Red River Formation
Three Forks Formation
Inyan Kara Formation

Timothy O. Nesheim
Julie A. LeFever
Jeffrey W. Bader
**Red River Formation: Kukersites**

Timothy O. Nesheim  
North Dakota Geological Survey

---

### Core Workshop

<table>
<thead>
<tr>
<th>No.</th>
<th>Well</th>
<th>Core Interval</th>
</tr>
</thead>
</table>
| 1   | Superior Oil Company - Novak #1  
NWSE Sec. 35, T152N, R102W, McKenzie County  
NDIC: 9618, API: 33-053-01542-00-00 | 13,621’-13,681’    |
| 2   | Terra Resources, Inc. - BNRR #1-17  
NWSW Sec. 17, T145N, R103W, McKenzie County  
NDIC: 7218, API: 33-053-00955-00-00 | 12,775’-13,034’    |
| 3   | H. L. Hunt - N.P.R.R. “A” #3  
NENW Sec. 23, T136N, R101W, Slope County  
NDIC: 4241, API: 33-087-00011-00-00 | 11,510’-11,568’    |
| 4   | H. L. Hunt - N.P.R.R. “A” #3  
NENW Sec. 23, T136N, R101W, Slope County  
NDIC: 4241, API: 33-087-00011-00-00 | 9,825’-9,863’      |
Overview of Red River Kukersites in western North Dakota

Introduction

The Ordovician Red River Formation has cumulatively produced more than 600 million barrels of oil equivalent from over 2,700 wells extending from southern Saskatchewan, through eastern Montana and western North Dakota, to northwestern South Dakota. Early work by Dow (1974) and Williams (1974) that dealt with identifying and evaluating petroleum source beds in the Williston Basin concluded that Red River hydrocarbons were externally sourced by the underlying Icebox Formation. However, numerous studies since have identified prospective sourced beds (referred to as kukersites) within the Red River Formation (reviewed below). Ongoing work by the North Dakota Geological Survey is focusing on delineating the extent of these prospective Red River source beds and evaluating their thermal maturity to determine the quantity and distribution of hydrocarbon generation within the Red River Formation (e.g. Nesheim et al., 2015).

Stratigraphy

The Red River Formation reaches a maximum thickness of over 700 ft. and has been informally divided into upper and lower subunits (Fig. 1). The lower Red River is made up of burrow-mottled fossil wackestone that comprises two-thirds of the Red River section in the central basin. The lower Red River becomes less fossiliferous, less burrow-mottled, and grades into dense dolostone towards that margins of the basin (Carroll, 1979). The upper Red River is composed of three shallowing, brining upward cycles referred to as the “A”, “B”, and “C” cycles in descending order (Longman, 1987; Fox, 1993). Each upper Red River cycle consists of the following lithologies in ascending order: burrowed lime mudstone to fossil wackestone, laminated microcrystalline dolostone, nodular to laminated anhydrite, and a thin argillaceous-dolomitic mudstone. Most of the Red River hydrocarbon production comes from the laminated dolomites within the “B” and “C” cycles and the underlying burrow-mottled “D” zone (Fig. 1).
Figure 1. Stratigraphic column of the Red River Formation and surrounding units with approximate nomenclature correlations between Saskatchewan (Sask.) and North Dakota (N.D.).
Previous Work

Petroleum source beds, commonly referred to as kukersites or kerogenites, have been previously described within the Red River “D” zone (equivalent to the “C” burrow member/upper Yeoman Formation) (Fig. 1) (Kendall, 1976; Kohm and Louden, 1978; Carroll, 1979; Longman et al., 1983). Kukersites contain abundant concentrations of the algae microfossil *Gloeocapsomorpha Prisca* (*G. Prisca*) (Stasiuk and Osadetz, 1990). Osadetz and Snowdon (1995) reported a 9.07% total organic carbon (TOC) average for kukersite samples from southern Saskatchewan with an average hydrogen index (HI) of 956 for immature samples, demonstrating that kukersites were deposited as very organic-rich and oil-prone source beds. Red River kukersites are interpreted to have formed within a subtidal marine setting with accumulation models that include: benthic algal mats that grew on the sea floor (Stasiuk and Osadetz, 1990), suspension settling of algae out of the water column during periodic algal bloom events (Pak et al., 2010), and periodic basin restriction where euxinic bottom water conditions developed (Kendall, 1976; Kohm and Louden, 1978). Kukersites are described as relatively thin (<2 ft thick), but have been noted to correlate from a local, field level scale (Kendall, 1976; Kohm and Louden, 1978) to a regional, basinwide scale (Longman et al., 1983).

Preliminary Summary of Red River Kukersites within North Dakota

Ten individual kukersites, referred to as K1 to K10 beds in ascending order, can be identified and correlated across western North Dakota using wireline logs and cores (Fig. 2). In core, kukersites are typically one to two feet thick and display significant textural/lithological variations including: fossil grain concentrations, amount and type of bioturbation, discontinuous-irregular bedding/laminations, and coloration which also reflects organic richness (e.g. Fig. 3). Kukersites grade laterally into marginally organic-rich (0.5-1.0% TOC) to organic-lean beds (<0.5% TOC) and are interbedded with burrow-mottled lime to dolomitic mudstone (e.g. Fig. 4). Kukersites sampled by this study were found to contain highly variable average TOC.
Figure 2. Stratigraphic cross-section of the Red River “C” and “D” zones correlating kukersites between the selected core workshop cores.
Figure 3. Core photograph examples of kukersites from the Red River “D” zone. A) K2 kukersite containing 6.9 to 20.5 wt. % TOC (12.4% average), B) K5 kukersite containing 0.2 to 3.2 wt. % TOC (1.1% average), C) K6 kukersite containing 2.0 to 12.6 wt. % TOC (8.5% average), and D) K7 kukersite containing 0.2 to 0.6 wt. % TOC (0.4% average). One inch scale bar in the bottom right corner and NDIC well number with approximate core depth in the bottom left corner of each photograph.
Figure 4. Core photographs from the Red River “D” zone. A) Dark grey, moderately organic-rich kukersite, K3 which contains 0.9 to 1.3 wt.% TOC, B) organic-lean (<0.5 wt. %), lateral equivalent of the K4 kukersite, C) light and dark grey, burrow-mottled lime mustone (<1% porosity), and D) tan-brown, burrow-mottled dolomitic mudstone (~9% porosity). One inch scale bar in bottom right corner and NDIC well number with approximate core depth in the bottom left corner of each photograph.
concentrations ranging from <1% to over 10%. On wireline logs, Kukersites that are ~1 ft. thick or more can be identified by subtle to pronounced high resistivity signatures (e.g. Fig. 2). The K2 and K6 beds tend to be more organic rich, containing TOC concentrations of 5% to 10% or more which results in subtle sonic and porosity wireline log responses. Each of these kukersite beds has a unique lateral extent along, thickness, and organic-richness variations which is still being delineated by the author. Overall, Red River kukersites extend approximately 20-30 miles east of the Montana border into western North Dakota, and from the Saskatchewan to South Dakota borders (Fig. 5). While kukersites are typically relatively thin (≤ 2 ft.) individually, they combine to commonly reach net thicknesses of 6 to 12 ft. or more within their area of extent in western North Dakota (Fig. 5).
Figure 5. Kukersite extent and thickness maps for western North Dakota with A) well and core control, and B) cores of interest and various structures. The black/dark grey lines represent isopach contours of kukersite net thickness.
References


NDIC File No: 9618  API No: 33-053-01542-00-00  County: MCKENZIE
Well Type: OG  Well Status: IA  Status Date: 3/20/2009  Wellbore type: VERTICAL
Location: NWSE 35-152-102  Latitude: 47.938932  Longitude: -103.69771
Current Operator: VANGUARD OPERATING LLC
Original Operator: SUPERIOR OIL CO.
Current Well Name: NOVAK 1
Original Well Name: NOVAK #1
Elevation(s) (ft.): 2,171 KB  2,146 GL  Total Depth: 13,805  Field: ELK
Spud Date(s): 7/9/1982

Formation Tops (true vertical depth in ft.)

Completion Data (true vertical depth in ft.)

Cumulative Production Data (reported in barrels)
Pool: STONEWALL  Cum Oil: 268,672  Cum MCF Gas: 371,894  Cum Water: 219,933
Pool: RED RIVER  Cum Oil: 225,482  Cum MCF Gas: 239,694  Cum Water: 237,886
Pool: MADISON  Cum Oil: 10,190  Cum MCF Gas: 9,632  Cum Water: 22,757

Production Test Data (reported in barrels)
IP Test Date: 12/20/1982  Pool: RED RIVER  IP Oil: 115  IP MCF: 0  IP Water: 11
IP Test Date: 3/21/2009  Pool: MADISON  IP Oil: 3  IP MCF: 2  IP Water: 10

Cores: (true vertical depth in ft.)
Type: RS  Top: 13,526  Bottom: 13,535  Formation: O-RR
Type: RS  Top: 13,535  Bottom: 13,543  Formation: O-RR
Type: RS  Top: 13,552  Bottom: 13,580  Formation: O-RR
Type: RS  Top: 13,621  Bottom: 13,681  Formation: O-RR
NDIC: 9618, API: 33-053-01542-00-00
NWSE Sec. 35, T152N, R102W
Superior Oil Company - Novak #1

Core Interval 13,621 - 13,650 ft.
Superior Oil Company - Novak #1

NDIC: 9618, API: 33-053-01542-00-00
NWSE Sec. 35, T152N, R102W
Core Interval 13,650 - 13,681 ft.
NDIC File No: 7218  API No: 33-053-00955-00-00  County: MCKENZIE
Well Type: OG  Well Status: DRY  Status Date: 4/26/1980  Wellbore type: VERTICAL
Location: NWSW 17-145-103  Latitude: 47.379808  Longitude: -103.839497
Current Operator: TERRA RESOURCES, INC.
Original Operator: TERRA RESOURCES, INC.
Current Well Name: BNRR 1-17
Original Well Name: BNRR #1-17
Elevation(s) (ft.): 2,606 KB  Total Depth: 13,125  Field: BICENTENNIAL
Spud Date(s): 1/28/1980

Formation Tops (true vertical depth in ft.)

Cumulative Production Data

Production Test Data (reported in barrels)
DST: 10,750-10,836  Recovery: 1000' WATER CUSHION, 5975' DRILLING MUD - SAMPLER: 2000 CC MUD
DST: 12,457-12,517  Recovery: ** MISRUN **, TOOL COULD NOT BE ROTATED
DST: 12,451-12,517  Recovery: ** MISRUN **, TOOL DID NOT OPEN., 1935' FRESH WATER, 103' NH3 & WTR CUSH C MUD - SAMPLER: 900 CC MUD
DST: 12,451-12,517  Recovery: ** MISRUN **, PACKER SEAT FAILURE., 2000' FRESH WATER, 2422' DRILLING MUD - SAMPLER: 300 CC MUD
DST: 12,775-12,835  Recovery: 2800' WATER CUSHION, TESTER VALVE DID NOT OPEN - SAMPLER: 1750 CC WATER
DST: 12,818-12,950  Recovery: 2790' WATER CUSHION, 1395' HEAVY MUD - SAMPLER: 1850 CC MUD
DST: 12,950-13,035  Recovery: 50' GAS CUT OIL, 2800' GAS CUT WATER CUSH, 2180' GAS CUT SALT WATER - SAMPLER: 2.11 CF GAS GOR 8387, 40 CC OIL @ 60 DEG, 1800 CC WATER
DST: 12,936-13,124  Recovery: 30' OIL, 2548' GC WTR CUSH/TR OIL, 372' WATER, GAS CUT MUD, 3194' GAS CUT SALT WATER - SAMPLER: 1.8 CF GAS GOR 7155, 40 CC OIL, 1840 CC WATER

Cores: (true vertical depth in ft.)
Type: CS  Top: 12,775  Bottom: 12,866  Formation: O-RR
Type: CS  Top: 12,866  Bottom: 13,030  Formation: O-RR
Type: LS  Top: 12,775  Bottom: 12,797  Formation: O-RR
Type: LS  Top: 12797  Bottom: 12952  Formation: O-RR
Type: LS  Top: 12952  Bottom: 13034  Formation: O-RR
NDIC: 7218, API: 33-053-00955-00-00
NWSW Sec. 17, T145N, R103W
Terra Resources, Inc. - BNRR #1-17

Core Interval 12,931 - 12,971 ft.
NDIC: 7218, API: 33-053-00955-00-00
NWSW Sec. 17, T145N, R103W
Terra Resources, Inc. - BNRR #1-17

Core Interval 12,972 - 13,015 ft.
NDIC File No: 4241  API No: 33-087-00011-00-00  County: SLOPE
Well Type: OG  Well Status: DRY  Status Date: 5/3/1967  Wellbore type: VERTICAL
Location: NENW 23-136-101  Latitude: 46.581042  Longitude: -103.334736
Current Operator: H. L. HUNT
Original Operator: H. L. HUNT
Current Well Name: NPRR A 3
Original Well Name: N.P.R.R. "A" #3
Elevation(s) (ft.): 2,868 KB  Total Depth: 11,588  Field: ELEVEN BAR
Spud Date(s): 3/13/1967

Formation Tops (true vertical depth in ft.)


Completion Data

Production Test Data (reported in barrels)

DST: 10,192-10,245  Recovery: 2200' WATER CUSHION, 1660' HGC SW W/TRACE OIL, 4437' SALT WATER
DST: 11,366-11,384  Recovery: 3000' WATER CUSHION, 6019' SLIGHTLY GAS CUT SALT WATER - SAMPLER: 2300 CC FLUID - NO BREAKDOWN GIVEN
DST: 11,426-11,487  Recovery: 3036' WATER CUSHION, 2446' WATER, 590' SLIGHTLY GAS CUT MUD
DST: 11,498-11,568  Recovery: 3100' WATER CUSHION, 6875' SALT WATER - SAMPLER: 2400 CC WATER

Cores: (true vertical depth in ft.)

Type: CH  Top: 11,369  Bottom: 11,459  Formation: O-RR
Type: CH  Top: 11,459  Bottom: 11,547  Formation: O-RR
Type: CH  Top: 11,547  Bottom: 11,569  Formation: O-RR
Type: CS  Top: 11,368  Bottom: 11,568  Formation: O-RR
Type: RS  Top: 11,368  Bottom: 11,568  Formation: O-RR
Core + 1.8 ft. = Log

Core + 1.8 ft. = Log

Core - 1.2 ft. = Log

K6

K8

11,500

11,400

Ω

Ω

"B" zone

Red River Formation

"C" zone

"D" zone

Stony Mt. Fm.

Stoughton Mbr.

Gamma Ray

Resistivity

Sonic Velocity

Porosity

Oil Saturation %

Oxygen Index

Oxygen Index

2000

80

40

0.01

100

0

430

0

10

11,400 ft.

11,500 ft.

Hydrogen Index

33-087-00011-00-00

NENW Sec. 23, T136N, R101W

H. L. Hunt

N.P.R.R. "A" #3

K. B. = 11,588 ft.
NDIC: 4241, API: 33-087-00011-00-00
NENW Sec. 23, T136N, R101W
H. L. Hunt - N.P.R.R. “A” #3

Core Interval 11,510 - 11,568 ft.
NDIC File No: 4669  API No: 33-011-00148-00-00  County: BOWMAN
Well Type: OG  Well Status: IA  Status Date: 6/27/1969  Wellbore type: VERTICAL
Location: SWNE 21-131-104  Latitude: 46.157292  Longitude: -103.68832
Current Operator: ABRAXAS PETROLEUM CORP.
Original Operator: INTERNATIONAL NUCLEAR CORP.
Current Well Name: MILLER 1-21
Original Well Name: MILLER #1-62
Elevation(s) (ft.): 3,158 KB  Total Depth: 9,930  Field: COYOTE CREEK
Spud Date(s): 5/8/1969

**Formation Tops** (true vertical depth in ft.)
- K-GH 3900
- K-M 4475
- K-N 4611
- K-IK 4886
- J-S 5310
- J-R 5683
- T-S 6033
- PM-MK 6600
- PM-OP 6646
- PM-BC 6763
- M-KL 7295
- M-MD 7409
- M-MDR 7602
- M-MDLP 8220
- D-DV 8826
- S-I 9110
- O-G 9485
- O-ST 9533
- O-RR 9604

**Completion Data** (true vertical depth in ft.)
- Pool: RED RIVER
- Perfs: 9,648-9,838 G
- Comp Dt: 6/27/1969
- Status: AL
- Status Dt: 6/18/2013
- Spacing: E2

**Cumulative Production Data** (reported in barrels)
- Pool: RED RIVER
- Cum Oil: 1,021,567
- Cum MCF Gas: 298,756
- Cum Water: 2,727,004

**Production Test Data** (reported in barrels)
- IP Test Date: 6/27/1969
- Pool: RED RIVER
- IP Oil: 332
- IP MCF: 0
- IP Water: 17
- **DST:** 7653-7669
  - Recovery: 10' MUD CUT SALT WATER WITH FLECKS OF BROWN OIL, 1326' MUD CUT SALT WATER CLEARED UP AT THE BASE - SAMPLER: 2100 CC WATER, TRACE OF MUD
- **DST:** 7882-7930
  - Recovery: 6330' SALT WATER (MUD CUT AT THE TOP) - SAMPLER: 2100 CC WATER, TRACE OF OIL
- **DST:** 8734-8766
  - Recovery: 1500' WATER CUSHION, 976' SALT WATER (MUD CUT AT TOP) - SAMPLER: 2100 CC WATER
- **DST:** 9774-9810
  - Recovery: 1500' HEAVY GAS CUT, OIL & MUD CUT WATER CUSHION, 5179' CLEAN OIL - SAMPLER: 2.8 CF GAS GOR 243, 1900 CC OIL 28.7 @ 60 DEG

**Cores:** (true vertical depth in ft.)
- Type: CS  Top: 9647  Bottom: 9673  Formation: O-RR
- Type: LS  Top: 9647  Bottom: 9673  Formation: O-RR
- Type: LS  Top: 9810  Bottom: 9813  Formation: O-RR
- Type: LS  Top: 9817  Bottom: 9821  Formation: O-RR
- Type: LS  Top: 9825  Bottom: 9860  Formation: O-RR
- Type: LS  Top: 9860  Bottom: 9863  Formation: O-RR
- Type: PH  Top: 9811  Bottom: 9859  Formation: O-RR
- Type: TS  Top: 9811  Bottom: 9839  Formation: O-RR
- Type: TS  Top: 9841  Bottom: 9859  Formation: O-RR
Three Forks Formation: Divide County

Julie A. LeFever
North Dakota Geological Survey

<table>
<thead>
<tr>
<th>No.</th>
<th>Well</th>
<th>Core Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Murex Petroleum Corp. - Jennifer Abigail 16-21H</td>
<td>8,287’-8,350’</td>
</tr>
<tr>
<td></td>
<td>NWNE Sec. 16, T162N, R101W, Divide County</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NDIC: 24642, API: 33-023-00975-00-00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>SM Energy Company - Tomlinson 3-1HN</td>
<td>8,708’-8,748’</td>
</tr>
<tr>
<td></td>
<td>Sec. 1, T161N, R100W, Divide County</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NDIC: 26745, API: 33-023-01120-00-00</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>SM Energy Company - Torgeson 2-15HS</td>
<td>7,975’-8,010’</td>
</tr>
<tr>
<td></td>
<td>NWNE Sec. 15, T163N, R100W, Divide County</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NDIC: 28042, API: 33-023-01190-00-00</td>
<td></td>
</tr>
</tbody>
</table>
Preliminary Look at the Three Forks Formation, Divide-Williams Counties, North Dakota

Julie A LeFever¹, Stephan H. Nordeng², Richard D. LeFever², and Kilynn Sandberg²
North Dakota Geological Survey¹, Grand Forks, North Dakota 58202
University of North Dakota², Grand Forks, North Dakota 58202

Introduction

The Bakken and Three Forks formations cover a significant portion of North Dakota, South Dakota, and Montana in the United States; and, Saskatchewan and Manitoba in Canada. Drilling activity since 2000 has been primarily focused on these two formations because of new advances in horizontal drilling technology. With these advances, the need for additional cores and data has enabled investigations into previous undrilled portions of the basin. This has resulted in good well and excellent core control (17 wells) in the study area (Fig. 1). A contour map of Three Forks production (Fig. 2) shows an anomalous high trend in Divide County that is the focus of this investigation. This study will examine the cores from four wells in Divide County across that production increase (Fig. 2).

Statigraphy

The Three Forks Formation conformably overlies the Birdbear Formation (Devonian) and can be divided into three informal members, in ascending order: lower, middle, and upper (Bottjer et al, 2011; Nordeng and LeFever, 2015; Nordeng et al, 2015). It reaches a maximum thickness of 255 ft and is present in the western half of North Dakota. Top of the Three Forks is marked by a significant unconformity and, in turn, is overlain by the Pronghorn or Lower Member of the Bakken Formation.

This workshop will focus on the upper half of the Three Forks Formation (Fig. 3). The lower half consists predominantly of silty and sandy dolomitic red beds with anhydrite nodules or beds. This interval is capped by a pervasive, basin-wide, clay-rich marker bed with larger dolostone clasts. Lithologies are similar for both the middle and upper portions of the Three Forks. Basal units for both are pink to tan mottled dolostones with interfingering green clay stringers. Soft-sediment deformation is predominantly due to dewatering of clay intervals. This section may be overlain by a parallel laminated to massive pink to tan dolostones followed by an interbedded sequence of apple green and tan mudstones and dolostones. Numerous structures are present in the interbedded sequence including uni- and bi-directional ripple laminations, mudcracks, soft-sediment deformation, and parallel to sub-parallel laminations. Capping the middle member is another grey-green silty mudstone bed with suspended dolostone clasts. This mudstone bed is also a basin-wide marker bed.

The upper member is unconformably overlain by either the Pronghorn or Lower Member of the Bakken Formation. Where present, the Pronghorn is 2 to 5 ft thick and is represented by a silty mudstone. Burrowed layers are common. Where the upper member is overlain by the Lower Member of Bakken, the contact is sharp with a thin lag deposit. Dark brown mudstone or dark black shale comprises the Lower Member of the Bakken.
Figure 1 – Index map of the study area in Divide and Williams counties. Cores available are labeled with NDIC numbers. Cross-section of interest (A-A’) is shown in red.

Figure 2 – Cumulative production map for the Three Forks Formation for Divide and McKenzie counties. Contour interval is 50,000 barrels.

The uppermost Three Forks Formation serves as the reservoir in the Divide County region. Permeabilities are low with porosities ranging from 5 to 8 %. Better reservoir rocks occur where the green, silty clay layers are at a minimum (Fig. 4).

Production in this area is poor from the Middle Member of the Bakken Formation. Grain size tends to be larger and subject to cementation. That in combination with the immaturity of the overlying upper shale makes it poor producer.

Discussion

Eight hundred wells were mapped to construct a series of isopach and geochemical maps for Divide County and the surrounding area. The Lower Member of the Bakken Formation is fairly constant
Figure 3 - Representative log section for Divide County showing the relationship between the uppermost Three Forks and the Bakken Formation.

Figure 4 – Plain and black light photographs representative of the upper Three Forks Formation from SM Energy Company – Tomlinson #3-1HN (Lot 3 Sec. 1, T161N, R100W).
Figure 5a – Isopach of the Lower Member of the Bakken Formation. The thickness reaches a maximum of 54 ft towards the depocenter shown in blue. The central portion of the study area in Divide County is marked by an increase in shale thickness. Control points are in black and cored wells are indicated in red. Contour interval is 2 ft.

Figure 5b – Isopach of the Three Forks Formation. The Nesson Anticline was a prominent feature during the deposition of the formation as indicated by the isopach thins. Much of Divide County appears to be a gradual shelf. Control points are indicated in black with cored wells indicated in red. Contour interval is 2 ft.

Figure 5c – Isopach of the upper member of the Three Forks Formation appears similar to that of the total Three Forks Formation. Control points are indicated in black with cored wells indicated in red. Contour interval is 2 ft.

Figure 5d – In contrast, the isopach of the middle member of the Three Forks Formation shows an increase in thickness over the northeastern portion of the county. Control points are indicated in black with cored well indicated in red. Contour interval is 2 ft.
over the county ranging in thickness from 22 to 26 ft (Fig. 5a). Isopach of the total Three Forks Formation (Fig. 5b) suggests a gentle shelf on the western side of the Elk Point Basin. This is also suggested by the contour map of the upper member (Fig. 5c). It also shows a limited thickness change. In contrast, the middle member appears to show a low ridge stretching from the Nesson Anticline, across the Divide County, into Montana (Fig. 5d).

The geochemical maps are presented as evidence of increased production noted in the study area. Geochemical data is from the Lower Member of the Bakken Formation because it is likely to be the primary source of oil. The Upper Member of Bakken appears immature in core. Figure 6 outlines a north-south area of lower total organic carbon,

**Figure 6** – Map of the Total Organic Carbon (TOCs) measured for the Lower Member of the Bakken Formation. Note the north-south oriented trend in lower TOCs indicated in tans and orange. Contour interval is 2 ft.

**Figure 7** – Contour map of TMAX values for the Lower Member of the Bakken Formation shows a similar north-south trend with higher TMAX values. Triangles indicate TMAX data point with cored locations indicated in red. Contour interval is 5 degrees.

**Figure 8** – Contour map of Bakken Formation kinetics continuing the northward trend through the center of Divide County. Contour interval is .5 ft.
suggesting that the area is marginally mature. This is supported by the contour maps of TMAX (Fig. 7) and kinetics (Fig. 8). The area of maturation is generally considered to be more southerly.

References Cited


NDIC File No: 24642  API No: 33-023-00975-00-00  County: DIVIDE  CTB No: 124642
Well Type: OG  Well Status: A  Status Date: 9/12/2013  Wellbore type: HORIZONTAL
Location: NWNE 16-162-101  Latitude: 48.864955  Longitude: -103.801611
Current Operator: MUREX PETROLEUM CORPORATION  
Original Operator: MUREX PETROLEUM CORPORATION
Current Well Name: JENNIFER ABIGAIL 16-21H  
Original Well Name: JENNIFER ABIGAIL 16-21H
Elevation(s) (ft): 2,208 KB  2,192 GR  2,192 GL  Total Depth: 18,206  Field: FORTUNA
Spud Date(s): 7/22/2013

**Formation Tops**  (true vertical depth in ft.)
T-S 5928  M-KL 6283  M-MD 6405  M-MDR 6813  M-MDLS 6868  M-MDFA 7175
MD-B 8205  D-TF 8301  D-BB 8467

**Completion Data**
Pool: BAKKEN  Perfs: 8579-18206  Comp Dt: 9/12/2013  Status: AL
Status Dt: 10/17/2013  Spacing: 2SEC

**Cumulative Production Data**
Pool: BAKKEN  Cum Oil: 97,285  Cum MCF Gas: 58,517  Cum Water: 264,457

**Production Test Data**  (reported in barrels)
IP Test Date: 9/17/2013  Pool: BAKKEN  IP Oil: 42  IP MCF: 19  IP Water: 570

**Cores**  (true vertical depth in ft.)
Type: LS  Top: 8169  Bottom: 8200  Formation: M-MDLP
Type: LS  Top: 8200  Bottom: 8208  Formation: MD-B
Type: LS  Top: 8208  Bottom: 8269  Formation: MD-B
Type: LS  Top: 8269  Bottom: 8294  Formation: MD-B
Type: LS  Top: 8294  Bottom: 8475  Formation: D-TF
8275
8300
8325
8350
0 200
GR
0.45 -0.15
Neutron Porosity
0.45 -0.15
Density Porosity
0.2 2000
Resistivity
33-023-00975-0000
#24642
NWNE Sec. 16, T162N, R101W
Murex Petroleum Corp.
Jennifer Abigail #16-21H
KB = 2208 ft
Core -6 = Log
NWNE Sec. 16, T.162N., R.101W
Murex Petroleum Corp.
Jennifer Abigail #16-21H

Cored Interval: 8287 - 8320 ft.
NWNE Sec. 16, T.162N., R.101W
Murex Petroleum Corp.
Jennifer Abigail #16-21H

Cored Interval: 8320 - 8354 ft.
NDIC File No: 26745  API No: 33-023-01120-00-00  County: DIVIDE  CTB No: 221888  
Well Type: OG  Well Status: A  Status Date: 3/14/2014  Wellbore type: HORIZONTAL  
Location: LOT3 1-161-100  Latitude: 48.806839  Longitude: -103.608352  
Current Operator: SM ENERGY COMPANY  
Original Operator: SM ENERGY COMPANY  
Current Well Name: TOMLINSON 3-1HN  
Original Well Name: TOMLINSON 3-1HN  
Elevation(s): 2,326 KB  2,300 GR  2,303 GL  Total Depth: 19,201  Field: WEST AMBROSE  
Spud Date(s): 12/9/2013  

**Formation Tops** (true vertical depth in ft.)  
J-R 5524  T-S 6146  M-KL 6691  M-MD 6862  M-MDR 7219  M-MDLS 7278  
M-MDFA 7563  MD-B 8620  D-TF 8722  

**Completion Data**  
Pool: BAKKEN  Perfs: 9090-19201  Comp Dt: 3/14/2014  Status: F  
Status Dt: 4/19/2014  Spacing: 2SEC  

**Cumulative Production Data**  
Pool: BAKKEN  Cum Oil: 107,078  Cum MCF Gas: 77,428  Cum Water: 175,777  

**Production Test Data**  
IP Test Date: 4/19/2014  Pool: BAKKEN  IP Oil: 717  IP MCF: 518  IP Water: 1,403  

**Cores** (true vertical depth in ft.)  
Type: LS  Top: 8618  Bottom: 8733  Formation: MD-B  
Type: LS  Top: 8733  Bottom: 8806  Formation: D-TF
33-023-01120-0000  
#26745  
Lot 3 Sec. 1, T161N, R101W  
SM Energy Company  
Tomlinson #3-1HN  
KB = 2326 ft

Core + 5 = Log
NDIC File No: 28042   API No: 33-023-01190-00-00   County: DIVIDE   CTB No: 220216
Well Type: OG   Well Status: A   Status Date: 11/24/2014   Wellbore type: HORIZONTAL
Location: NWNE 15-163-100   Latitude: 48.951477   Longitude: -103.648983
Current Operator: SM ENERGY COMPANY
Original Operator: SM ENERGY COMPANY
Current Well Name: TORGESON 2-15HS
Original Well Name: TORGESON 2-15HS
Elevation(s): 2,167 KB  2,142 GR  2,145 GL   Total Depth: 17,868   Field: WEST AMBROSE
Spud Date(s): 6/25/2014

**Formation Tops** (true vertical depth in ft.)
- K-P 1144
- K-GH 3612
- K-M 3856
- K-N 4000
- K-IK 4240
- J-S 4580
- J-R 5062
- T-S 5682
- M-KL 6022
- M-MD 6161
- M-MDR 6528
- M-MDLS 6588
- M-MDFA 6844
- M-MDLP 7357
- MD-B 7883
- D-TF 7991

**Completion Data**
- Status Dt: 12/19/2014   Spacing: 2SEC

**Cumulative Production Data**
- Pool: BAKKEN   Cum Oil: 59,921   Cum MCF Gas: 34,183   Cum Water: 110,856

**Production Test Data**
- IP Test Date: 12/19/2014   Pool: BAKKEN   IP Oil: 236   IP MCF: 102   IP Water: 375

**Cores** (true vertical depth in ft.)
- Type: LS   Top: 7883   Bottom: 7995   Formation: MD-B
- Type: LS   Top: 7995   Bottom: 8063   Formation: D-TF
## Inyan Kara Formation

Jeffrey W. Bader  
North Dakota Geological Survey

---

**Well Core Interval**

<table>
<thead>
<tr>
<th>No.</th>
<th>Well</th>
<th>Core Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Amerada Petroleum Corporation - Math Iverson #1</td>
<td>4,590’ - 4,647’</td>
</tr>
<tr>
<td></td>
<td>SWNW Sec. 1, T155N, R96W, Williams County</td>
<td>4,937’ - 4,980’</td>
</tr>
<tr>
<td></td>
<td>NDIC: 165, API: 33-105-00097-00-00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shell Oil Company - USA #42-10</td>
<td>5,165’ - 5,257’</td>
</tr>
<tr>
<td></td>
<td>SENE Sec. 10, T148N, R105W, McKenzie County</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NDIC: 90015, API: 33-053-90015-00-00</td>
<td></td>
</tr>
</tbody>
</table>
Introduction

Significant volumes of co-produced water are generated daily during production operations for oil and gas in North Dakota. Produced water is an oil and gas industry term that describes the formation water that is generated as a by-product of oil and gas production. Formation water, also referred to as connate water, exists naturally within the formation along with the hydrocarbons which, because of lower density, float on the water. Formation water initially reflects the water quality of the depositional environment of the petroleum reservoir: marine, brackish, or fresh water. Approximately 7 to 10 barrels, equivalent to 280-400 gallons of water, are generated for every barrel of oil produced worldwide (USDI, 2011). Oil reservoirs generally contain significantly greater volumes of water than gas reservoirs; therefore, the amount of produced water in North Dakota is significant with approximately 13,000 producing oil wells currently in the state (NDIC, 2015). In North Dakota, over a million barrels of produced water are generated daily. In addition, the amount of produced water generated usually increases over the life of a well because oil and gas is depleted as hydrocarbons are extracted from the subsurface.

Injection of Produced Water into Favorable Geologic Units

Geology of the area is the major factor in determining if injection is a viable option for produced water disposal. North Dakota’s Williston Basin has an ideal sequence of geologic units (Dakota Group) present at an optimal depth for produced water disposal. The Lower Cretaceous (~100-113 million years) Dakota Group of North Dakota consists of four formations (fig. 1). In descending order they are:

- Mowry Formation—marine shale
- Newcastle Formation—marginal marine sandstone
- Skull Creek Formation—marine shale
- Inyan Kara Formation—marginal marine and non-marine sandstone and shale

Overlying the Dakota Group are several thousand feet of Cretaceous marine deposits including the 2300-foot-thick Pierre Formation. The Jurassic (~150-200 million years) Swift Formation unconformably underlies the Dakota Group and consists of up to 725 ft. (221 m) of marginal marine shale with interbedded limestone. The Dakota Group is present at approximately 5,000-6,200 ft. (1524-1890 m) in the heart of the Williston basin.

These Cretaceous and Jurassic rocks are present throughout the Williston Basin of North Dakota and provide a complete succession of rocks for produced water injection. Of specific importance is the Inyan Kara Formation, which consists of sandstones and shales deposited in incised valleys along the coastline of the Cretaceous Western Interior Seaway (figs. 2 and 3). These valleys were cut by north-northwesterly flowing rivers that drained into the seaway from highlands in southern North Dakota, Minnesota, and Canada. The valleys formed as the Cretaceous seaway withdrew (regressed) from North Dakota twice over a period of approximately 10 million years. The seaway transgressed back into the area forming estuaries, and sands were deposited in the valleys as sea-level rose, again in two transgressive events.

Inyan Kara sandstones deposited in these valleys are thick, porous (20-30% porosity), and permeable (Darcy level) enough to accept the injected water and the lateral continuity of the units allows for injected water to easily move into the formation (fig. 4), especially along valley trends. Between these valleys, in the interfluve area, sandstones are thinner, much less continuous, and have porosity/permeability an order of magnitude lower than incised valley sandstones. Therefore interfluve sandstones are not optimal for injection of produced water.
Although some lateral continuity is important, these units must have good seals above to protect shallow aquifers. The thick shales of the Pierre Formation provide such a seal and it, along with the underlying Swift Formation, allow for excellent confining layers that will vertically contain injected brines within the Inyan Kara Formation.

Summary
North Dakota produced its three billionth barrel of oil in January 2015 (NDIC, 2015) and it is estimated that four billion barrels will be achieved by 2018. That is four billion barrels or more of produced water that must be disposed. North Dakota will need to have new, innovative, and environmentally sound practices in managing these prodigious amounts of produced water.

An understanding of the depositional environment of the Inyan Kara Formation is critical in determining saltwater disposal well placement. This understanding begins with a thorough core and log analysis with emphasis on sequence stratigraphic concepts prior to mapping sandstone bodies, both in plain view (isopachs) and cross-sections.

References
NDIC File No: 165   API No: 33-105-00097-00-00   County: WILLIAMS
Well Type: OG   Well Status: PA   Status Date: 6/25/1987   Wellbore type: VERTICAL
Location: SWNW 1-155-96   Latitude: 48.278661   Longitude: -102.975888
Current Operator: AMERADA HESS CORPORATION
Original Operator: AMERADA PETROLEUM CORP.
Current Well Name: BEAVER LODGE-MADISON UNIT G-11
Original Well Name: MATH IVERSON #1
Elevation(s) (ft.): 2,340 KB  2,329 GL   Total Depth: 8,430   Field: BEAVER LODGE
Spud Date(s): 4/16/1953

Formation Tops (true vertical depth in ft.)
PM-MK 6313   PM-OP 6340   PN-T 6794   M-KL 7385   M-MD 7522   M-MDR 8107
M-MDLS 8170   M-MDFA 8367

Completion Data (true vertical depth in ft.)

Cumulative Production Data (reported in barrels)
Pool: MADISON   Cum Oil: 1,016,716   Cum MCF Gas: 102,167   Cum Water: 1,575,950

Production Test Data (reported in barrels)
IP Test Date: 6/7/1953   Pool: MADISON   IP Oil: 645   IP MCF: 668   IP Water: 1
DST: 4,599-4,647   Recovery: 3360' VERY SLIGHTLY MUD CUY WATER
DST: 4,939-4,988   Recovery: 4110' SLIGHTLY MUDDY BRACKISH WATER
DST: 5,174-5,273   Recovery: 306' DRILLING MUD

Cores: (true vertical depth in ft.)
Type: CH   Top: 4,590   Bottom: 4,647   Formation: K-IK
Type: CH   Top: 4,628   Bottom: 4,634   Formation: K-IK
Type: CH   Top: 4,930   Bottom: 4,990   Formation: K-UN
Type: DC   Top: 4,500   Bottom: 5,300
Type: DC   Top: 5,310   Bottom: 6,110
Type: DC   Top: 6,110   Bottom: 6,880
Type: DC   Top: 6,880   Bottom: 7,600
Type: DC   Top: 7,600   Bottom: 8,430
Type: LS   Top: 4,590   Bottom: 4,597   Formation: K-IK
Type: LS   Top: 4,597   Bottom: 4,615   Formation: K-IK
Type: LS   Top: 4,614   Bottom: 4,647   Formation: K-IK
Type: LS   Top: 4,937   Bottom: 4,952   Formation: K-IK
Type: LS   Top: 4,956   Bottom: 4,980   Formation: K-IK
Neutron Intensity Increase

Gamma Ray Intensity Increase

Core - 4 ft. = Log

Core = Log

Skull Creek Fm. (part)

Inyan Formation

Swift Fm. (part)

Core 4600

Core = Log

Corale 4800 4700 4900 4500

Amerada Petroleum Corporation
Math Iverson #1
K.B. = 2,340 ft.
<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>Lithology Graphic</th>
<th>Lithology Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4590</td>
<td>Claystone, dark gray to black</td>
<td>Planar laminated to wavy siltstone laminations throughout</td>
</tr>
<tr>
<td>4595</td>
<td>Trough cross-lamination</td>
<td>Bioturbated, convolute lamination</td>
</tr>
<tr>
<td>4600</td>
<td>Claystone, carbonaceous</td>
<td>Siltstone, brownish gray, laminated to thinly bedded, wavy, burrows</td>
</tr>
<tr>
<td>4605</td>
<td>Silty sandstone, light gray, very fine grained</td>
<td>Muddy lamination/clay drapes throughout, ripple lamination</td>
</tr>
<tr>
<td>4610</td>
<td>Vertical burrows (skolithos)</td>
<td>Claystone interbeds</td>
</tr>
<tr>
<td>4615</td>
<td>Laminated to very thin-bedded, wavy</td>
<td>Ripple cross-lamination, ripple lamination</td>
</tr>
<tr>
<td>4620</td>
<td>Claystone interbeds</td>
<td>Fluid escape structures (?)</td>
</tr>
<tr>
<td>4625</td>
<td>Contoured/slumped bedding</td>
<td>Ripple cross-lamination, climbing ripples</td>
</tr>
<tr>
<td>4630</td>
<td>Vertical burrows (skolithos)</td>
<td>Becomes fine-grained, oxidized</td>
</tr>
<tr>
<td>4635</td>
<td>Load structures</td>
<td>Fluid escape structures (?)</td>
</tr>
<tr>
<td>4640</td>
<td>Ripple lamination/cross-lamination</td>
<td>Ripple lamination/cross-lamination</td>
</tr>
<tr>
<td>4645</td>
<td>Contoured/slumped bedding</td>
<td>Plant fragments, coaly</td>
</tr>
<tr>
<td>4645</td>
<td>Claystone, black</td>
<td>Very carbonaceous, coaly (wood fragments)</td>
</tr>
<tr>
<td>4645</td>
<td>Oxidized</td>
<td></td>
</tr>
<tr>
<td>4645</td>
<td>Siltstone, light gray</td>
<td></td>
</tr>
<tr>
<td>4645</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Math Iverson #1
3310500970000
#165
4937 - 4980 ft. (Core = Log)

**Depth (ft.)**

**Lithology Graphic**

**Lithology Description**

**Sedimentary breccia**, brownish black, poorly sorted
Iron oxide cement

**Siltstone**, gray

**Sandstone**, light gray, very fine to fine grained, ripple cross lamination

Low-angle, multi-directional cross beds (tabular planar)

Ripple cross-laminated/ripples, climbing ripples

Low-angle, multi directional cross beds (tabular planar)

Wavy bedding

Tabular planar to trough cross-bedding

Multi-directional, planar tabular cross-bedding
Becomes dark gray and fine to medium grained

**Carbonaceous**: coal, sulfur

**Lag** with clasts of green claystone up to 2 cm

**Sandstone**, light gray

Very fine grained; undirectional, gently inclined, very low-angle planar lamination

**Claystone**, green
SWNW Sec. 1, T.155N, R.96W
Amerada Petroleum Corporation
Math Iverson #1

Cored Interval: 4631 - 4647 ft.
4937 - 4956 ft.
NDIC File No: 90015  API No: 33-053-90015-00-00  County: MCKENZIE
Well Type: SWD  Well Status: IA  Status Date: 6/18/1979  Wellbore type: VERTICAL
Location: SENE 10-148-105  Latitude: 47.658097  Longitude: -104.03483
Current Operator: XTO ENERGY, INC.
Original Operator: SHELL OIL CO.
Current Well Name: USA 42-10
Original Well Name: USA #42-10
Elevation(s) (ft.): 1,980 KB  1,967 GL  Total Depth: 5,670  Field: MONDAK

**Formation Tops** (true vertical depth in ft.)
- K-GH 4243
- K-M 4676
- K-N 4835
- K-IK 5060
- J-S 5576

**Cumulative Production Data**

**Cumulative Injection Data** (reported in barrels)
- UNIC NO: A0072S0119D  Pool: DAKOTA  Cum Salt Water Disposed: 19,432,897

**Cores:** (true vertical depth in ft.)
- Type: CC  Top: 5,165  Bottom: 5,177  Formation: K-IK
- Type: CC  Top: 5,177  Bottom: 5,260  Formation: K-IK
- Type: CP  Top: 5,196  Bottom: 5,250  Formation: K-IK
- Type: CS  Top: 5,165  Bottom: 5,183  Formation: K-IK
- Type: CS  Top: 5,183  Bottom: 5,257  Formation: K-IK
- Type: RS  Top: 5,165  Bottom: 5,258  Formation: K-IK
Gamma Ray

Resistivity

Inyan    Kara    Formation (Kik)

Js

Ksc

Core + 7 ft. = Log

Core
USA 42-10
33053900150000
5165-5260 ft. (C + 7 ft. = Log)

**Depth (ft.)** | **Lithology Graphic** | **Lithology Description**
--- | --- | ---
5165 | | Claystone, black
5170 | | Siltstone, gray, planar to convolute/contorted bedding
5175 | | Siltstone/claystone interbedded, light gray to black, bioturbated (planolites throughout, skolithos, and technichnus), fluid escape structures
5180 | | Ironstone concretion
5185 | | Convolute laminations
5190 | | Claystone, dark gray
5195 | | Siltstone, light gray, clayey, wavy, and ripple laminations throughout
5200 | | Burrowed
5205 | | Siltstone/claystone interbedded, planar laminated to wavy laminated/ripple cross-laminations and climbing ripples, bioturbated in silty zones
5210 | | More clayey
5215 | | Planar laminated claystone with thin silty laminations
5220 | | Siderite precipitates?
5225 | | Claystone, light to dark gray
5230 | | Bioturbated
5235 | | Sandstone, gray, very fine to fine grained
5240 | | Oxidized
5245 | | Skolithos burrows
5250 | | Gently inclined, planar laminated
5255 | | Sandstone, gray, medium grained (upper)
5260 | | Cross-laminated to planar laminated (multi-directional)
5265 | | Sandstone, gray, medium grained (lower), massive
5270 | | Siltstone, mottled, maroon to gray, argillaceous
SENESec. 10, T.148N., R.105W
Shell Oil Company
USA #42-10

Cored Interval: 5165-5201 ft.