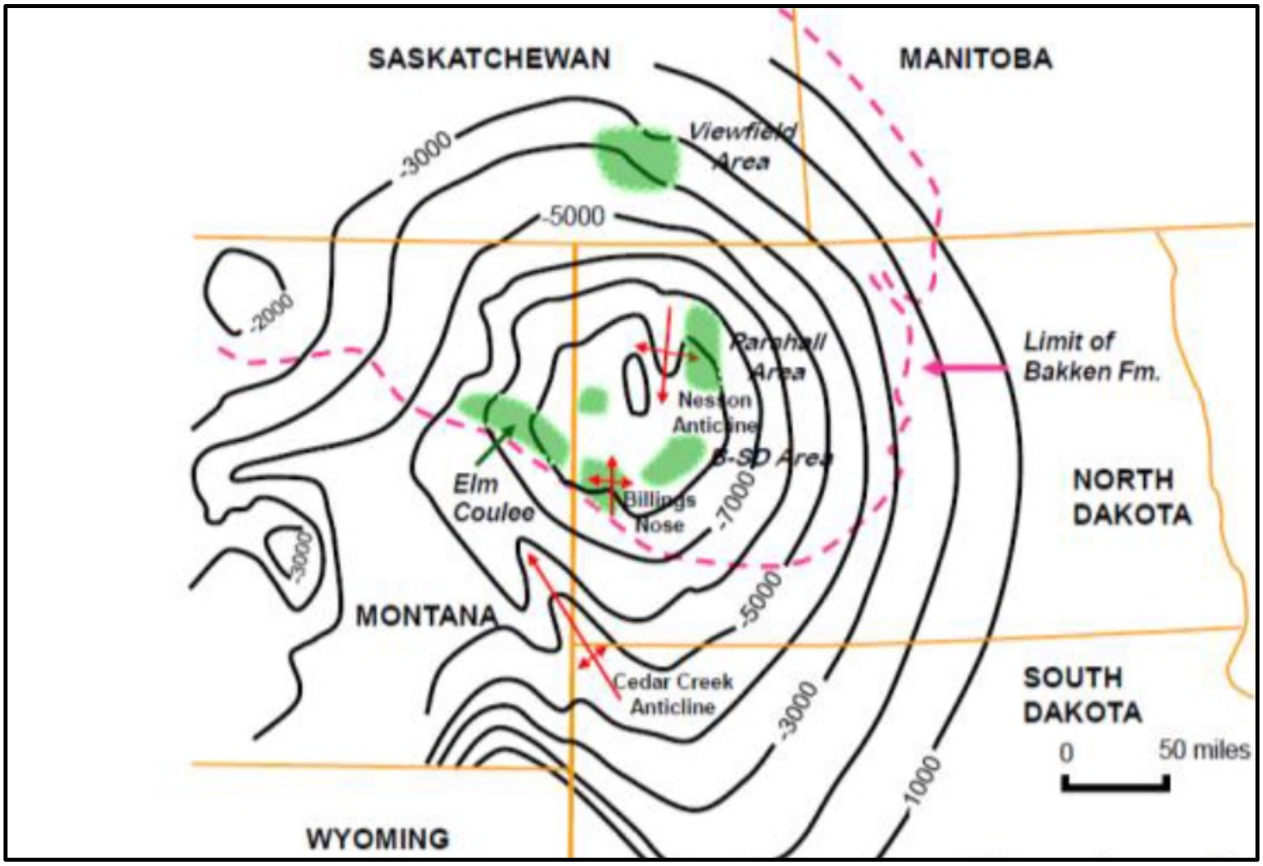
3.7 Structural Setting

The Williston Basin is a structurally simple syncline with gentle dip. It is cut by six major lineaments. Most of these features (Cedar Creek, Nesson) are associated with major N-S trending vertical faults with large displacement, as shown in Exhibit 3-7. The exception is the NE-SW trending Brockton-Froid that cuts across the Williston Basin to the north of Elm Coulee all the way to the NE side of the basin in Canada. North of this feature, Bakken wells tend to produce high water rates, possibly due to large hydraulic stimulations that link into the Nisku and Dawson Bay formations, both of which contain regional porosity zones that act as carrier beds and salt-water aquifers (Silver, 2013).

The Elm Coulee field in Montana is characterized by NE/SW left-lateral strike-slip system that may be related to the Brockton-Froid Lineament. Detailed study of the Bakken interval at Elm

Coulee field revealed that small vertical-offset, laterally extensive faults appear to correspond with higher productivity areas of the field (Honsberger, 2013).

Exhibit 3-7 Location and Structural Features of the Williston Basin (structure contour at the base of Mississippian)

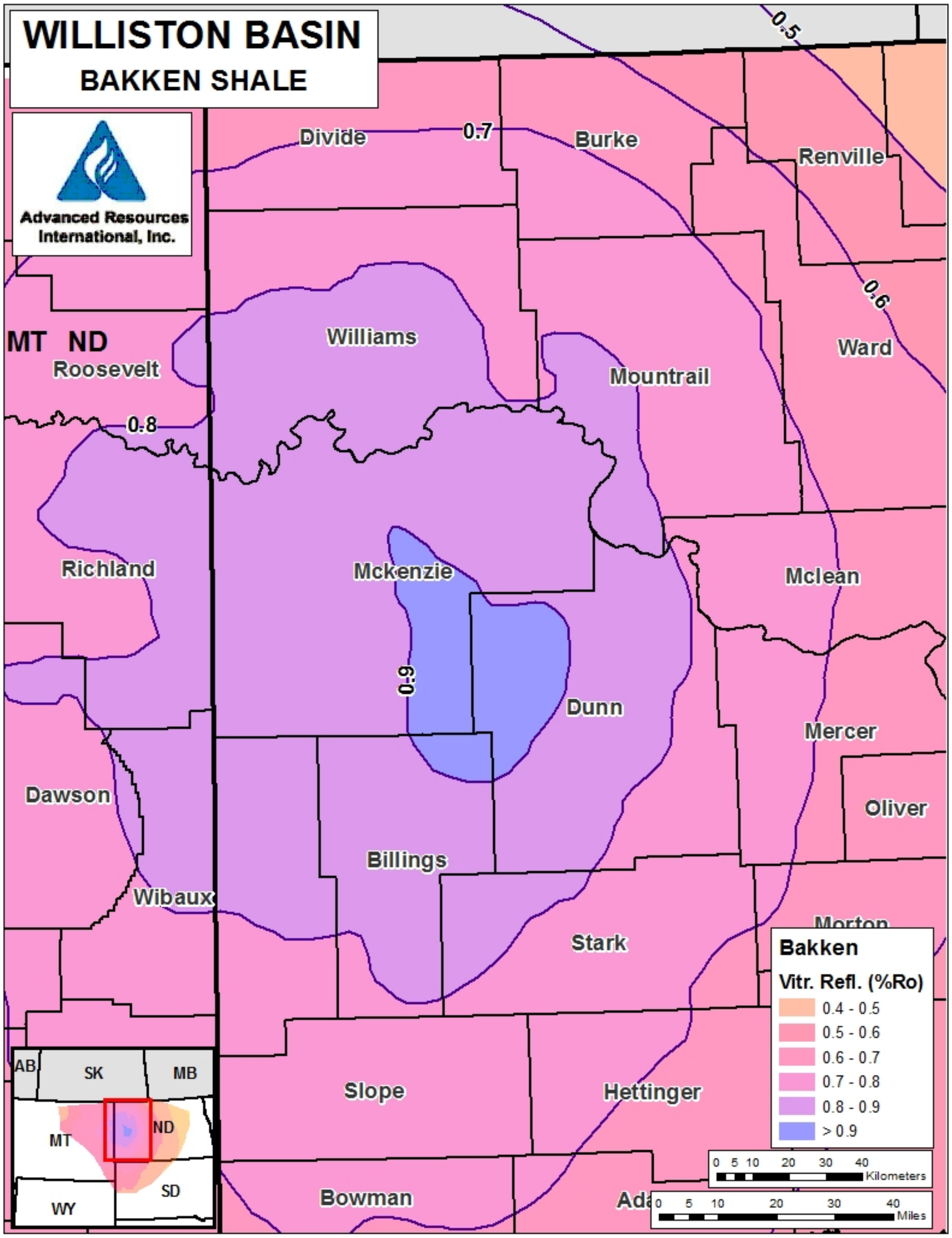


Source: Jin and Sonnenberg, 2013.

3.8 Thermal Maturity

The thermal maturity of the Bakken Shale is measured using vitrinite reflectance (% Ro) and varies from a Ro of over 0.9 percent in the basin center to a Ro below 0.5 percent towards the basin margins. The best wells, primarily in Mountrail, McKenzie and Dunn counties, have an Ro of over 0.8 percent along with higher gas-oil ratios (GORs), as shown in Exhibit 3-8.

Exhibit 3-8 Bakken Shale Thermal Maturity



Source: Advanced Resources International, 2019.

4 RESERVOIR PROPERTIES

The reservoir properties of the Bakken Shale vary greatly, both vertically within the Bakken Shale interval and horizontally across the large shale deposition area. To capture the key reservoir property values and their distribution, the research team assembled published data on the Bakken Shale from a variety of sources as well as performed some of the data assembly, interpretation and mapping tasks.

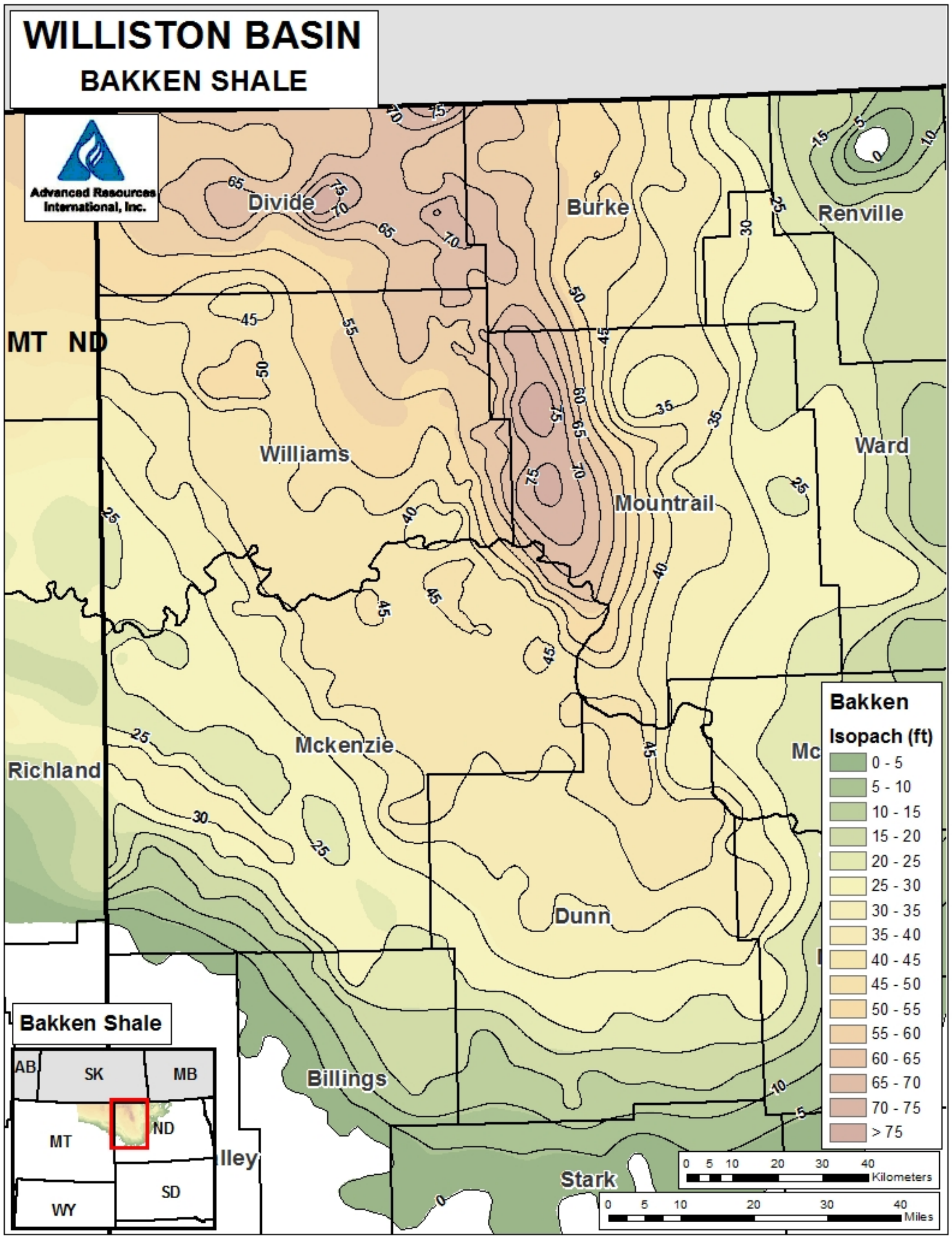
4.1 SHALE ISOPACH

The thickness of the Bakken Shale interval (including the Upper, Middle, and Lower Members) ranges from less than 50 feet (ft) along the basin margin to over 150 ft in the basins center. In the actively developed areas, the Middle Bakken Shale interval generally ranges from 60 ft to 90 ft, as shown in Exhibit 4-1.

The Upper Bakken Shale Member represents a thin but consistent interval that overlies the Middle Bakken Member. The thickness of the Middle Member ranges from 5 ft to 10 ft in the basin margins of the Bakken Shale to 20 ft in the basin center of the Bakken Shale, as shown in Exhibit 4-2.

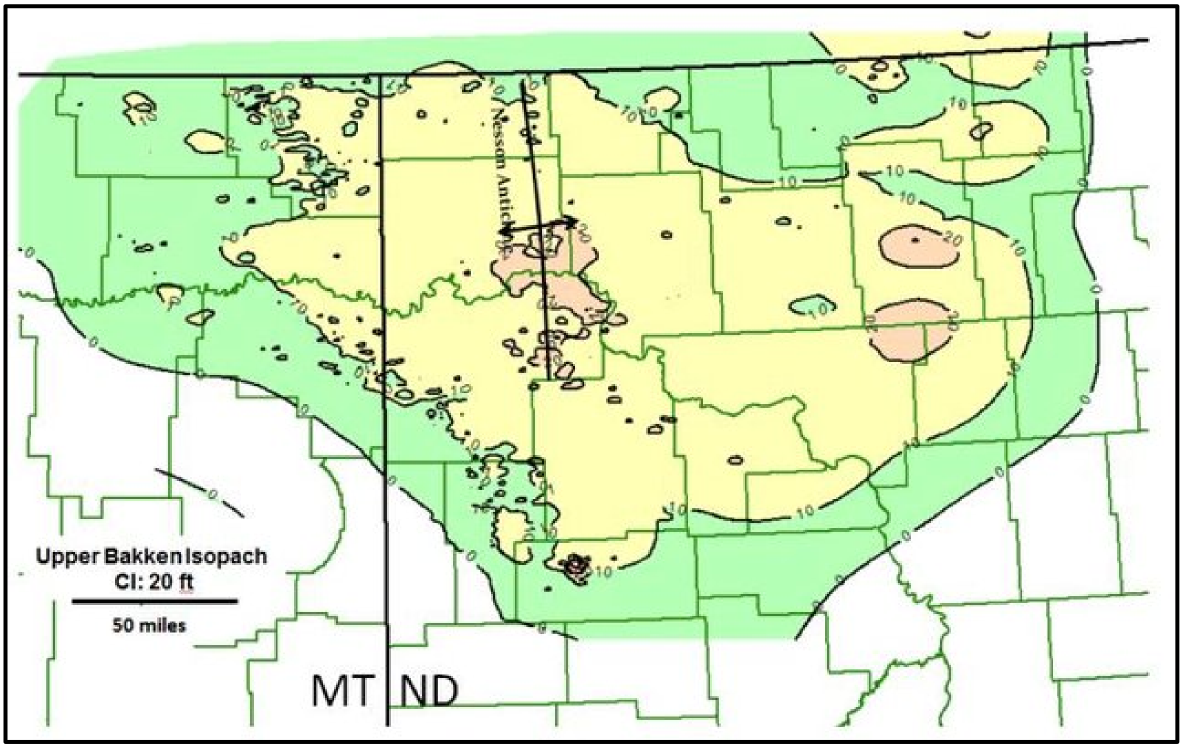
The thickness of the Lower Bakken Shale Member ranges from 20 ft to 40 ft in the basin center of the Bakken Shale to 10 ft to 20 ft in the basin margins of the Bakken Shale, as shown in Exhibit 4-3. The Lower Bakken Member thins to 10 ft and less in the Montana portion of the Bakken Shale.

Exhibit 4-1 Middle Bakken Shale Isopach (Thickness) Map



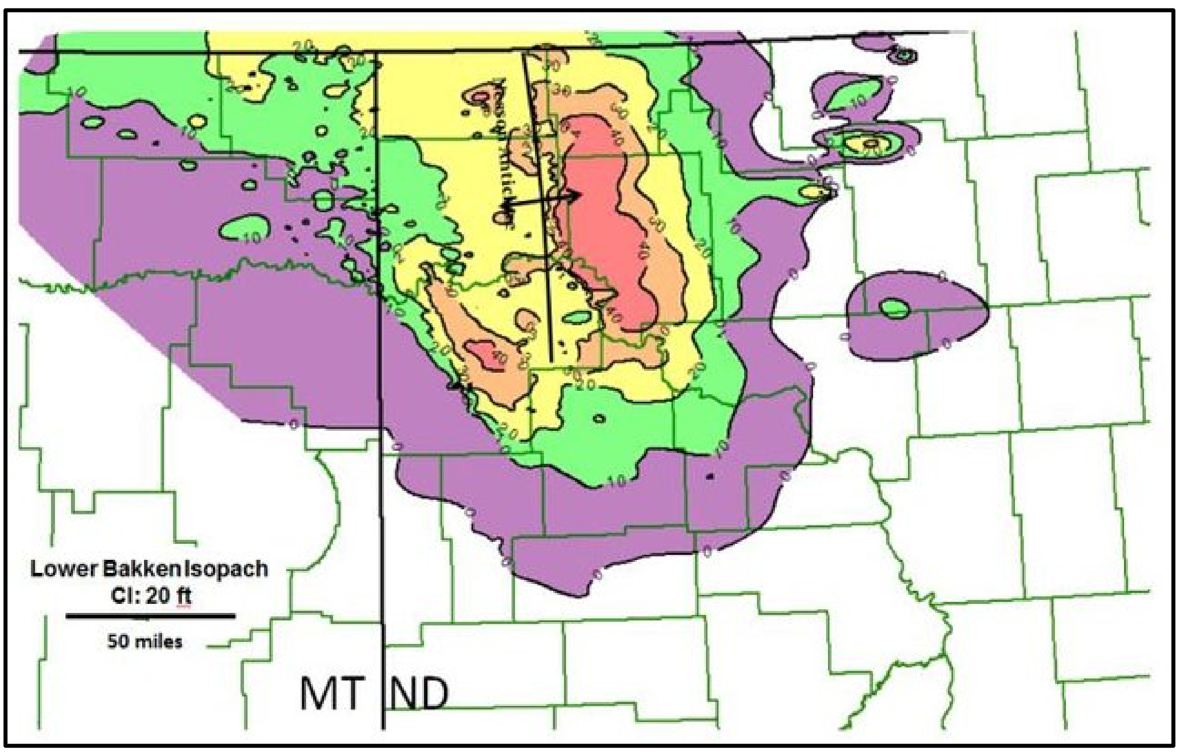
Source: Advanced Resources International, 2018.

Exhibit 4-2 Upper Bakken Shale Isopach (Thickness) Map



Source: Jin and Sonnenberg, 2013.

Exhibit 4-3 Lower Bakken Shale Isopach (Thickness) Map



Source: Jin and Sonnenberg, 2013.

4.2 Reservoir Porosity

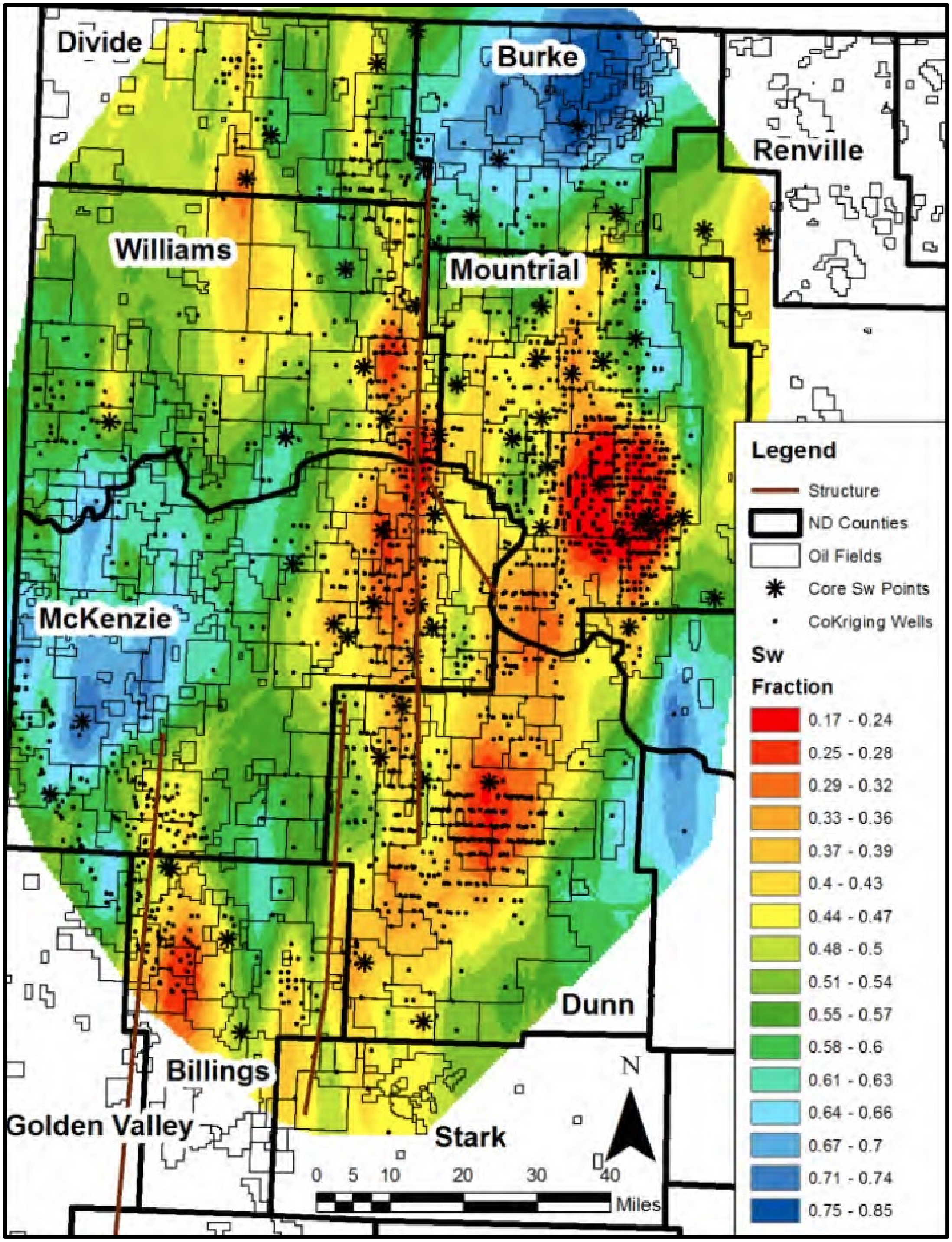
Information on the porosity of the Bakken Shale is scarce in the technical literature for specific areas of the shale. Establishing the significant porosity values in the organic portions of the shale is particularly challenging. Based on industry published information, the porosity of the Bakken Shale matrix ranges from 5 percent to 7 percent (Energy & Environmental Research Center (EERC), 2019a). The natural fracture system adds about 0.1 percent to the matrix porosity values.

4.3 Oil and Water Saturation

Oil saturations reported in the technical literature vary in the Bakken Shale from over 75 percent in the center of the Bakken Shale to less than 50 percent in the northern Bakken Shale area particularly in Burke County, as shown in Exhibit 4-4 (Schmidt, D., 2011).

Laboratory derived information for the Bakken Shale indicates that the shale, in the Basin Center and southern portion of the Bakken Margin Area, has an initial oil saturation of about 75 percent and an immobile water saturation of about 25 percent (EERC, 2019a). In the two northern partitions of the Basin Margin Bakken Shale Area, in Divide and Burke counties, the initial oil saturation ranges from 40 to 55 percent (EERC, 2019b).

Exhibit 4-4 Core Based Information on Bakken Shale Oil Saturations

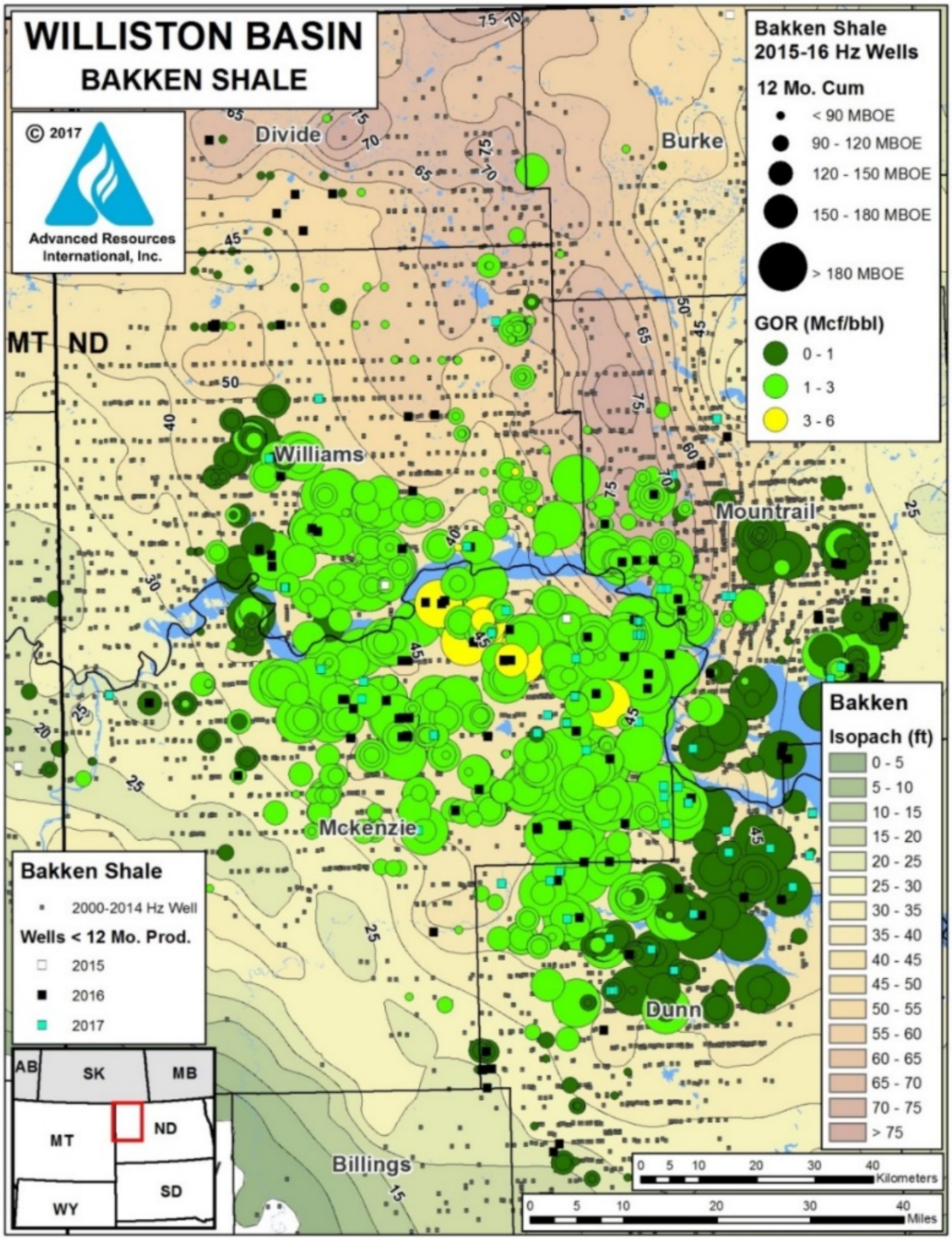


Source: Schmidt, D., 2011

4.4 Producing Gas-Oil Ratio

The producing gas-oil ratio for the Bakken Shale ranges from less than 1 thousand cubic feet per barrel (Mcf/bbl) along the basin margins to over 3 Mcf/bbl in the basin center, with a typical value of about 2 Mcf/bbl, as shown in Exhibit 4-5.

Exhibit 4-5 GORs and TOC Map for the Bakken Shale

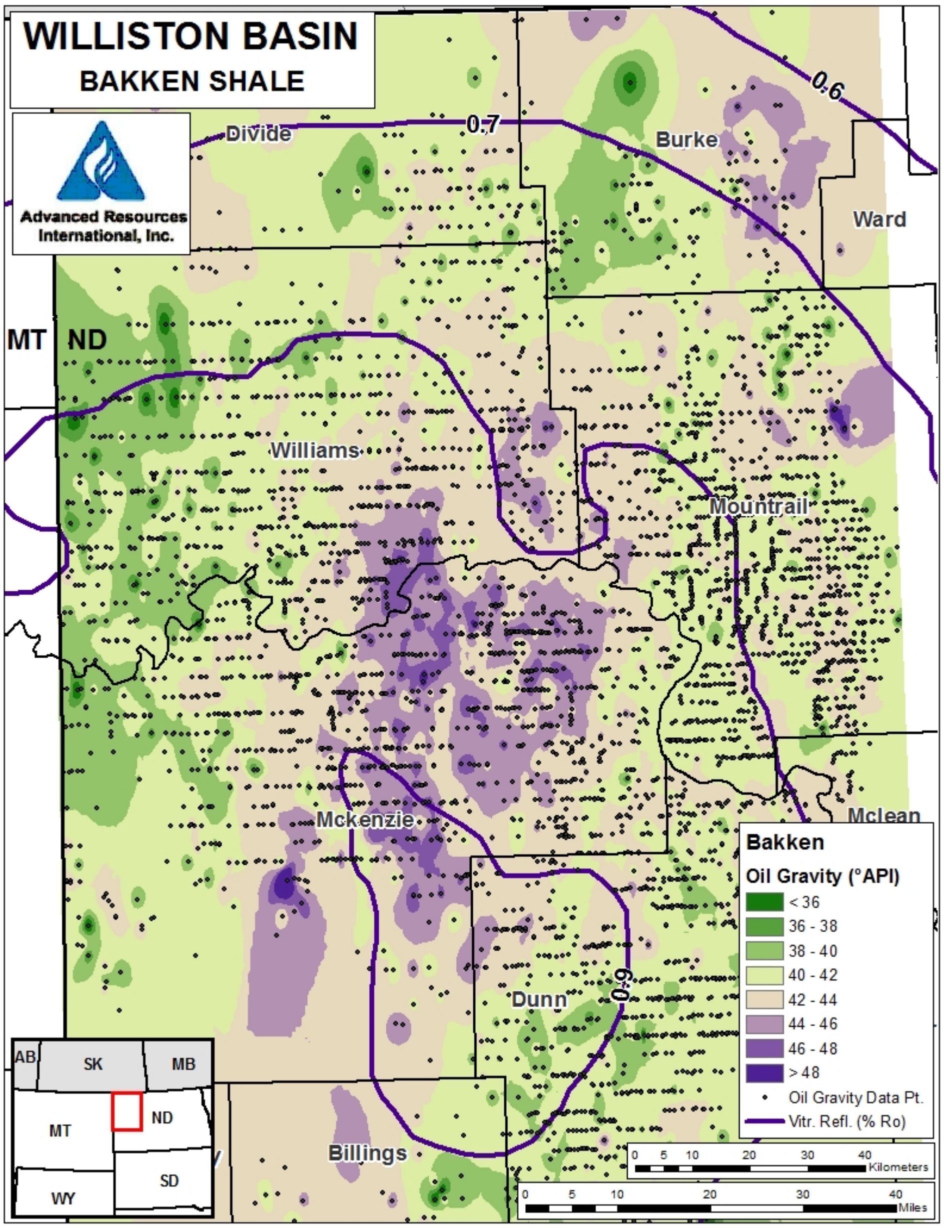


Source: Advanced Resources International, 2018

4.5 Oil Gravity

The API gravity of Bakken Shale oil ranges from 36 degrees in the thermally less mature areas to the north and west to higher API gravity values, in excess of 50 degrees, in the maturing hot spots in central McKenzie County, Exhibit 4-6. These values are consistent with the thermal maturity map of the Bakken Shale shown previously on Exhibit 3-8.

Exhibit 4-6 Bakken Shale API Gravity



Source: Advanced Resources International, 2019.

4.6 Oil Composition

Pressure volume temperature (PVT) data and oil composition for the Bakken Shale was based on information provided by EERC (EERC, 2019a), displayed in Exhibit 4-7.

Exhibit 4-7 Bakken Shale PVT and Oil Composition Data

Hydrocarbon Component	Mol % Bakken
CO2	0.0051
N2	0.015
CH4	0.3313
C2-C4	0.3019
C5-C7	0.1058
C8-C12	0.1151
C13-C19	0.0712
C20-C30	0.0389
>C30	0.0157

Source: EERC, 2019a.

4.7 Matrix Permeability

Matrix permeability in the Bakken Shale is highly variable, ranging from 0.0003 mD to 15 mD, depending on lithofacies of the formation (EERC, 2019a). The average permeability for the Bakken Shale is 0.055 mD across the basin and each of the three Bakken Shale intervals based on data provided by EERC. Other authors have cited correlations between matrix permeability within the Bakken Shale with clay contents, the size of the pore throats, and stress settings (Alexandre et al, 2011).

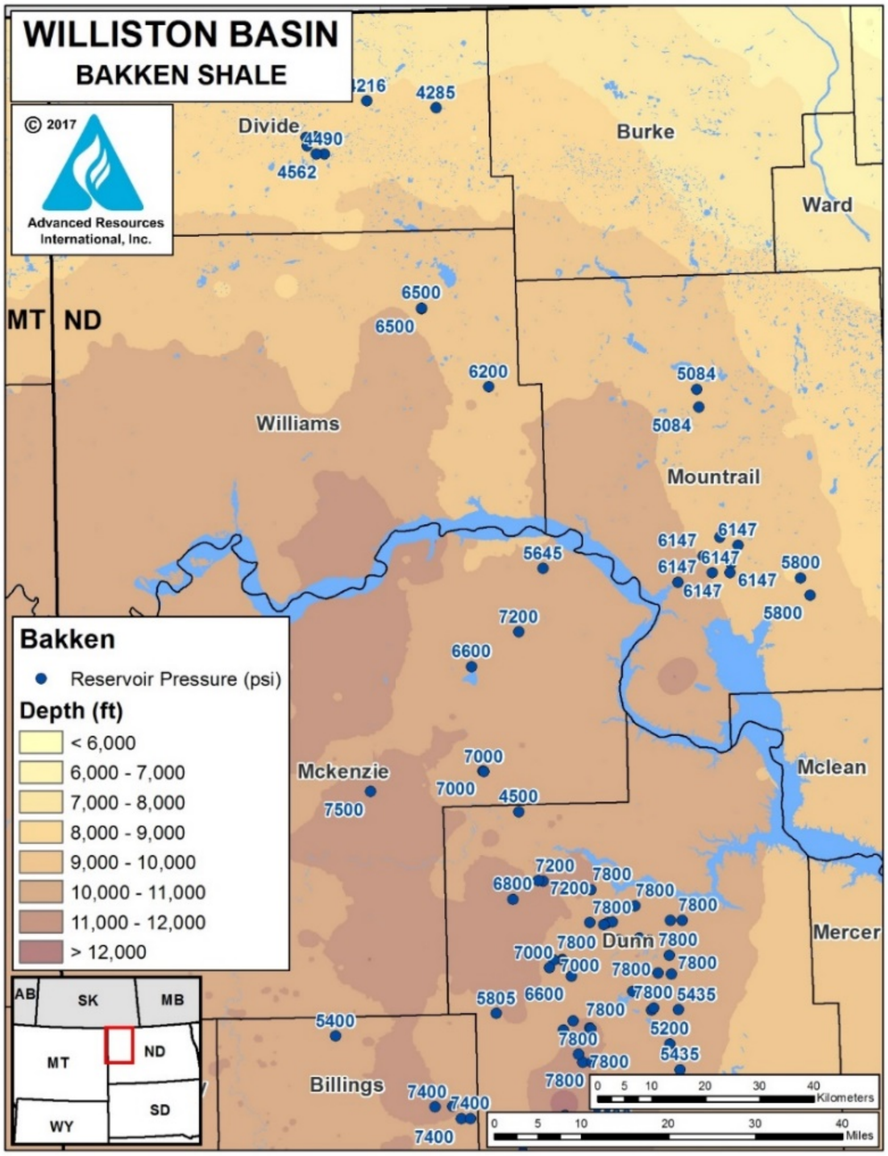
4.8 Reservoir Temperature

The bottom-hole reservoir temperature of the Bakken Shale varies considerably across the Williston Basin, ranging from 175ºF to 270ºF, with lateral variations in the thermal gradient consistent with thermal maturity and the depth of the shale (Hester and Schmoker, 1985).

4.9 Reservoir Pressure

There is significant variability in the reservoir pressure of the Bakken Shale, with highest pressures observed in the thermally mature areas in the basin center. The reported pressure gradients for the Bakken Shale range from (0.5 pounds per square inch per foot of depth (psi/ft)) along the northern, less thermally mature portions of the basin margin to highly over pressured (0.7 psi/ft) in the more thermally mature basin center (Schmidt, D. 2011). In the deeper shale area of Dunn County, the Bakken Shale reservoir pressure typically is about 7,000 pounds per square inch (psi), as shown in Exhibit 4-8.

Exhibit 4-8 Bakken Shale Depth and Reservoir Pressure



Source: Advanced Resources Int'l, 2018.

5 Estimates of Original Oil In-Place

5.1 Challenges in Estimating Original Oil In-Place

Establishing a rigorous estimate for the original oil in-place (OOIP) in the Bakken Shale is a challenging task, influenced by numerous uncertainties, including:

- Developing reliable estimates for porosity for a resource where a significant portion of the porosity is within the organic content of the shale.
- Establishing accurate estimates for initial oil and water saturations, particularly for the northern portion of the Bakken Shale in North Dakota.
- Arriving at a reasonable value for the western extent of the Bakken Shale in Montana, outside the thermally mature basin center.

Even with these challenges and uncertainties, developing an estimate for OOIP (admittedly with a considerable error bound) is a useful exercise. It puts into print the assumptions and data used for the OOIP resource estimate. It also provides a placeholder for additional information sharing by industry and researchers on newly collected geologic and reservoir properties for the Bakken Shale.

5.2 Sources of Information for OOIP Resource Estimate

The OOIP resource estimate for the Bakken Shale is based on the following set of information sources assembled for this Basin Study:[a]

- Assembly of information from well completion and other reports to establish data on formation tops and the gross interval for the Bakken Shale.
- Review of information, in various prior studies and technical reports, on geologic and reservoir properties published for the Bakken Shale.
- Compilation of publicly shared industry information on Bakken Shale reservoir properties for selected lease areas provided by industry.

5.3 Assessment Methodology

To provide some granularity to the estimates of OOIP, the Basin Study has partitioned the Bakken Shale into Basin Center and Basin Margin areas in North Dakota with a third geographic area established for Montana. The study further subdivided each of these three geographically established areas into the various counties comprising the three larger geographic areas. For each county, the study assembled representative volumetric and other reservoir properties essential for estimating OOIP.

First, the study established the areal extent for each of these county-level resource assessment units of the Bakken Shale. Then, the study risked these areas assuming that about 80 percent of each assessment unit would be accessible and geologically viable. In the future, a somewhat higher

[a] A great bulk of the information on Bakken Shale reservoir properties has been assembled from prior work performed by Advanced Resources International for various clients. Advanced Resources is contributing a portion of this earlier work to this Basin Study. However, the underlying data used to construct the maps in this report are proprietary and are not available for public release.

accessibility and viability value may prove to be appropriate for the Basin Center area and a somewhat lower access and viability value may prove to be appropriate for the Basin Margin and Montana areas.

The primary focus is establishing OOIP values for the organically-rich Bakken Shale that has been the target of current primary recovery efforts and is also a target for applying enhanced oil recovery. A valuable future expansion of this Basin Study would be to add the Three Forks Shale to the Willison Basin Shale resource assessment.

The OOIP resource estimates draw heavily on the series of maps and exhibits provided in the earlier sections of this report. Additional geologic and reservoir property information specific to each of the eight resource assessment units (counties) in the three geographic areas of the shale – Basin Center, Basin Margin, and Montana areas – was assembled from the technical literature.

New information from the U.S. DOE's NETL as well as additional data released by basin operators would improve the rigor and reliability of the OOIP resource estimates assembled for the Bakken Shale in this Basin Study.

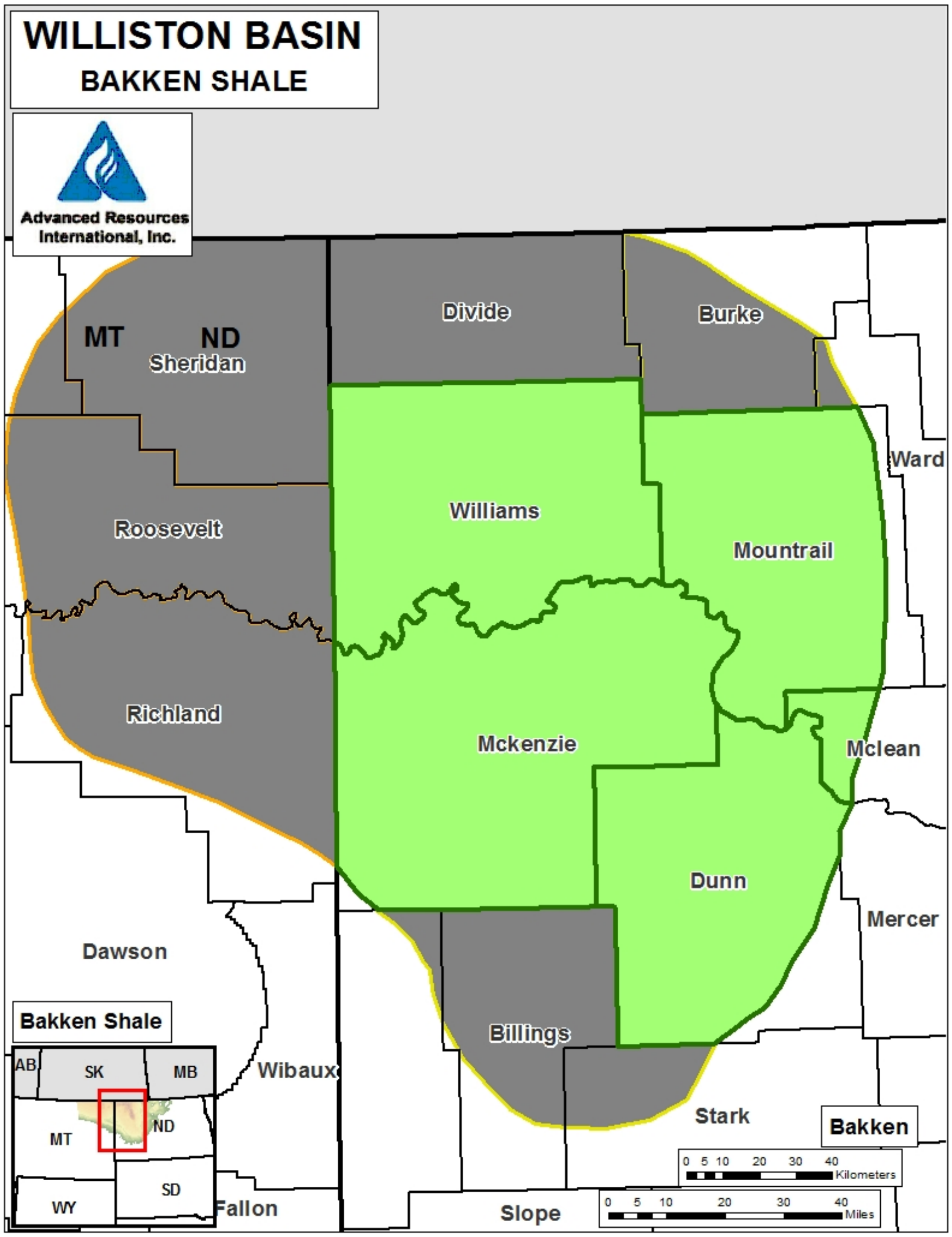
5.4 Basin Center Shale Area

The Basin Center Shale Area of the Bakken Shale extends across 8,670 mi^2 (6,930 mi^2, risked) in Mountrail, McKenzie, Dunn and Williams counties, as shown in Exhibit 5-1. Portions of this area, particularly the Nesson Anticline in Mountrail County, have seen extensive well drilling. Overall, more than 8,250 Hz Bakken Shale oil wells have been drilled and completed in the Basin Center Area of the Bakken Shale as of the end of 2018.

The depth of the Bakken Shale in the Basin Center Shale Area ranges from about 8,000 feet on its eastern border in Mountrail County to below 12,000 ft in the center of the basin in Williams and McKenzie counties, as shown in Exhibit 5-2.

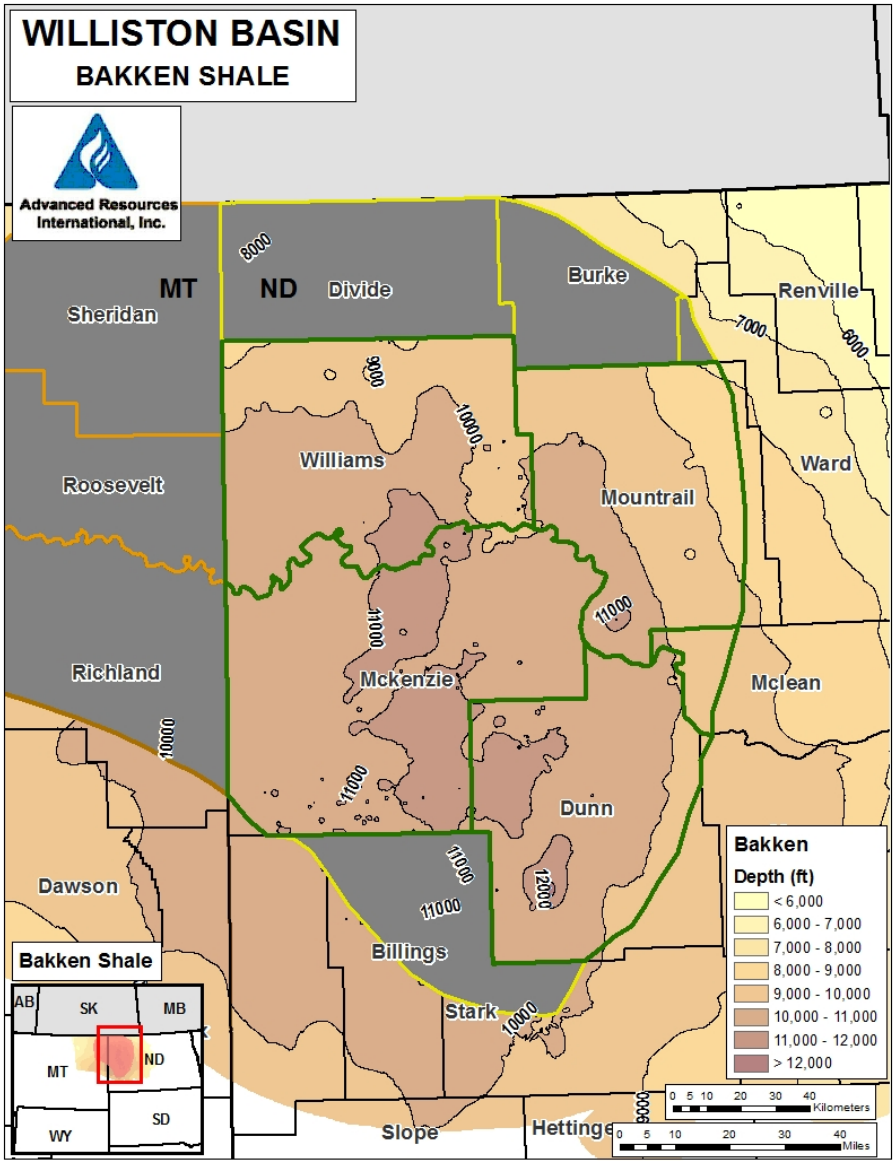
Exhibit 5-3 provides the isopach map for the middle member of the Bakken Shale in the Basin Center Shale Area. Exhibit 5-4 provides Mountrail County well log representatives for a portion of the Basin Center Shale Area, showing the thickness of the Upper, Middle, and Lower Bakken Shale members.

Exhibit 5-1 Outline Map of Basin Center Bakken Shale Area



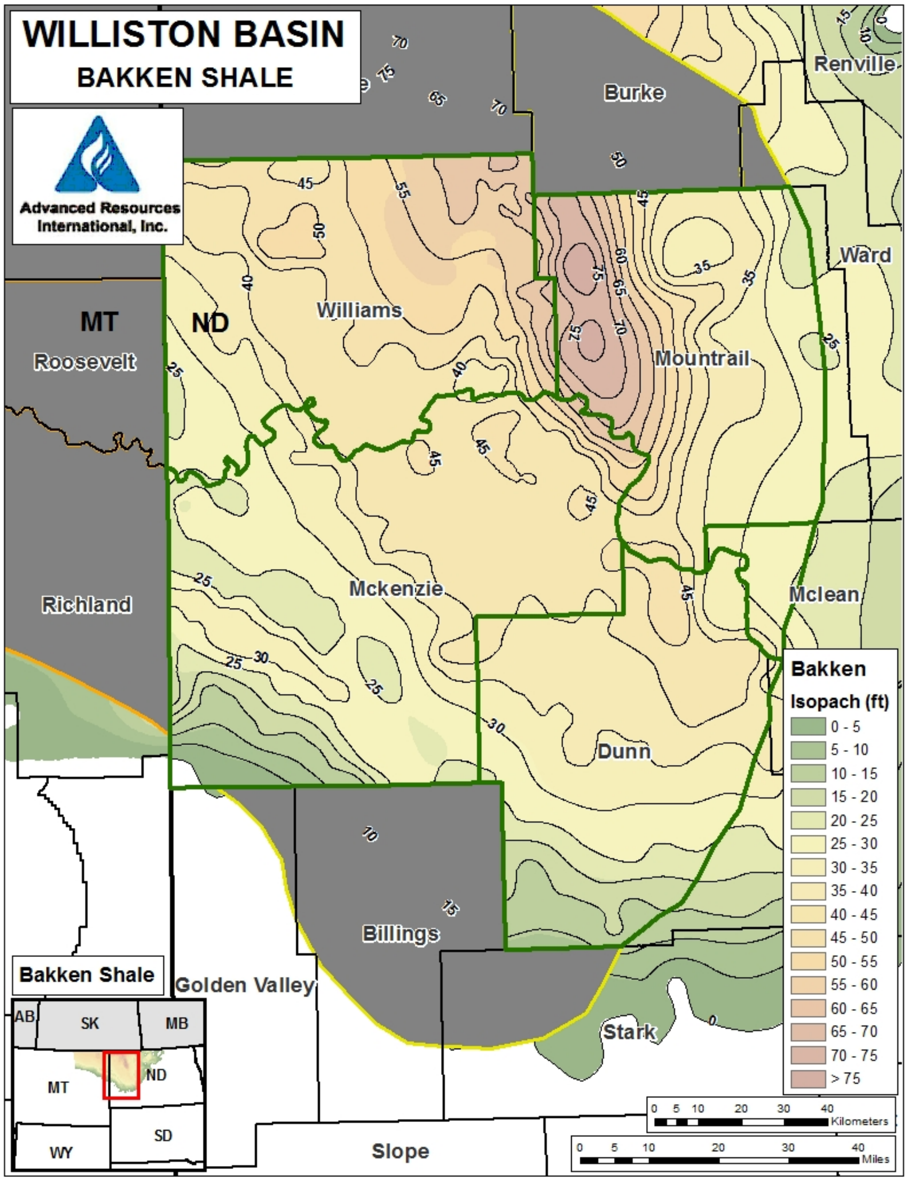
Source: Advanced Resources International, 2019.

Exhibit 5-2 Depth of Basin Center Bakken Shale Area



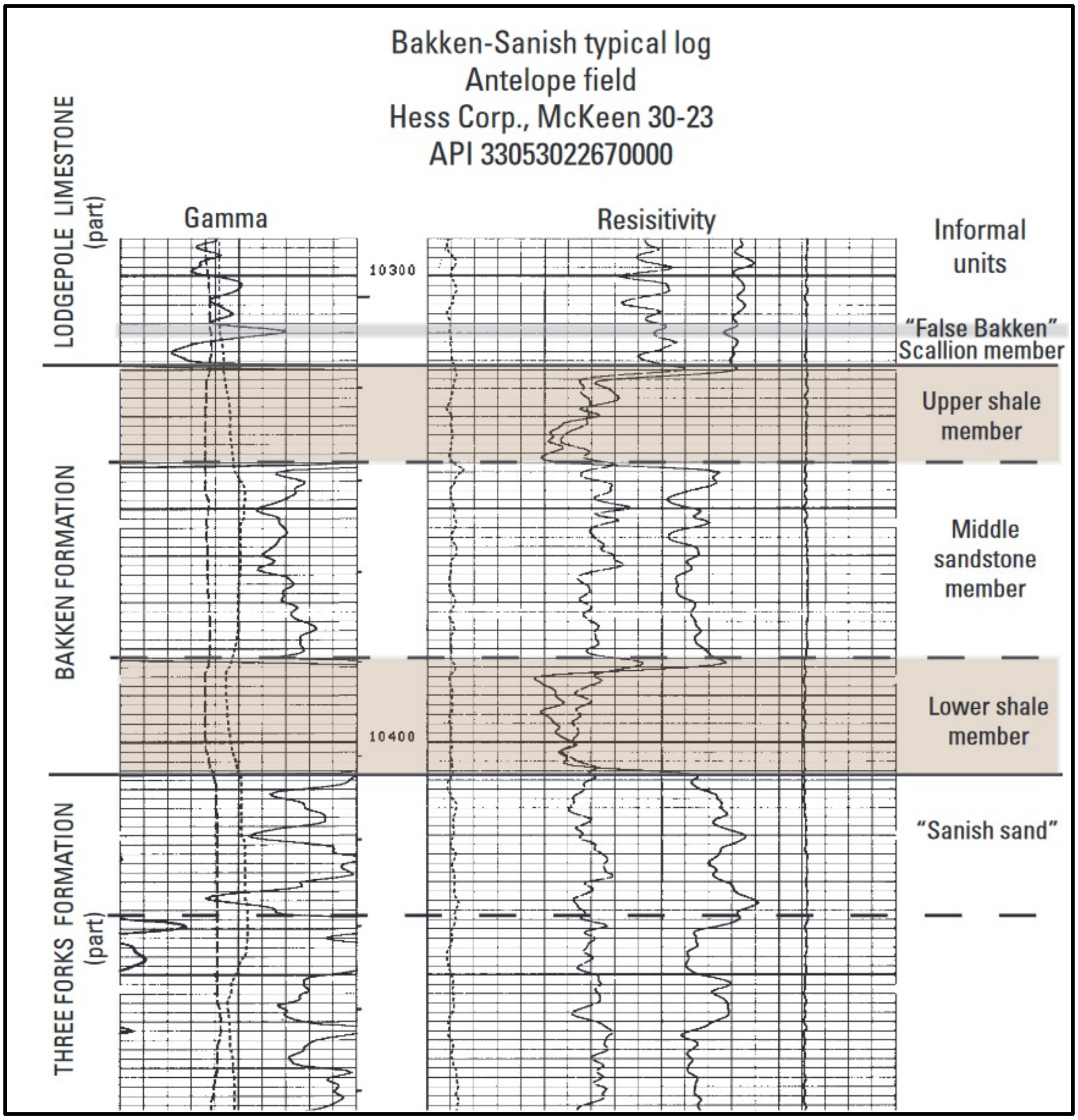
Source: Advanced Resources International, 2019.

Exhibit 5-3 Middle Shale Member Isopach Map for Basin Center Shale Area



Source: Advanced Resources International, 2019

Exhibit 5-4 Mountrail County Well Log, Basin Center Shale Area



Source: EERC, 2019a

Exhibit 5-5 provides the volumetric and other reservoir properties for the four counties in the Basin Center Bakken Shale Area.

Exhibit 5-5 Reservoir Properties for Estimating OOIP, Basin Center Bakken Shale Area

Reservoir Property	Mountrail Co.	McKenzie Co.	Dunn Co.	Williams Co.
Total Area	1,890 mi^2	2,840 mi^2	1,790 mi^2	2,150 mi^2
Risked Area	1,510 mi^2	2,270 mi^2	1,430 mi^2	1,720 mi^2
Average Depth	9,750 ft	10,750 ft	10,500 ft	10,000 ft
Net Pay (Shale Unit)				
▪ Upper Bakken	10 ft	10 ft	10 ft	10 ft
▪ Middle Bakken	50 ft	40 ft	40 ft	50 ft
▪ Lower Bakken	30 ft	30 ft	20 ft	20 ft
Porosity (Shale Unit)				
▪ Upper Bakken	5.4%	5.4%	5.4%	5.4%
▪ Middle Bakken	5.2%	5.2%	5.2%	5.2%
▪ Lower Bakken	6.9%	6.9%	6.9%	6.9%
Oil Saturation	75%	75%	75%	75%
Formation Volume Factor (RB/STB)	1.8	1.8	1.8	1.8
Solution GOR (Mcf/B)	1.5	1.5	1.5	1.5

Source: Advanced Resources International, 2019

Mountrail County. Using the volumetric reservoir properties on Exhibit 5-5, the OOIP for the Bakken Shale in Mountrail County is 16.3 billion barrels, Exhibit 5-6.

Exhibit 5-6 OOIP of Bakken Shale in Mountrail County, Basin Center Shale Area

County/Interval	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ Mountrail – Upper Bakken	1,510	1,120	1,690
▪ Mountrail – Middle Bakken	1,510	5,380	8,130
▪ Mountrail – Lower Bakken	1,510	4,280	6,480
Total	**1,510**	**10,780**	**16,300**

Source: Advanced Resources International, 2019

McKenzie County. Using the volumetric reservoir properties on Exhibit 5-5, the OOIP for the Bakken Shale in McKenzie County is 22.1 billion barrels, Exhibit 5-7.

Exhibit 5-7 OOIP of Bakken Shale in McKenzie County, Basin Center Shale Area

County/Interval	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ McKenzie – Upper Bakken	2,270	1,120	2,540
▪ McKenzie – Middle Bakken	2,270	4,300	9,780
▪ McKenzie – Lower Bakken	2,270	4,280	9,730
Total	**2,270**	**9,700**	**22,050**

Source: Advanced Resources International, 2019

Dunn County. Using the volumetric reservoir properties on Exhibit 5-5, the OOIP for the Bakken Shale in Dunn County is 11.9 billion barrels, Exhibit 5-8.

Exhibit 5-8 OOIP of Bakken Shale in Dunn County, Basin Center Shale Area

County/Interval	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ Dunn – Upper Bakken	1,430	1,120	1,600
▪ Dunn – Middle Bakken	1,430	4,300	6,160
▪ Dunn – Lower Bakken	1,430	2,860	4,090
Total	**1,430**	**8,280**	**11,850**

Source: Advanced Resources International, 2019

Williams County. Using the volumetric reservoir properties on Exhibit 5-5, the OOIP for the Bakken Shale in Williams County is 16.1 billion barrels, Exhibit 5-9.

Exhibit 5-9 OOIP of Bakken Shale in Williams County, Basin Center Shale Area

County/Interval	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ Williams – Upper Bakken	1,720	1,120	1,920
▪ Williams – Middle Bakken	1,720	5,380	9,250
▪ Williams – Lower Bakken	1,720	2,860	4,910
Total	**1,720**	**9,360**	**16,080**

Source: Advanced Resources International, 2019

Basin Center Shale Area. The total OOIP of the Bakken Shale in the Basin Center Shale Area is 66.3 billion barrels, Exhibit 5-10.

Exhibit 5-10 OOIP of the Bakken Shale, Basin Center Shale Area

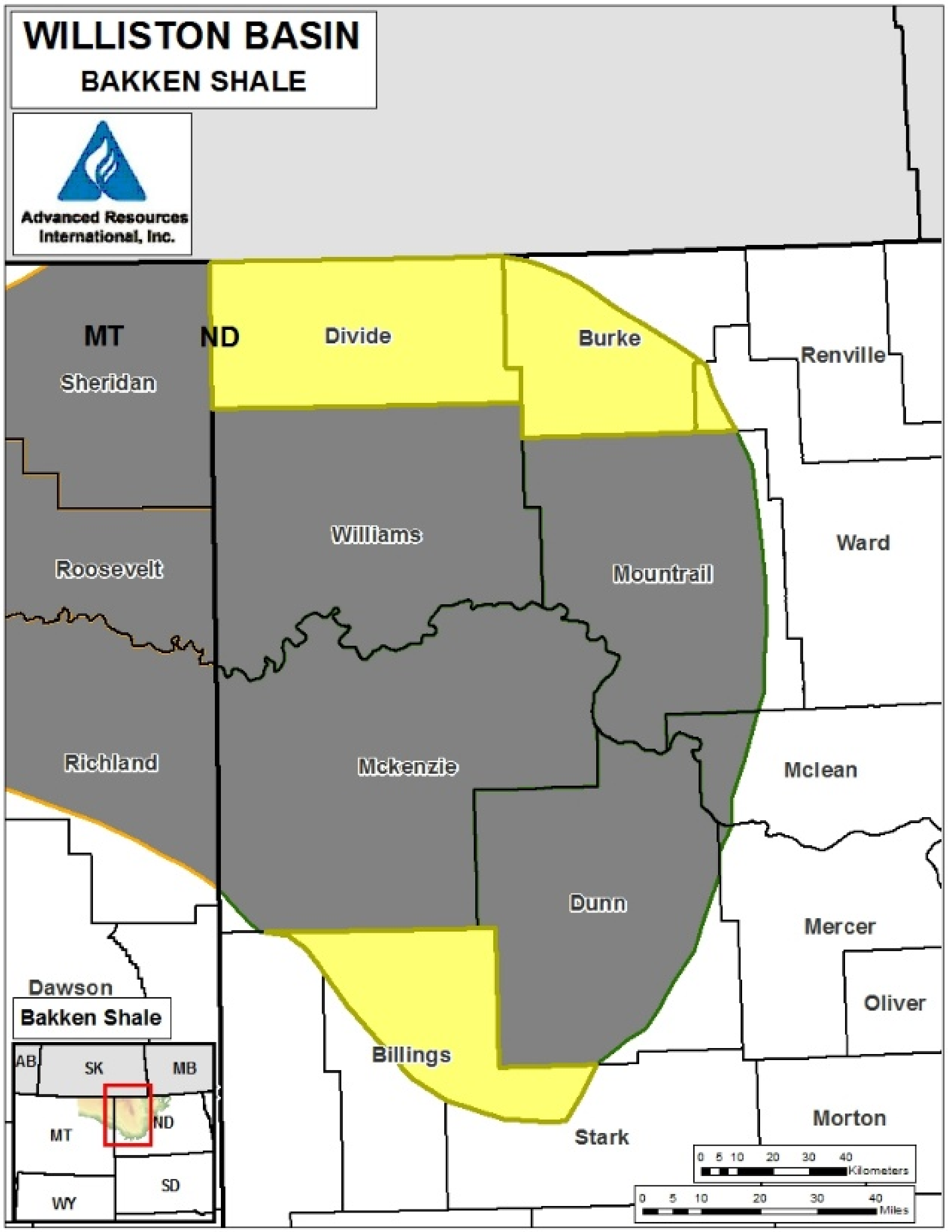
County	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ Mountrail Co.	1,510	10,780	16,300
▪ McKenzie Co.	2,270	9,700	22,050
▪ Dunn Co.	1,430	8,280	11,850
▪ Williams Co.	1,720	9,360	16,080
Total	**6,930**	**38,120**	**66,280**

Source: Advanced Resources International, 2019

5.5 Basin Margin Shale Area

The Basin Margin Shale Area of the Bakken Shale covers 2,920 mi^2 (2,320 mi^2, risked) in Divide, Burke, Billings and Stark counties, as displayed in Exhibit 5-11. Only limited Hz well drilling has occurred, so far, in the Basin Margin Shale Area.

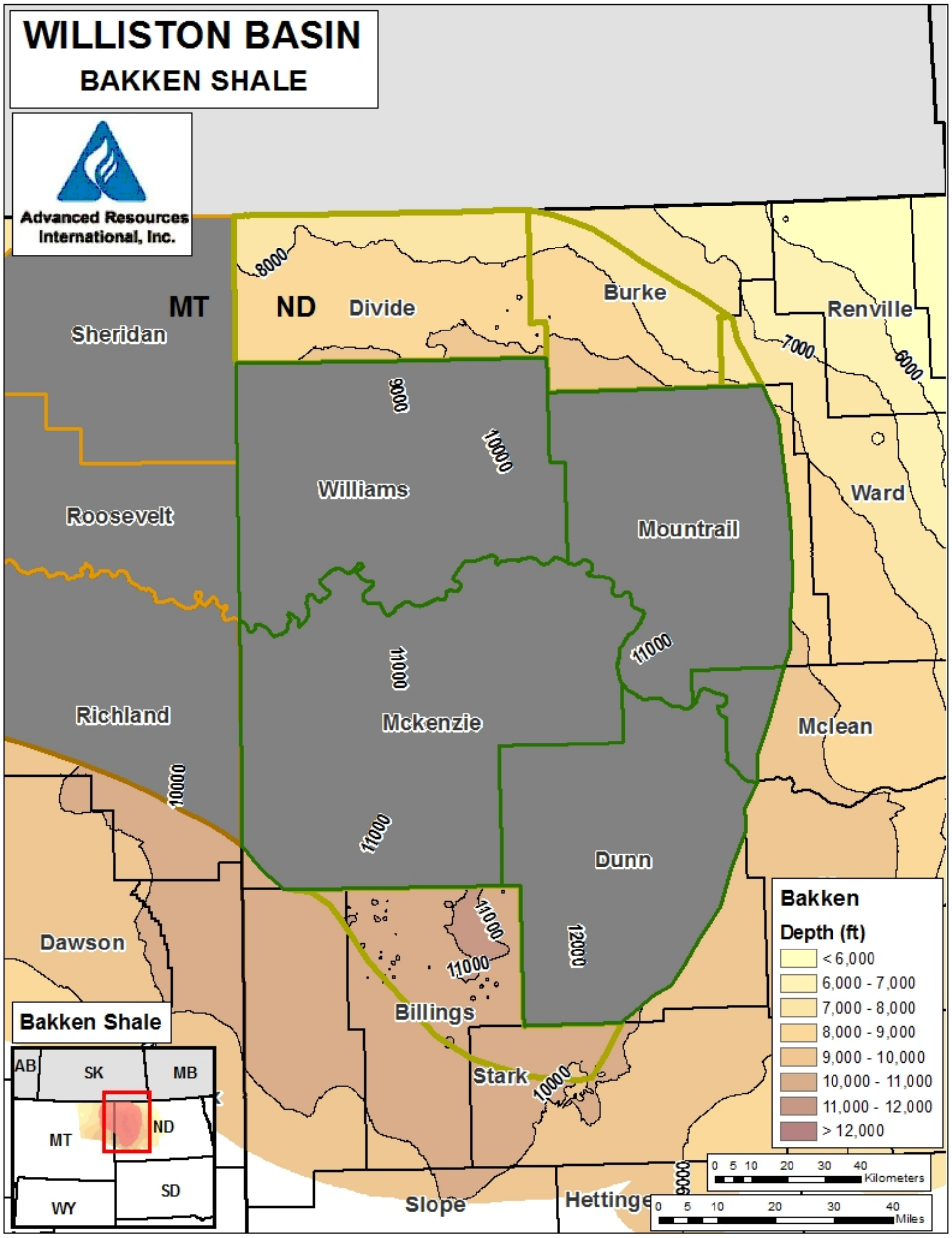
Exhibit 5-11 Outline Map of Basin Margin Shale Area



Source: Advanced Resources International, 2019.

The depth of the Bakken Shale in the Basin Margin Shale Area ranges from 7,000 ft on the north in Burke County to over 10,000 ft on the south in Billings County, as shown in Exhibit 5-12.

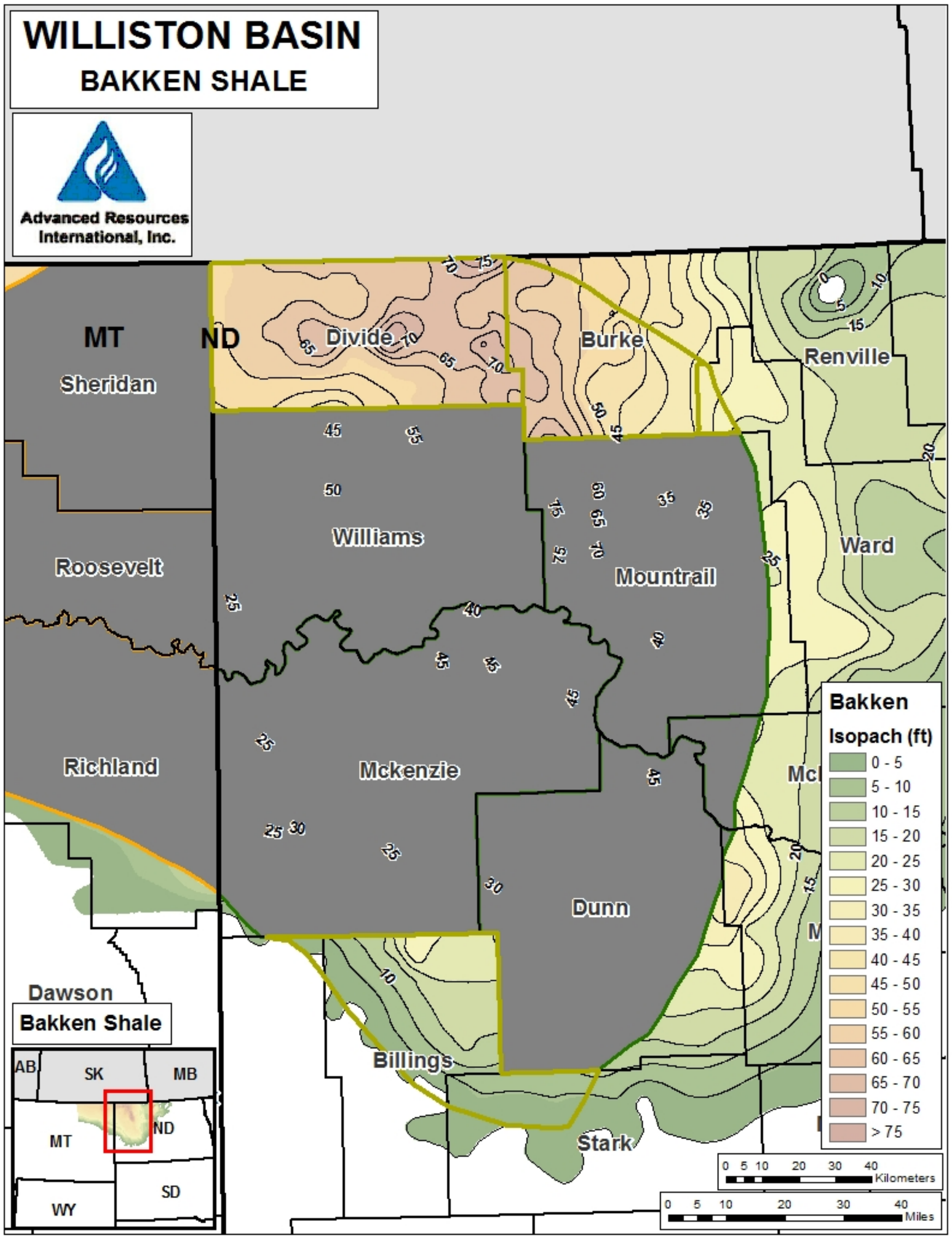
Exhibit 5-12 Depth of Basin Margin Shale Area



Source: Advanced Resources International, 2019.

Exhibit 5-13 provides the isopach map for the Middle Member of the Bakken Shale in the Basin Margin Shale Area.

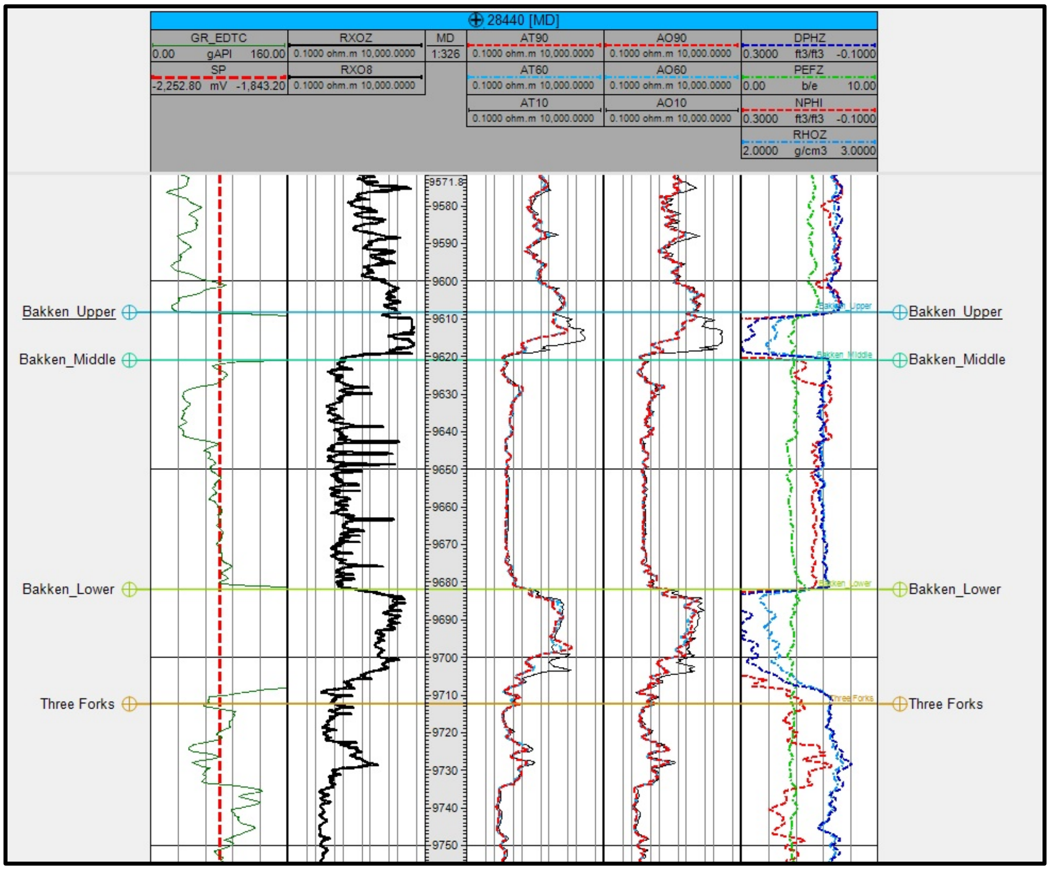
Exhibit 5-13 Middle Shale Member Isopach Map for Basin Margin Shale Area



Source: Advanced Resources International, 2019.

Exhibit 5-14 provides a well log representative of the northern portion of the Basin Margin Shale Area, showing the thickness of the Upper, Middle, and Lower Bakken Shale Members.

Exhibit 5-14 Well Log, Basin Margin Shale Area



Source: EERC, 2019b.

Exhibit 5-15 provides the volumetric and other reservoir properties of the three resource assessment units (counties) of the Basin Margin Bakken Shale Area.

Exhibit 5-15 Reservoir Properties for Estimating OOIP, Basin Margin Shale Area

Reservoir Property	Divide Co.	Burke Co.	Billings-Stark Co.
Total Area	1,290 mi^2	780 mi^2	850 mi^2
Risked Area	1,030 mi^2	620 mi^2	680 mi^2
Average Depth	8,000 ft	8,000 ft	10,250 ft
Net Pay (Shale Unit)			
▪ Upper Bakken	10 ft	10 ft	5 ft
▪ Middle Bakken	65 ft	45 ft	10 ft
▪ Lower Bakken	20 ft	30 ft	5 ft
Porosity (Shale Unit)			
▪ Upper Bakken	7.0%	7.0%	5.4%
▪ Middle Bakken	7.5%	7.5%	5.2%
▪ Lower Bakken	7.0%	7.0%	6.9%
Oil Saturation	55%	40%	75%
Formation Volume Factor (RB/STB)	1.6	1.6	1.8
Solution GOR (Mcf/B)	1.3	1.3	1.5

Source: Advanced Resources International, 2019

Divide County. Using the volumetric reservoir properties on Exhibit 5-15, the OOIP for the Bakken Shale in Divide County is 12.3 billion barrels, Exhibit 5-16.

Exhibit 5-16 OOIP of Bakken Shale in Divide County, Basin Margin Shale Area

County/Interval	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ Divide – Upper Bakken	1,030	1,200	1,230
▪ Divide – Middle Bakken	1,030	8,320	8,590
▪ Divide – Lower Bakken	1,030	2,390	2,470
Total	**1,030**	**11,910**	**12,290**

Source: Advanced Resources International, 2019

Burke County. Using the volumetric reservoir properties on Exhibit 5-15, the OOIP for the Bakken Shale in Burke County is 4.8 billion barrels, Exhibit 5-17.

Exhibit 5-17 OOIP of Bakken Shale in Burke County, Basin Margin Shale Area

County/Interval	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ Burke – Upper Bakken	620	870	540
▪ Burke – Middle Bakken	620	4,190	2,610
▪ Burke – Lower Bakken	620	2,610	1,630
Total	**620**	**7,670**	**4,780**

Source: Advanced Resources International, 2019

Billings-Stark County. Using the volumetric reservoir properties on Exhibit 5-15, the OOIP for the Bakken Shale in for Billings-Stark counties is 1.6 billion barrels, Exhibit 5-18.

Exhibit 5-18 OOIP of Bakken Shale in Billings-Stark County, Basin Margin Shale Area

County/Interval	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ Billings-Stark – Upper Bakken	680	560	380
▪ Billings-Stark – Middle Bakken	680	1,080	730
▪ Billings-Stark – Lower Bakken	680	710	490
Total	**680**	**2,350**	**1,600**

Source: Advanced Resources International, 2019

Basin Margin Shale Area. The OOIP for the Bakken Shale in the Basin Margin Shale Area is 18.7 billion barrels, Exhibit 5-19.

Exhibit 5-19 OOIP of Basin Margin Shale Area

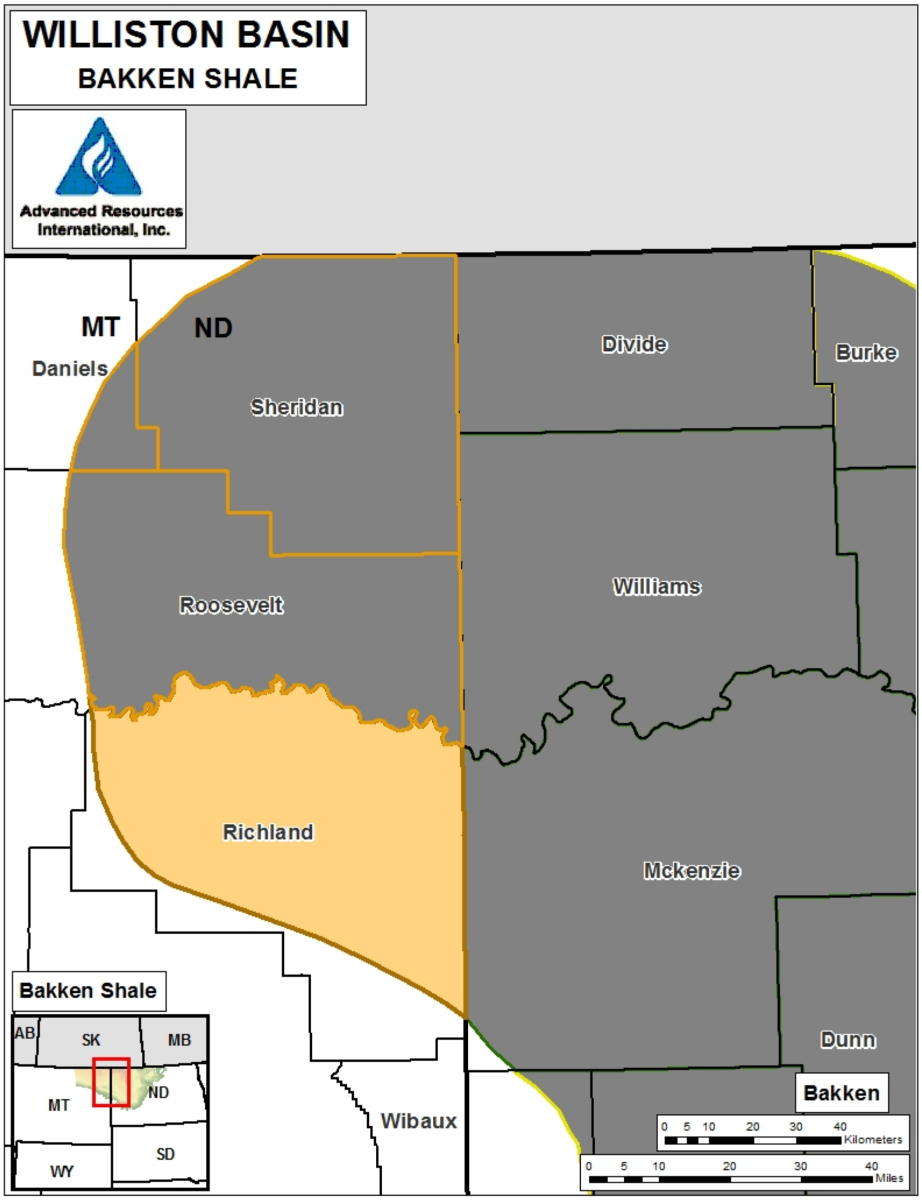
County	**Risked Area** (mi^2)	**Resource Concentration** (MMB/mi^2)	**Oil/Condensate OOIP** (Million Barrels)
▪ Divide Co.	1,030	11,910	12,290
▪ Burke Co.	620	7,670	4,780
▪ Billings-Stark Co.	680	2,350	1,600
Total	**2,330**	**21,930**	**18,670**

Source: Advanced Resources International, 2019

5.6 Montana Shale Area

The Montana Area of the Bakken Shale extends across 1,620 mi^2 (1,300 mi^2, risked) in Richland County, Montana, as shown in Exhibit 5-20. The study has excluded both Roosevelt and Sheridan counties in Montana from the Montana Shale Area due to limited development.

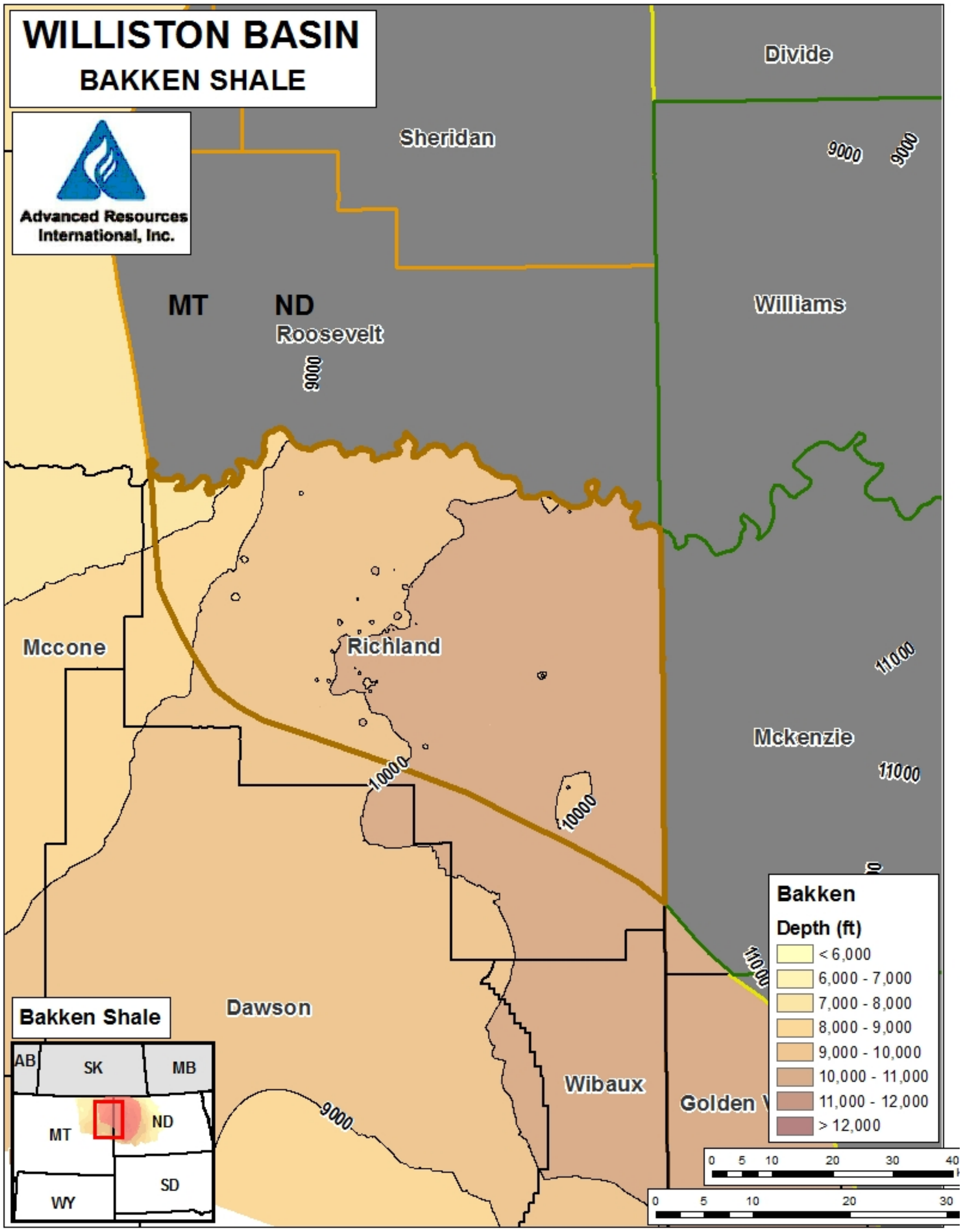
Exhibit 5-20 Outline Map of Montana Shale Area



Source: Advanced Resources International, 2019

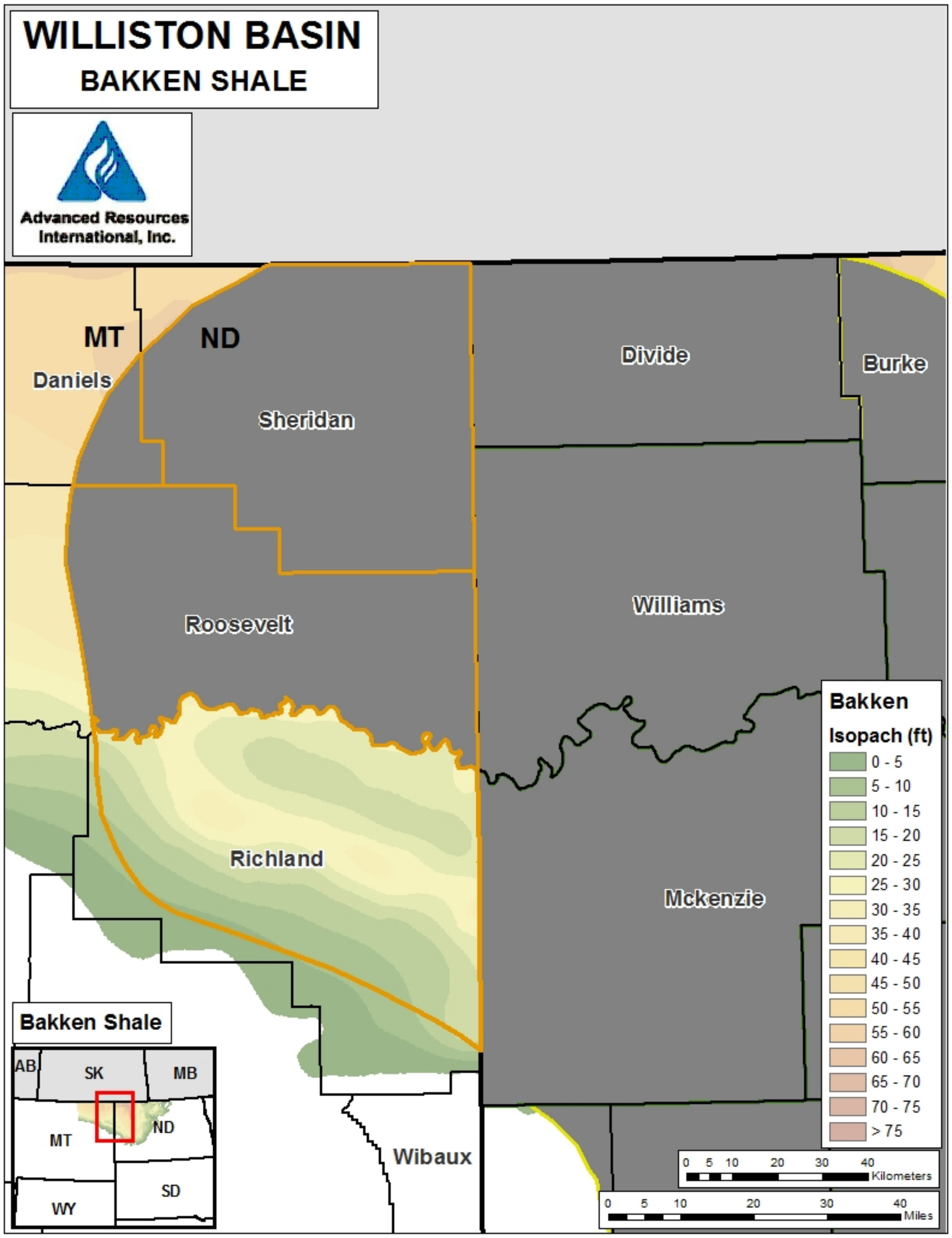
The depth of the Bakken Shale in Montana ranges from 8,000 ft on the west to over 10,000 ft on the North Dakota and Montana border, Exhibit 5-21. Exhibit 5-22 provides the isopach map for the Middle Member of the Bakken Shale in Montana. Exhibit 5-23 provides a Bakken Shale well log for the Elm Coulee field area in Richland County, Montana.

Exhibit 5-21 Depth of Montana Shale Area



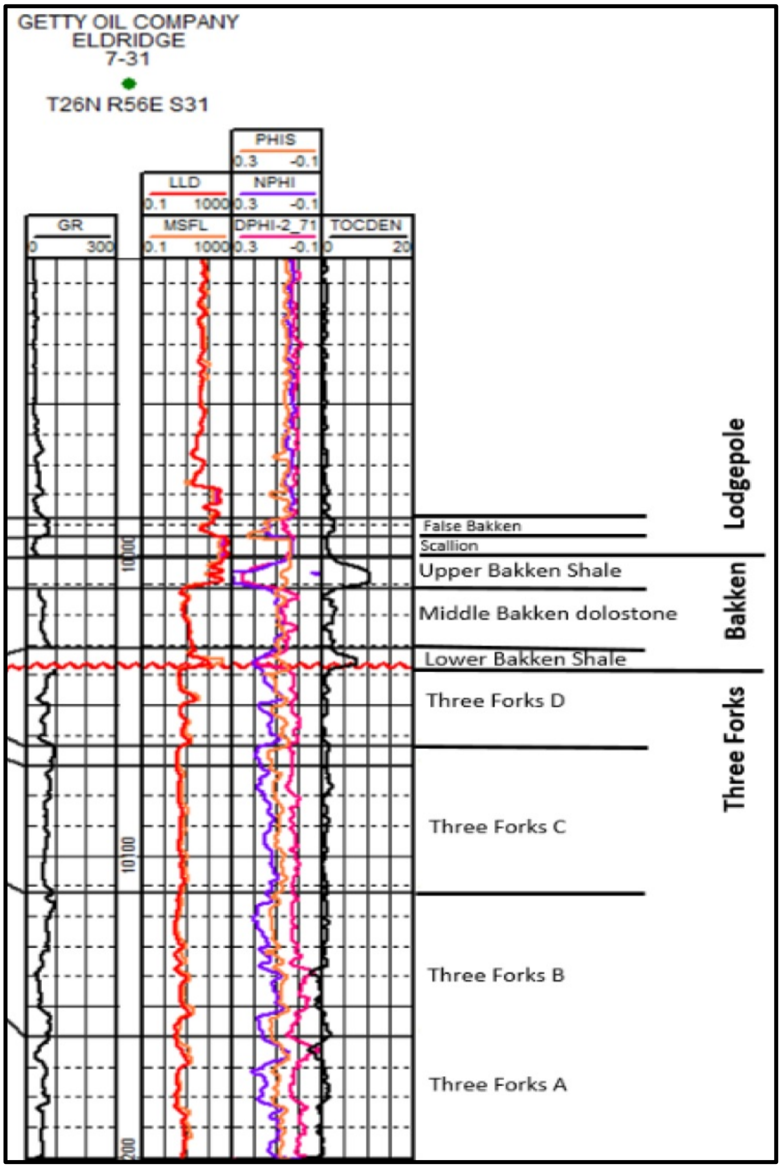
Source: Advanced Resources International, 2019

Exhibit 5-22 Middle Shale Member Isopach Map for Montana Shale Area



Source: Advanced Resources International, 2019

Exhibit 5-23 Well Log, Richland County, Montana Shale Area



Source: Sonnenberg, 2014.

Exhibit 5-24 provides the volumetric and other reservoir properties for the Richland County resource assessment unit of the Montana Shale Area.

Exhibit 5-24 Reservoir Properties for Estimating OOIP, Montana Shale Area

Reservoir Property	Montana
Total Area	1,620 mi^2
Risked Area	1,300 mi^2
Average Depth	9,500 ft
Net Pay (Shale Unit)	
▪ Upper Bakken	10 ft
▪ Middle Bakken	25 ft
▪ Lower Bakken	5 ft
Porosity (Shale Unit)	
▪ Upper Bakken	5.4%
▪ Middle Bakken	5.2%
▪ Lower Bakken	6.9%
Oil Saturation	75%
Formation Volume Factor (RB/STB)	1.8
Solution GOR (Mcf/B)	1.5

Source: Advanced Resources International, 2019

Montana. Using the volumetric reservoir properties on Exhibit 5-24, the OOIP for the Bakken Shale in Montana is 5.9 billion barrels, Exhibit 5-25.

Exhibit 5-25 OOIP of Bakken Shale, Montana Shale Area

County/Interval	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
▪ Montana – Upper Bakken	1,300	1,120	1,450
▪ Montana – Middle Bakken	1,300	2,690	3,490
▪ Montana – Lower Bakken	1,300	710	930
Total	**1,300**	**4,520**	**5,870**

Source: Advanced Resources International, 2019

5.7 Total Bakken Shale Area

Combining OOIP estimates for the eight resource assessment units (counties) within the three geographic Bakken Shale Areas – the Basin Center Area, the Basin Margin Area, and the Montana

Area – the study estimates an overall risked OOIP value for the Bakken Shale of 90.8 billion barrels, as displayed in Exhibit 5-26.

Reservoir simulation, involving the use of volumetric data for OOIP developed in this report and history matching of Bakken Shale oil production, provided a primary recovery efficiency of 10 percent to 12 percent for the three intervals of the Bakken Shale in the Basin Center Area. This work, performed by ARI, with sponsorship by U.S. DOE/NETL is provided in a separate (publication pending) report entitled "Reservoir Simulation of Enhanced Tight Oil Recovery: Bakken Shale."

Exhibit 5-26 Total OOIP for Bakken Shale

Shale Areas	Risked Area (mi^2)	Resource Concentration (MMB/mi^2)	Oil/Condensate OOIP (Million Barrels)
Basin Center Bakken Shale Area			
▪ Mountrail Co.	1,510	10,780	16,300
▪ McKenzie Co.	2,270	9,700	22,050
▪ Dunn Co.	1,430	8,280	11,850
▪ Williams Co.	1,720	9,360	16,080
Sub-Total			**66,280**
Basin Margin Bakken Shale Area			
▪ Divide Co.	1,030	11,910	12,290
▪ Burke Co.	620	7,670	4,780
▪ Billings-Stark Co.	680	2,350	1,600
Sub-Total			**18,670**
Montana Bakken Shale Area			
▪ Montana	1,300	4,520	**5,870**
		Total OOIP	**90,820**

Source: Advanced Resources International, 2019

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