2018 Core Workshop

Bakken-Three Forks Formations
Madison Group
Spearfish Formation

Jeffrey W. Bader
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Timothy O. Nesheim
Travis D. Stolldorf
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WILLISTON BASIN PETROLEUM CONFERENCE
Core Workshop

Bakken-Three Forks

Jeffrey W. Bader and Julie A. LeFever
North Dakota Geological Survey

Figure 1
Formation Extent

Workshop Cores

<table>
<thead>
<tr>
<th>No.</th>
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<th>Core Interval</th>
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<td>11,228-11,571</td>
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<td>2</td>
<td>American Hunter Exploration-Grassy Butte 12-31 H3&lt;br&gt;NW NE Sec. 12, T146N, R99W, McKenzie County&lt;br&gt;NDIC: 12772, API: 33-053-02308-00-00</td>
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Sequence Stratigraphy of the Bakken Petroleum System and Beyond

The Bakken petroleum system is composed of the Devonian-Mississippian Bakken Formation, consisting of the Upper and Lower Shale, Middle, and Pronghorn Members. The system was originally defined to include the lower 50-feet of the overlying Mississippian Lodgepole Formation and the upper 50-feet of the Devonian Three Forks Formation (Nordeng, 2009). However, the total petroleum system may also include the entire 200+ ft. of the Three Forks section within the central, deeper portions of the basin (Nesheim, 2018). Estimates indicate that over 300-billion barrels (BBO) of oil have been generated from Bakken shales, sourcing Bakken reservoirs, as well as reservoirs in the lower Lodgepole and Three Forks Formations (Price and LeFever, 1992; NDIC, 2006). To date, the Bakken petroleum system has produced only 2 BBO of oil in North Dakota, or approximately < 1% of the estimated in-place resource, even with recent innovations in drilling technology over the last decade. This indicates that the Bakken petroleum system is a relatively untapped, giant, continuous oil accumulation in the Williston Basin (Sonnenberg, et al., 2017). Amounts of recoverable oil from this huge resource are unknown and are dependent on the discovery and development of new technologies in both exploration and drilling.

The Bakken petroleum system is present over much of the Williston Basin of North Dakota, Montana, and Canada with the depositional axis and deepest portions of the basin in western North Dakota (Fig. 1). Recent studies have shown the importance of core/log-based evaluations using sequence stratigraphy in recognizing unconformities and sequence stratigraphic surfaces within the Bakken petroleum system (Fig. 2; Skinner et al., 2015). Such studies have led to discoveries of giant oil fields within the Bakken-play, such as the Pronghorn play that spans the Park, Bell, and surrounding fields in southwestern North Dakota.

This core workshop will focus on two wells that illustrate the importance of recognizing not only erosion surfaces, but what type of erosion surface, and the stratigraphic and sedimentological implications of correctly, or incorrectly, identifying these features in core (Figs. 3 and 4). In addition, emphasis will also be placed on recognition of these features on the gamma-ray log (Catuneanu, 2006), to help identify 3rd, 4th, and even 5th order sequences that can then be used to better identify rock type, facies, and depositional environments, etc. as they relate to fluctuations in relative sea-level (Fig. 5). Sequence stratigraphic principles may also be utilized for other siliciclastic units in the Williston Basin that may also have untapped petroleum potential, such as the Spearfish, Tyler, Icebox, Black Island, and Deadwood formations. Better understanding of sequence stratigraphic principles in petroleum exploration, combined with technological advancement in drilling and seismic (stratigraphic and structural) will allow for increased production from these conventional and unconventional reservoirs.
Figure 2

Modified from Skinner et al. 2015
NDIC File No: 19918  API No: 33-053-03358-00-00  County: MCKENZIE  CTB No: 119918
Well Type: OG  Well Status: A  Status Date: 6/12/2011  Wellbore type: HORIZONTAL
Location: SWSE 22-152-99  Footages: 265 FSL 1965 FEL  Latitude: 47.964578  Longitude: -103.333939
Lateral 1  Start Coordinates 22 N 8 W From Wellhead, End Coordinates 10032 N 75 W From Wellhead
Current Operator: CONTINENTAL RESOURCES, INC.
Original Operator: CONTINENTAL RESOURCES, INC.
Current Well Name: CHARLOTTE 1-22H
Original Well Name: CHARLOTTE 1-22H
Elevation(s): 2352 KB  2330 GR  2331 GL  Total Depth: 21090  Field: BANKS
Spud Date(s): 2/16/2011
Digital or Image Log(s) available: AIG-CND1.las 13.7MB, AIG-CND2.las 4.7MB, AIG-CND3.las 3.9MB, AIG-CND4.las 601KB, AIG 5.5MB, AIG1.las 3.1MB, AIG2.las 2MB, AIG3.las 281KB, CAL.las 967KB, CAL 1.5MB, CBL.las 1.8MB, CBL 2.9MB, CIL.las 22.4MB, CIL 2.8MB, CND 1.9MB, DTSM1 2.3MB, DTSM2 1MB, DTSM3 9.8MB, ECS 1.3MB, GR.las 295KB, MRI-ECS1.las 579KB, MRI-ECS2.las 1.4MB, MRI.las 258KB, MRI 1.2MB
Formation Tops
J-R 6734  T-S 7268  PM-MK 7675  PM-OP 7702  PM-EBA 7958  PN-T 8254
M-EBS 8471  M-KL 8817  M-MD 8865  M-MDR 9604  M-MDLS 9697  M-MDFA 9901
M-MDLP 10476  MD-B 11265  D-TF 11356  D-BB 11573
Casing String(s): 9.625" 2243'  7" 11530'
Completion Data
Spacing: 2SEC
Cumulative Production Data
Pool: BAKKEN  Cum Oil: 266968  Cum MCF Gas: 343026  Cum Water: 127246

Production Test Data
### Continental Resources Inc.

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<th>Depth (ft)</th>
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<td>Crinoidal Limestone</td>
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<tr>
<td>Middle Bakken</td>
<td>11571-21080</td>
<td>Crinoidal Limestone</td>
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**Core Photographs**

- **Photo 1**: Crinoidal Limestone
- **Photo 2**: Lodgepole
- **Photo 3**: Middle Bakken

**Core Description Profile**

- **HST**: Lodgpole Prograding Inland Deposits
- **LST**: Correlative Conformity
- **TST**: Transgressive Surface of Erosion
- **MFS**: Maximum Flooding Surface (false Bakken)
- **MRS**: Maximum Regressive Surface
End of Core at 11,571 ft

Three Forks

Photo 6
Lower Three Forks

Birdbear

Core Photographs

Correlative Conformity
End of Core at 11,571 ft
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Modified from Nordeng et al., 2015

Figure 3
EXPLANATION

CC - Correlative Conformity
FB - False Bakken
LP - Lodgepole
MFS - Maximum Flooding Surface
MB - Middle Bakken
MRS - Maximum Regressive Surface
TSE - Transgressive Surface of Erosion
UBS - Upper Bakken Shale

Highstand Systems Tract
Transgressive Systems Tract
Lowstand Systems Tract

Cored Interval: 11,228 - 11,282 ft.
SWSE Sec. 22, T152N, R99W
Continental Resources, Inc.
Charlotte 1-22H

Cored Interval: 11,282 - 11,328 ft.

EXPLANATION

LBS - Lower Bakken Shale
MB - Middle Bakken
MRS - Maximum Regressive Surface
SU - Subaerial Unconformity

- Highstand Systems Tract
- Transgressive Systems Tract
- Lowstand Systems Tract
MTF - Middle Three Forks
SU - Subaerial Unconformity
UTF - Upper Three Forks

EXPLANATION
MFS - Maximum Flooding Surface
MTF - Middle Three Forks
SU - Subaerial Unconformity
UTF - Upper Three Forks

Highstand Systems Tract
Transgressive Systems Tract
Lowstand Systems Tract

SWSE Sec. 22, T152N, R99W
Continental Resources, Inc.
Charlotte 1-22H

Cored Interval: 11,382 - 11,410 ft.
SWSE Sec. 22, T152N, R99W
Continental Resources, Inc.
Charlotte 1-22H

Cored Interval: 11,410 - 11,464 ft.

EXPLANATION

LTF - Lower Three Forks
MFS - Maximum Flooding Surface
MRS - Maximum Regressive Surface
MTF - Middle Three Forks
SU - Subaerial Unconformity

Highstand Systems Tract
Transgressive Systems Tract
Lowstand Systems Tract
SWSE Sec. 22, T152N, R99W
Continental Resources, Inc.
Charlotte 1-22H

Cored Interval: 11,464 - 11,510 ft.

EXPLANATION

LTF - Lower Three Forks

Lowstand Systems Tract
SWSE Sec. 22, T152N, R99W
Continental Resources, Inc.
Charlotte 1-22H

Cored Interval: 11,510 - 11,564 ft.

LTF - Lower Three Forks
Lowstand Systems Tract
SWSE Sec. 22, T152N, R99W
Continental Resources, Inc.
Charlotte 1-22H

Cored Interval: 11,564 - 11,571 ft.

EXPLANATION
BB - Birdbear
CC - Correlative Conformity
LTF - Lower Three Forks

Lowstand Systems Tract
NDIC File No: 12772  API No: 33-053-02308-00-00  County: MCKENZIE  CTB No: 112772  
Well Type: OG  Well Status: DRY  Status Date: 4/29/1991  Wellbore type: HORIZONTAL  
Location: NWNE 12-146-99  Footages: 660 FNL 1980 FEL  Latitude: 47.485595  Longitude: -103.234115  
Lateral 1 Start Coordinates 16 N 130 W From Wellhead, End Coordinates 1903 S 272 W From Wellhead  
Lateral 2 Start Coordinates 15 N 130 W From Wellhead, End Coordinates 1127 S 519 W From Wellhead  
Current Operator: AMERICAN HUNTER EXPLORATION LTD.  
Original Operator: AMERICAN HUNTER EXPLORATION LTD.  
Current Well Name: AHEL ET AL GRASSEY BUTTE 12-31 H3  
Original Well Name: AHEL ET AL GRASSEY BUTTE #12-31 H3  
Elevation(s): 2599 KB  Total Depth: 12164  Field: WILDCAT  
Spud Date(s): 11/7/1989  
Digital or Image Log(s) available: CAL 3.4MB, CND 4.9MB, CYB 1.1MB, DSW 9MB, DTS1 473KB, DTS2 785KB, DTS3 556KB, DTSM 5MB, GR 145KB, GWD1 1.1MB, GWD10 206KB, GWD2 1.1MB, GWD3 417KB, GWD4 332KB, GWD5 234KB, GWD6 676KB, GWD7 685KB, GWD8 452KB, GWD9 234KB, NGS 1.7MB, PHI 9.3MB  
Formation Tops  
T-S 7185  PM-MK 7637  PM-OP 7691  PM-EBA 7977  PN-T 8480  M-EBS 8610  
M-KL 8926  M-MD 9072  M-MDR 9610  M-MDLS 9675  M-MDFA 9868  M-MDFY 10046  
M-MDLP 10380  MD-B 11240  D-TF 11308  
Casing String(s): 9.625" 2421'  7" 11823'  
Completion Data  
Cumulative Production Data  
Pool: BAKKEN  Cum Oil: 0  Cum MCF Gas: 485  Cum Water: 0  [Interactive Performance Curve] [PDF Curve]  
Production Test Data  
IP Test Date: 4/9/1990  Pool: BAKKEN  IP Oil: 10  IP MCF: 0  IP Water: 0  
DST: 11230-11270  Recovery: ** MISRUN **, REVERSE SUB PINS BROKE.  
DST: 11223-11270  Recovery: 100' INVERT DRILLING MUD - SAMPLER: 0.23 CF GAS, 2400 CC MUD  
DST: 11705-11823  Recovery: 20 BBLS GAS CUT MUD, 10 BBLS HIGH GAS CUT OIL, (CASED HOLE DST) - SAMPLER: SAMPLER RESULTS NOT GIVEN
NWNE Sec. 12, T146N, R99W
American Hunter Exploration Ltd.
Grassy Butte 12-31 H3

Cored Interval: 11,239 - 11,270 ft.

EXPLANATION

CC - Correlative Conformity
LP - Lodgepole
MFS - Maximum Flooding Surface
MRS - Maximum Regressive Surface
MB - Middle Bakken
UBS - Upper Bakken Shale
NWNE Sec. 12, T146N, R99W
American Hunter Exploration Ltd.
Grassy Butte 12-31 H3

Cored Interval: 11,299 - 11,330 ft.

EXPLANATION

Acadian Unconformity
MRS - Maximum Regressive Surface
UTF - Upper Three Forks
PH - Pronghorn
SU - Subaerial Unconformity
Figure 4
## Gamma Ray and Resistivity Logs

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<th>Core Depth</th>
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<th>Gamma Ray 160</th>
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### Systems Tracts

- **Lodgpoloe**
- **Bakken**
- **Three Forks**
- **Increased Anhydrite Zone**
- **Sabhka (Stillstand)**

### Figure 5

- **HST**
- **TST**
- **LST**
- **SU**
- **CC**
- **AU/SU**
References


Skinner, O., Canter, L., Sonnenfeld, M.D., and Williams, M., 2015, Discovery of the “Pronghorn” and “Lewis and Clark” fields: Sweet-spots within the Bakken Petroleum System producing from the Sanish/Pronghorn Member NOT the Middle Bakken or Three Forks: American Association of Petroleum Geologists Search and Discovery Article #110176 (2015).

INTRODUCTION

Over a dozen horizontal wells, completed using multi-stage hydraulic fracturing, have been drilled during the past few years targeting the Midale-Rival section within the Portal-Flaxton field area (Figs. 1 and 2). Production results from these wells have been encouraging (e.g. Fig. 3). Also, several additional older horizontal Midale-Rival wells, initially completed as open-hole producers, have been re-completed using multi-stage hydraulic fracturing which has notably bolstered production (e.g. Fig. 4). This emerging Midale-Rival play appears to be the first successful augmentation of horizontal drilling and hydraulic fracturing within the Mississippian Madison Group for the North Dakota portion of the Williston Basin.

Across western and north-central North Dakota, over 1 billion barrels of oil (BBO) have been produced from approximately 6,100 Madison wells (Fig. 5) (NDIC, 2018). Vertical well oil production from Madison reservoirs began in the early 1950’s and horizontal Madison wells (non-hydraulically fractured) started emerging during the late 1980’s to early 1990’s (LeFever, 1992). As the Midale-Rival play continues to develop, renewed interest in the Madison Group across North Dakota’s portion of the basin may follow. The following core workshop material will examine two cores, including: 1) a representative core of the Midale-Rival play from the Flaxton Field of northern Burke County, the northeastern flank of the basin, and 2) a core spanning the majority of the greater Ratcliffe Interval (including the Midale) from southwestern Williams County, located towards the central portions of the basin. Comparison of these two cores will highlight facies changes within the Midale subinterval, help further develop a regional stratigraphic framework of the Ratcliffe Interval, and provide insights into the emerging Midale-Rival horizontal play as well as future continued exploration and development of Madison reservoirs.

STRATIGRAPHY

The Midale subinterval forms the base of the Ratcliffe Interval, which is Mississippian in age and, depending on the stratigraphic position of the deepest evaporite bed, ranges from being part of the Charles Formation to part of the Mission Canyon Formation of the Madison Group (Fig. 1) (Cook, 1976; LeFever and Anderson, 1986). The Ratcliffe has been partially divided into four formal to informal subintervals within the central portions of the Williston Basin, which include in ascending stratigraphic order: Midale, Berentson, Alexander, and Flat Lake (Fig. 1) (Hendricks, 1987; Nordeng, 2007). These four formal/informal units have been described and interpreted as shallowing upward subintervals that grade from sabkha environments in the east to open marine carbonate environments in the central, western portions of the basins (Hendricks, 1987). Further north, within the Flaxton Field area, the Midale is interpreted to record an initial transgression followed by a regression (Lindsay, 1985). The regressive portion of the Midale includes: burrowed dolomitic limestone beds deposited within a low-
Figure 1. Generalized stratigraphic column for the Mississippian Mission Canyon and Charles Formations in North Dakota. Formally recognized (by the state of North Dakota) intervals that comprise these formations include in ascending order: Tilston, Frobisher-Alida, Ratcliffe, and Poplar. Also displayed are the formal Midale and Rival subintervals, which reside at the base of the Ratcliffe and top of the Frobisher-Alida Intervals, and the more semi-formal Berentson, Alexander, and Flat Lake subintervals proposed by Hendricks (1987).

Figure 2. Field map of northern Burke County, North Dakota showing the location of Madison horizontal wells with open-hole completions (light orange lines), horizontal wells with initial open-hole completions that have been re-completed with multi-stage hydraulic fracturing (thick red lines), and recent horizontal Midale-Rival wells completed with multi-stage horizontal fracture completions (bold black lines). Most of the Madison horizontal wells with open-hole completions displayed are positioned within the Rival subinterval. Small grey circles depict vertical wells that have produced from Madison Group reservoirs, including the Midale and Rival subintervals. The yellow star depicts the location of the Faith #1 well. Blue squares show the locations of towns in the map area.
Figure 3. Monthly production diagram for Petro Harvester’s Busch 32-1H (Sec. 5, T163N, R92W; NDIC: 28214; API: 33-013-01792-00-00), which was drilled with a ~5,400 ft. lateral in the Rival and completed using multi-stage hydraulic fracturing.

Figure 4. Monthly production diagram for the Nelson Unit 1 (Sec. 2, T162N, R91W; NDIC: 16220; API: 33-013-01353-00-00), which was initially drilled in 2006 with two ~1-mile long horizontal laterals targeting the Rival. The production was from open-hole completions until the well was recompleted in late 2016 using multi-stage horizontal fracturing, which reported was recompleted on just one of the two mile-long laterals. Monthly production averaged 5-6 barrels of oil per day (BOPD) prior to the recompletion, and afterwards reached monthly averages of ~147 BOPD before leveling off around 50-70 BOPD for the past several months.

Figure 5. Madison production map for central and western North Dakota. Black circles show the distribution of oil and gas wells that have produced from Madison reservoirs, including the Charles, Mission Canyon, and Lodgepole Formations. Reference index map in relation to the Williston Basin and North America are displayed in the bottom right hand corner. Green outlined and shaded area shows the location of the Figure 2 map area. The pink outlined area indicates the Figure 9 map area.
energy restricted nearshore marine setting, laminated to thinly bedded dolostone deposited within a peritidal setting, and nodular- to laminate-bedded dolomitic anhydrite (Lindsay, 1985).

The Rival subinterval, also referred to informally as the Nesson, is generally placed within the Frobisher-Alida Interval which directly underlies the Ratcliffe and is part of the Mission Canyon Formation in western North Dakota (Fig. 1) (Cook, 1976). The Mission Canyon Formation has been described as a regressive-shoaling upward carbonate to anhydrite sequences (Lindsay, 1987), similar to the overlying Ratcliffe Interval. The upper several feet of the Rival subinterval within the Flaxton Field area has been interpreted as a minor transgressive event, were oolitic/peloidal lime packstone-grainstone beds overlay nodular (Sabkha) anhydrite (Lindsay, 1985).

**RATCLIFFE PRODUCTION**

*Northern Burke County – Northern Flank*

The Flaxton Field was discovered in 1956 with the completion of the Texota Oil Company 1 Sorum (SESE Sec. 23, T163N, R92W), a vertical well which initially produced 80 BOPD (barrels of oil per day) from the Rival subinterval (Voldseth, 1987) (Fig. 1). The Flaxton Field has been described as a combination structure-stratigraphic trap (Voldseth, 1987). Unitization and water flooding was attempted within the Flaxton and surrounding oil fields (Lindsay, 1985). However, with the exception of the Rival Field, water flooding for secondary recovery was marginally successful at best due to reservoir heterogeneity within the Rival-Midale section (Lindsay, 1985). Addiotion oil reserves were later discovered in the Flaxton Field within various subintervals of the underlying Mission Canyon Formation (Voldseth, 1987). Horizontal well drilling with open-hole completions began during the 1990’s and continued through the 2000’s, which included some horizontal re-entries of pre-existing vertical wells. These horizontal wells primarily targeted the upper Rival and yielded varying results, which include multi-lateral wells that have cumulatively produced upwards of 200+ MBO (thousand barrels of oil) and are still actively producing.

Most recently, ~1-2 mile long horizontal wells with multi-stage hydraulic fracture completions are being drilled targeting the Midale-upper Rival section. The initial horizontal Midale-Rival wells with hydraulic fracture completions were drilled with ~1 mile laterals, and more of the recent wells have ~2 mile laterals. So far there have been 13 of these Midale-Rival horizontal wells drilled and completed that are off confidential status (Figs. 2 and 3). At least 7 pre-existing horizontal Rival wells with initial open-hole completions have been re-stimulated with hydraulic fracturing (Figs. 2 and 4). Initial production from these horizontal-hydraulically fractured wells has ranged from 40 to 470 BOPD (30-day average), which is sometimes reached during the wells 2nd or 3rd month of production. Initial GOR’s have been around 1 MCF gas per BBL oil, but steadily climb during continued production sometimes reaching 5-6 MCF/BBLS.
**McKenzie-Williams Counties – Central Basin**

Both vertical and horizontal oil and gas wells have been drilled targeting the Alexander and Flat Lake subintervals within the central portions of the Williston Basin (e.g. northwestern McKenzie and southern Williams counties – Fig. 5) (Hendricks, 1987; Nordeng, 2007). Ratcliffe reservoirs in the central basin consist of burrowed skeletal dolomitic mudstones/wackestones within the Alexander subinterval and peloidal-coated grain lime packstone of the Flat Lake subinterval (Hendricks, 1987). Exploration and development was initially comprised of vertical wells until the early to middle 2000’s, when horizontal well drilling with open-hole completions emerged, including the Foreman Butte Field discovery in 2004 targeting the Flat Lake subinterval (Nordeng, 2007).

**CORE LITHOFACIES**

*Open marine facies*

The open marine facies consists of dark brown-grey to mostly dark-very dark grey, slightly argillaceous, fossil peloidal lime wackestone. Fossil assemblages often include abundant brachiopods and crinoids, moderate amounts of rugose coral, and occasional tabulate coral (e.g. Fig. 6A). Weak to moderately pronounced wispy laminations are commonly present which are discontinuous, approximately horizontal, gently curvy, and non-parallel in texture. Slight to moderate bioturbation (bioturbation index: 2-4) with horizontal to inclined burrows that are millimeter-scale in diameter. Beds of fossil packstone-grainstone are sometimes present both as occasional thin, intermittent beds (≤2 inch thick) as well as thicker beds, more prevalent beds up to several feet in thickness.

The fossil assemblages of this facies reveal that deposition very likely took place under normal marine (water salinity) conditions. Also, the overall matrix (mud) supported texture suggests a subtidal/below normal fair weather wave base setting. Occasional thin beds of fossil packstone-grainstone indicate possible periodic storm deposition, placing water-depth above storm wave base. The thicker beds of fossil packstone-grainstone are suggestive of a higher energy environment proximal to the open-marine subtidal setting.

*Restricted facies*

The restricted facies is comprised of medium to medium/dark tan-brown, bioturbated to laminated lime wacke-mudstone to packstone. This facies is commonly dolomitic limestone, but overall ranges from non-dolomitic limestone to dolostone. Laminations, when present, are horizontal, parallel in part, flat to gently wavy, and discontinuous (e.g. Figs. 6B and 6C). Bioturbation index varies from 2 to 6 which can include Zoophycos and Planolites (Fig. 6C). Fossil assemblages more commonly include ostracods and small, unidentifiable shell fragments. Occasionally individual to minor amounts of crinoid stems, rugose coral, and/or brachiopod shells can be present.

The overall matrix dominated texture of the facies as well as the abundance of burrows suggests deposition occurred in a subtidal, below normal fair weather wave base setting. Elongate Planolites and Zoophycos burrows, as well as the negligible open marine fauna, indicate a restricted water setting.
Figure 6. Core photographs from the Midale-Rival subintervals, including: A) argillaceous fossil lime wackestone with crinoids (CR) and brachiopods (BR) (Midale), B) massive (heavily burrowed) fossil-peloidal wacke-packstone (borderline grain supported) (Midale), C) bioturbated fossil-peloidal dolomitic lime wackestone, (Midale) and D) massive peloidal lime packstone-graintstone (Rival/Midale).
(Hendricks, 1987), where reduced oxygen conditions and/or increased water salinity caused by the restriction of marine water circulation made conditions too harsh to support open marine fauna. The occasional crinoid, brachiopod, or rugose coral fragment may have simply washed in during a high-energy storm event.

**Peloidal-ooilitic packstone-grainstone**

The peloidal-ooilitic packstone-grainstone light to very dark tan-brown, greyish in part, peloidal lime packstone to grainstone (Fig. 6D & Fig. 7A). Peloids are typically very round and fine grained in size, and ooids are sometimes present in variable amounts. This facies is typically massive in texture but can also display weakly to moderately developed laminations that are semi-continuous to discontinuous and wispy to flat in texture. Low angle cross-bedding is occasionally present. Fossil content is overall minimal. Caliche (calcite cement) may locally be present within portions of this facies (e.g. Fig. 7A).

The grain-supported texture consisting of round peloids of comparable size (typically fine grained) indicates deposition within a relatively high-energy, above normal fair weather wave base setting that has concentrated the rounded peloid grains. Occasional ooids and/or oolitic laminations-beds further suggest a high-energy setting. Lindsay (1985) suggested that peloids within the Flaxton Field area were originally ooids that had undergone diagenic alteration to lose their interval concentric ring texture. Caliche, when present indicates periods of subaerial exposure.

**Microcrystalline dolostone facies**

The microcrystalline dolostone facies is composed of light to medium tan-brown, finely laminated to massive in texture, micro- to finely crystalline dolostone (Fig. 7B-C). Facies also displays occasional wave ripple laminae (Fig. 7B) as well as cross-bedding (Fig. 7C). Some of the finely laminated texture appears to be microbial in origin. Distinct horizontal burrows are sometimes present.

Based upon some burrows being preserved and the inconsistent wave ripple laminae texture, deposition of this facies may have partly occurred between storm wave base and normal fair weather wave base, where higher-energy events (storms) occurred intermittently. Also, where laminae texture is more consistent and displays cross-bedding, deposition may have occurred above normal, fair weather base. Negligible open marine fauna indicates facies is not proximal to open marine conditions. Microbial laminae, when/if present, would indicate shallow water with overall calm/low-energy conditions.

**Anhydritic facies**

Anhydrite varies from nodular (chicken-wire) to laminated-bedded in texture and is typically very light to dark grey in color (e.g. Fig. 7D). The anhydrite is also commonly dolomitic to occasionally calcareous in part and can be interbedded with microcrystalline tan-brown dolostone as well as grey argillaceous lime mudstone-calcareous shale.
Figure 7. Core photographs of the Midale-Rival subintervals: A) fossil peloidal lime packstone-grainstone with caliche (CL) cement (Rival), B) ripple laminated silty dolostone, C) finely laminated (microbial?) dolostone displaying possible cross-bedding, and D) nodular (chicken-wire texture) dolomitic anhydrite (Rival).
The prevalence of the nodular, chicken-wire texture within the Ratcliffe anhydrite beds, as well as their spatial location around the margins of the basin point to deposition within a sabkha setting (Warren and Kendall, 1985). The anhydrite with laminated to bedded texture may represent deposition in isolated salina depressions along the otherwise sabkha coastline (Warren and Kendall, 1985).

**CORE NOTES:**

Monsanto’s Faith #1 (NDIC: #9797)

*Rival Sedimentology*

The Rival section within the Flaxton Field area is comprised of mostly anhydrite overlain by several feet of moderately porous peloidal wacke-packstone to grainstone. A lag deposit that includes rip-up clasts is sometimes present between the upper Rival limestone and underlying anhydrite within the Flaxton Field area. Overall, the upper Rival limestone grades upwards from wacke-packstone at the base into peloidal packstone-grainstone near the top. The Rival anhydrite (sabkha) section undergoes a facies changes towards the southwest, transitioning into carbonate facies, which may have implications with the stratigraphic trapping of hydrocarbons within the upper Rival-Midale section. Lindsay (1985) interpreted that the upper Rival section represents a minor transgressive event.

**Midale Sedimentology**

An initial transgression (transgressive systems tract) is interpreted where peloidal packstone-grainstone at the base of the Midale transitions upwards into a two-foot thick bed of dark grey, slightly argillaceous fossil peloidal lime wackestone (open marine facies) with abundant amounts of marine fossils (e.g. brachiopods and crinoids). The two-foot thick grey wackestone with open marine fossils is interpreted to represent maximum flooding as it is believed to be the deepest water deposit of the Midale section and is prevalent throughout the Flaxton-Portal Field area.

Following the maximum flooding, the majority of the remaining overlying Midale section represents an overall normal regression (highstand systems tract) (Figs. 8-10). Open marine fossils disappear upwards in section, replaced by bioturbated dolomitetic (restricted facies) and later anhydrite beds. The middle of the Midale is comprised largely of bioturbated fossil peloidal dolomitic lime wacke-mudstone to packstone. This facies is partially dolomitized based on the wireline log signature and a reduced, but still persistent reaction to HCl acid, and grain density values from standard core analysis data that are typically intermediate between calcite (2.71 g/cm³) and dolomite (2.84 g/cm³). Fossil assemblages are largely small, unidentifiable shell fragments with a few discernable ostracods. Elongate *Zoophycos* and *Planolites* burrows are sometimes present which, along with the limited fossil content, may be evidence for a restricted marine depositional setting (Hendricks, 1987). The prevalence of preserved burrow structures and generally matrix supported texture indicates subtidal, below normal fair weather wave base deposition. At least one re-flooding event occurs in the middle Midale where a ~1 foot bed of grey fossil wackestone with moderate amounts of open marine fossils occurs.
The bioturbated wacke-packstone beds are overlain by massive to finely laminated microcrystalline dolostone that display wave ripples and cross-bedding, indicative of shallower water depth with at least intermittent high-energy. Some of the fine laminations may be microbial in origin, which point again to shallower depths. Anhydritic cryptocrystalline dolostone and dolomitic anhydrite displaying nodular (chicken-wire) to laminated/bedded texture form the top of the Midale Section as well as the overlying Berentson. The stratigraphic positioning (top of section), special location (appears near base margins), and nodular texture of the anhydrite suggests a Sabkha-type depositional origin (Warren and Kendall, 1985). Many of the described facies and depositional interpretations above are overall comparable with those of Lindsay (1985), who also examined the Rival-Midale of northern Burke County.

Reservoir Summary

The Midale-Rival reservoir interval consists of up to four distinct porous reservoir beds that vary in lithology from peloidal lime packstone (Rival) to bioturbated dolomitic lime wacke-packstone (middle Midale) to microcrystalline dolostone (upper Midale). The basal Midale-upper Rival contains approximately 8-9 feet of peloidal wacke-packstone to grainstone with 4-8% porosity and permeability values of generally ≤0.1 millidarcy. Oil saturations range from 1% to 18% with associated water saturations of 30-67%. The middle Midale is primarily comprised of light/medium tan bioturbated fossil peloidal dolomitic lime wacke-mudstone to mudstone beds with 8-22% porosity and permeability values of 0.1 to 0.6 millidarcies. Core plug oil saturations are ~5-25% with water saturations of ~50-70%. Near the top of the Midale, just below the dolomitic anhydrite, permeability values climb above 1 millidarcies along with higher core plug water saturations (~80-90%). Separating the four distinct beds described above are lower porosity lime wacke-mudstone beds that exhibit lower core plug porosity and permeability values coupled with lower oil and higher water saturations. While this reservoir summary is based upon the Faith #1 core, surrounding Midale-Rival cores are very similar in lithology and reservoir properties.

Gulf Oil's Gorder #1-19-2B (NDIC: #7926)

Within the Gorder #1-19-2B, the entire Midale and overlying Berentson subintervals (>60 ft. thick) are almost entirely comprised of the open marine facies, which is the same facies that was only ~2 ft. thick near the base of the Midale within the Faith #1 core. Meanwhile, the overlying Alexander subinterval largely consists of the bioturbated peloidal dolomitic wacke-mudstone to packstone, the restricted facies that is near identical to the Midale reservoir of the Faith #1 core. The middle to upper portions of the Flat Lake section are composed of peloidal to oolitic packstone-grainstone, higher energy deposits that were likely deposited more proximal to the paleo shoreline than the underlying section. Just above the cored interval is a ~30 ft. thick anhydrite section that is speculated to be, at least in part, a sabkha anhydrite. Overall, the Ratcliffe Interval appears to represent one large (~400 ft. thick) shallowing upward, normal regressive sequence within the central portions of the basin, where open marine deposits (Midale-Berentson) transition upwards into restricted and proximal carbonates (Alexander-Flat Lake) and eventually Sabkha anhydrite-dolostone. The shallowing upward cycle of the Midale
Reservoir Summary

The Alexander subinterval contains approximately 26 ft. net thickness of oil-stained, moderately porous (4-16%) bioturbated dolomitic lime wacke-mudstone to packstone with overall low permeability (0.01-0.6 millidarcies). Core plug oil saturations are generally 6-20% with 50-60% water saturations. The Alexander reservoir beds are similar to the middle Midale beds of the Flaxton Field area in both lithology and reservoir quality, although the Alexander beds have slightly lower porosity and permeability overall but exhibit more pronounced oil-staining in the Gorder core and slightly higher core plug oil saturations. The overlying Flat Lake subinterval contains additional potential pay comprised of oil-stained oolitic peloidal lime packstone with porosity (log) values of up to ~15% and low permeability (<0.13 millidarcies) and similar oil-water saturations to the moderately porous beds of the underlying Alexander subinterval. The Flat Lake packstone-grainstone beds are comparable in lithology and reservoir quality (porosity and permeability) to the upper Rival limestone section of the Flaxton Field area. Potential net-pay of the upper Berentson-Alexander-Flat Lake subintervals may be upwards of 40+ ft. based on oil staining and standard core analysis data in conjuncture with wireline logs.

Additional Ratcliffe cores across southwestern Williams and northwestern McKenzie counties display comparable facies, lithologic stacking patterns, and reservoir qualities. However, notable variations do occur that include the quantity (net-thickness) of the reservoir facies.

CONCLUDING REMARKS

The Ratcliffe Interval is comprised of one large sequence of deposition, where the initial maximum flooding event occurred near the base of the interval (basal Midale) followed by an overall normal regression with numerous parasequences caused by brief phases of re-flooding. Following the initial flooding of the basin during Ratcliffe deposition, a restricted/protected carbonate platform developed along the coastline in present-day northern Burke County, which was proximal to an open marine, inland seaway. During continued deposition, the restricted carbonate platform environment appears to have prograded basinward during normal regression as the basin infilled with sediment. Restricted carbonate platform deposits occur within the Midale subinterval on the margins of the basin, the overlying Alexander subinterval near the basin-center, and potentially may occur within the intermediate Berentson subinterval in between the basin margins and center.

Sedimentary deposits from the restricted platform include bioturbated peloidal dolomitic lime wacke-packstone beds that are moderately to highly porous (4->20%), but with generally low permeability (≤1 millidarcy). The overall low permeability has likely reduced the productiveness of these reservoir beds with vertical well completions. Developmental horizontal drilling coupled with hydraulic fracture stimulation is beginning to expand within the Midale subinterval (basal Ratcliffe) within the northeastern flank of the Williston Basin. The Midale undergoes a significant facies change from the...
Figure 8. Depositional model for the Midale subinterval and greater Ratcliffe Interval showing the lateral transition of time equivalent facies from Open Marine to Protected/Restricted Shelf (reservoir) to Sabkha anhydrite (hydrocarbon seal). During deposition of the Midale, as well as the overlying Ratcliffe section, these facies appear to have migrated (moved) towards the central portions of the Williston Basin during a normal regression (highstand systems tract).

Figure 9. Generalized facies map for the Midale subinterval. The “Open Marine Facies” area (blue) represents where the Midale is composed primarily of the dark grey lime wackestone with abundant marine fossils (e.g. Fig. 6A), which does not appear to constitute hydrocarbon reservoir rock. The “Restricted Facies” area (orange) depicts where the Midale section contains significant amounts of bioturbated dolomitic to lime wackestone to packstone and various dolostone facies (e.g. Fig. 6B-D and 7A-C) which serves are reservoir rock for oil and gas productive Midale wells. The “Transitional Zone” area (blue and orange diagonals) contains an interbedding of the Open Marine and Restricted facies in relatively comparable proportions. Green stars depict the two wells-cores reviewed in this workshop chapter. Yellow stars depict locations of additional Ratcliffe cores examined to date by the author.
Figure 10. Cross-section between well #7926 and #9797 showing schematic facies correlations/changes.
northeastern flank towards basin-center as it transitions from containing porous dolomitic reservoir beds (restricted platform) to consisting almost exclusively of low porosity limestone (open marine). However, the restricted reservoir facies occurs near basin-center within the overlying Alexander subinterval, where it has shallowed stratigraphically in Ratcliffe section. Therefore, potential exists for unconventional-style exploration and development to expand spatially and stratigraphically beyond the Midale of northern Burke County and into overlying Ratcliffe subintervals across the Williston Basin.

REFERENCES


Lindsay, R.F., 1985, Rival, North and South Black Slough, Foothills and Lignite Oil Fields: their depositional facies, diagenesis, and reservoir character, Burke County, North Dakota: The Society of Economic Paleontologists and Mineralogists (SEPM), Rocky Mountain Carbonate Reservoirs, p. 217-263.


NDIC File No: 9797  API No: 33-013-00945-00-00  County: BURKE
Well Type: OG  Well Status: PA  Status Date: 11/21/1984  Wellbore type: VERTICAL
Location: SESE 1-163-91  Footages: 660 FSL 660 FEL
       Latitude: 48.968444  Longitude: -102.416649
Current Operator: BHP PETROLEUM COMPANY, INC.
Original Operator: MONSANTO CO.
Current Well Name: FAITH 1
Original Well Name: FAITH #1
Elevation(s): 1940 KB  Total Depth: 6000  Field: FLAXTON
Spud Date(s): 10/14/1982

Digital or Image Log(s) available: CND, CYB, DLL

Formation Tops
   T-S 5015  M-MD 5287  M-MDR 5515  M-MDFA 5705  M-MDSA 5758

Casing String(s): 9.625" 1110'  5.5" 5989'

Completion Data

Cumulative Production Data
   Pool: MADISON  Cum Oil: 184  Cum MCF Gas: 0  Cum Water: 1302

IP Test Date: 1/19/1983  Pool: MADISON  IP Oil: 1  IP MCF: 0  IP Water: 13
   DST: 5660-5715  Recovery: 12.5 BBLs SWC MUD, 2.0 BBLs SG&OC MUD -
   SAMPLER: 0.68354 CF GAS GOR 5434, 20 CC OIL, 100 CC WATER, 1610 CC MUD
   DST: 5756-5804  Recovery: 2.35 BBLs GAS & SULFUR WATER CUT MUD -
   SAMPLER: 2.62 CF GAS GOR 10400, 40 CC OIL, 1240 CC WATER
   DST: 5800-5860  Recovery: 47.8 BBLs GC SALT WATER (HIGH SULFUR CONTENT) - SAMPLER: 1.29 CF GAS GOR 4919, 100 CC OIL, 1880 CC WATER

Cores and Samples
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   Type: RS  Top: 5757  Bottom: 5857  Formation: M-MD
   Type: TS  Top: 5763  Bottom: 5800  Formation: M-MD
   Type: TS  Top: 5789  Bottom: 5847  Formation: M-MD
Mississippian - Madison Group

Charles Formation

Ratliffe Interval

Midale

F.A.

Rival

\[ \begin{array}{c|c|c}
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\hline
\text{Gamma Ray} & 6 & 75 \\
\end{array} \]

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\text{Neutron } \phi \text{ (Lime)} & 0.3 & -0.1 \\
\hline
\text{Density } \phi \text{ (Lime)} & 0.3 & -0.1 \\
\end{array} \]

\[ \begin{array}{c|c|c}
\text{S. Resistivity} & 0.2 & 2000 \\
\hline
\text{D. Resistivity} & 0.2 & 2000 \\
\end{array} \]

K.B. = 1,940 ft

F.A.

Monsanto Co.

Faith #1

33-013-00945-00-00

9797
5,700 5,675 5,650
Mississippian - Madison Group
F.A. Interval
Ratcliffe Interval
Rival
Midale subinterval
Berentson 😁

9797
33-013-00945-00-00
Monsanto Co.
Faith #1
K.B. = 1,940 ft

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Density φ (Lime)
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0.2
0.3
-0.1
0.2
0.2
-0.1
0.2

Resistivity
0.3
0.2
0.3
0.2
0.3
0.2
0.3

Core Water Sat.
100
100
100
100
100
100
100
100

Core Perm.
0.01
100
100
100
100
100
100
100

Core Porosity
0
30
30
30
30
30
30
30

3.3-013-00945-00-00
Monsanto Co.
Faith #1
K.B. = 1,940 ft
White-light grey massive nodular dolomitic anhydrite, sharp upper contact

Medium to dark brown fossil peloidal lime wacke-packstone to grainstone, lime clasts and nodules near base, massive to mottled texture, small discontinuous vugs

White-light grey massive nodular dolomitic anhydrite, sharp upper contact

Light to medium tan to grey, laminated/bedded to nodular/mottled dolomitic anhydrite, calcareous in part, occasional microbial laminae horizon

Tan brown microbial laminated dolostone, dense possibly anhydritic laminae

Tan brown peloidal wacke-mudstone, dolomitic limestone (base) to dolostone (top)

Light-medium greyish tan to tan, fossil fragmental peloidal limestone (top & base) to wacke-packstone, bioturbated (BI: 3-6), wispy laminations in part

Light-medium tan-brown fossil peloidal lime wackestone (top) to wacke-packstone (base), dolomitic in part

Medium to medium-dark grey to brown-grey wispy laminated, bioturbated (BI: 2-4) crinoid-peloidal lime wackestone

Light to medium brown weakly laminated, bioturbated (BI: 3-5), fossil peloidal dolomitic lime wacke-packstone to wacke-packstone

Medium to dark brown fossil packstone (base) overlain by laminated-bedded fossil bioturbated wacke-packstone with 2 thin grainstone beds

Dark grey wispy laminated fossil peloidal argillaceous lime wackestone with abundant crinoids and brachiopods

Medium brown fossil-peloidal packstone-grainstone (top base) to weakly laminated wackestone (middle)

Medium to dark brown fossil peloidal lime wacke-packstone to grainstone, lime clasts and nodules near base, massive to mottled texture, small discontinuous vugs

Light-medium tan-brown fossil peloidal lime wacke-packstone (top) to wacke-packstone (base), dolomitic in part

Midale subinterval

Rival

Berentson?
NDIC: 9797, API: 33-013-00945-00-00
SESE Sec. 1, T163N, R91W
Monsanto Co. - Faith #1

Core Interval 5,665-5,715 ft.
NDIC File No: 7926  API No: 33-105-00867-00-00  County: WILLIAMS
Well Type: OG  Well Status: PA  Status Date: 8/9/1982  Wellbore Ype: VERTICAL
Location: NENE 19-153-103  Footages: 660 FNL 660 FEL
Latitude: 48.066075  Longitude: -103.972914
Current Operator: GULF OIL CORP.
Original Operator: GULF OIL CORP.
Current Well Name: GORDER 1-19-2B
Original Well Name: GORDER #1-19-2B
Elevation(s): 2295 KB  Total Depth: 10010  Field: FT. BUFORD
Spud Date(s): 9/10/1980

Digital or Image Log(s) available: BCS, CND, DLL
Formation Tops
   T-S 7190  PM-MK 7485  PM-OP 7504  PM-EBA 7676  PN-T 7835  M-KL 8384
   M-MD 8525  M-MDR 9110  M-MDLS 9178  M-MDFA 9410

Casing String(s): 9.625" 2833'  5.5" 9978'

Completion Data
   Spacing: NE

Cumulative Production Data
   Pool: MADISON  Cum Oil: 5633  Cum MCF Gas: 2706  Cum Water: 5207

Production Test Data
   IP Test Date: 1/24/1981  Pool: MADISON  IP Oil: 40  IP MCF: 20  IP Water: 140

Cores and Samples
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   Type: LS  Top: 9262  Bottom: 9291  Formation: M-MD
   Type: LS  Top: 9294  Bottom: 9382  Formation: M-MD
   Type: LS  Top: 9382  Bottom: 9410  Formation: M-MD
   Type: LS  Top: 9412  Bottom: 9414  Formation: M-MD
   Type: LS  Top: 9657  Bottom: 9686  Formation: M-MD
   Type: LS  Top: 9700  Bottom: 9759  Formation: M-MD
   Type: TS  Top: 9318  Bottom: 9412  Formation: M-MD
   Type: TS  Top: 9407  Bottom: 9411  Formation: M-MD
### Gulf Oil Corp.

**Gorder #1-19-2B**

K.B. = 2,295 ft

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**Poplar Interval**

- Base of last salt

**Mission Canyon Formation**

- Charles Formation

**Middle Berenson Alexander Flat Lake**

**F.A. Rival**

**Mississippian - Madison Group**

- Midale
- Rival
Core + 4 ft. = ~log

100
90
80
70
60

Core
Depth

Lithology

Laminae
Geometry
Color
Oil Staining

Fossils
Sed.
Str.

Density $\phi$ (Lime)
0.3
0.1

Neutron $\phi$ (Lime)
0.3
0.1

Resistivity
2
2000

Medium to dark grey fossil lime wackestone to argillaceous lime wackestone, fissile in part, laminated to thinly bedded, continuous - flat lamination texture in middle and top of section

Medium/dark tan-brown fossil peloidal packstone, mostly fine grain size, massive, may be matrix supported in part, abrupt contacts

Dark to very dark grey peloidal fossil wacke-mudstone to wacke to wacke-packstone/packstone, - horizontal - discontinuous - parallel to sub-parallel - wispy laminae, weakly to moderately bioturbated disrupting laminae texture, horizontal and vertical fractures

Medium to medium dark/brown, finely crystalline fossil peloidal lime wacke-packstone to packstone-grainstone, horizontal to slightly inclined laminae, possibly horizontal burrowing, intermediate contacts

Medium/dark grey to mostly dark very grey slightly argillaceous fossil lime wacke-mudstone to wackestone with occasional thin beds of apparent packstone, finely laminated to thinly bedded, sub horizontal - non-parallel - gently wavy - wispy laminae, occasional vertical and horizontal fractures (white mineralization along fracture planes)

Medium tan-brown, fossil fragmental peloidal to possibly oolitic lime packstone to grainstone, weakly laminated to massive/bedded, stylolites common in basal two-thirds of section and small vugs present in upper few feet, vertical fractures
#7926
33-105-00867-00-00
Gulf Oil Corp.
Gorder #1-19-2B
K.B. = 2.295 ft

## Berensson subinterval
- Medium tan-brown peloidal lime wacke-packstone, laminae texture ranges from wispy to flat to irregular-discontinuous, abrupt but conformable appearing contacts
- As below

## Alexander subinterval
- Medium tan-brown bioturbated to laminated silty dolo wacke-mudstone to wackestone, calcareous near top and base, laminae are approximately horizontal - gently curvy - irregular - discontinuous
- As below

## Core + 4 ft.
- Core Depth
- Lithology
  - Medium tan-brown peloidal lime wacke-grainstone/grainstone
  - Dark brown-grey massive peloidal lime wacke-mudstone
  - Medium tan-brown bioturbated to laminated silty dolo wacke-mudstone to wackestone, calcareous near top and base, laminae are approximately horizontal - gently curvy - irregular - discontinuous
  - Medium tan-brown bioturbated to laminated silty peloidal-fossil fragmental dolomitic lime to calcareous dolo wacke-mudstone to wacke-packstone, interbedded with dark brown-grey massive fossil lime wacke-mudstone
  - Dark brown-grey weakly/poorly laminated fossil-fossil fragmental peloidal wacke-mudstone (middle) to wacke-packstone (top and base), sharp lower and gradational upper contacts
  - Medium dark tan-brown, mild to moderately bioturbated, laminated lime wackestone to possibly packstone in part, dolomitic in part, horizontal to parallel & flat to gently wavy discontinuous laminae, interbedded in upper half of section with medium dark brownish grey dense fossil lime wackestone
  - Dark to very dark grey laminated fossil peloidal lime wacke-packstone, laminae texture ranges from wispy to flat to irregular-discontinuous, abrupt but conformable appearing contacts
  - Medium to dark grey calcareous shale to argillaceous limestone, lime wacke-packstone underlain by green claystone at base, no observable fossils in shale
  - Medium grey-brown to medium dark grey fossil peloidal wacke-packstone to packstone with discontinuous wispy laminae, sharp/abrupt upper and lower contacts, dark colored and organic-rich looking laminae
  - As below
Intervals of medium tan peloidal wackestone overlain by lime-clast packstone-grainstone beds (rip-up clasts/breccia), interbedded with dark tan-brown oolitic (?) peloidal wacke-packstone.

Dark to very dark tan-brown laminated to bedded lime wacke-packstone to grainstone, occasional scour surface, possible low angle cross-bedding, finer grained within middle of section with larger grains at top and base, wispy to flat laminae/bedding surfaces.

Medium tan-brown peloidal wackestone-mudstone (base) grading upwards into oolitic peloidal grainstone (top), dolomitic packstone in middle of section.

Medium tan laminaed peloidal lime packstone-grainstone.

Tan lime clast packstone/breccia (base) overlain by oolitic (?) peloidal wacke-packstone (top) with wispy laminae and styolites.

Medium to medium/dark tan-brown fossil fragmental (?) peloidal lime grainstone grading upwards into peloidal wacke-mudstone, intermittent horizontal discontinuous wispy laminae, sharp-non-conformable upper contact.
NDIC: 7926, API: 33-105-00867-00-00
NENE Sec. 19, T153N, R103W
Gulf Oil Corp. - Gorder #1-19-2B

Core Interval 9,290-9,329 ft.
Core Interval 9,329.9,364 ft.

NDIC: 7926, API: 33-105-00867-00-00
Gulf Oil Corp. - Gorder #1-19-2B
NENE Sec. 19, T153N, R103W Core Interval 9,329.9,364 ft.
NDIC: 7926, API: 33-105-00867-00-00
NENE Sec. 19, T153N, R103W
Gulf Oil Corp. - Gorder #1-19-2B

Core Interval 9,365-9,399 ft.
NDIC: 7926, API: 33-105-00867-00-00
NENE Sec. 19, T153N, R103W
Gulf Oil Corp. - Gorder #1-19-2B

Core Interval 9,400-9,414 ft.
**Sedimentary/Core Symbols:**

- microbiolites
- wave ripple laminae
- lag
- scouring
- burrows
- Th. burrowing
  - pyrite
  - nodule/s
  - lithoclast/s
  - anhydrite nodule/s
  - Ooids
  - peloids
  - styolitic
  - contorted lam./bedding
  - Cross-bedding
- mottled
- vugs/vuggy
- Anhydritic
- Dolomitic
- Slickensides
- breccia
- rip up clast
- fossil bed
- Shells
- Brachiopod/s
- Amphipora
- Crinoid/s
- Gastropod/s
- Rugose Coral
- Tabulate Coral
- Ostracod/s
- light oil staining
- moderate oil staining
- heavy oil staining
Williston Basin Petroleum Conference 2018
Core Workshop

**Spearfish Formation**
Travis Stolldorf
North Dakota Geological Survey

1. API: 33009022460000
   NDIC: 21504
   T164N R76W S31

2. API: 33009016290000
   NDIC: 10452
   T163N R77W S29

3. API: 33009003250000
   NDIC: 1978
   T161N R79W S4

4. API: 33009016550000
   NDIC: 10845
   T160N R78W S8
The Spearfish Formation of north-central North Dakota

Introduction

Initial commercial production of the Spearfish Formation began in 1953 with the Ekrehagen 1 well in the Scandia field (NDIC Oil and Gas Division statistics). Early development focused on commingling the lower Spearfish sand (Sand D) with the underlying Madison group. This commingled play has produced over 57 MMBO (107 MMBW, 1,850 BCF) in North Dakota since 1953 (NDIC Oil and Gas Division statistics). With the advent of new drilling and completion techniques in the 2000’s, notably horizontal wells with multi-stage hydraulic fracs, Spearfish development evolved into a standalone play. In 2010 the first horizontal well exclusively targeting the Spearfish, the Scandia 1-34H, was drilled and completed with a multi-stage hydraulic frac (NDIC Oil and Gas Division statistics). Between 2010 and 2014, before low oil prices drove capital allocations away from the play, over 100 horizontal wells were drilled to exploit the standalone Spearfish play. To date, these horizontal wells have produced over 3.5 MMBO (9.1 MMBW, 800 MCF) in North Dakota (NDIC Oil and Gas Division statistics). The play’s development has centered on the Spearfish Formation in north-central Bottineau County, North Dakota (Figure 1) where the formation is relatively shallow (reduced D&C costs) and rests unconformably on the Madison Group, which allows for migration of hydrocarbons from the underlying Madison Group up into the Spearfish (Bachryn, 1982; Hansen, 1987).

Previous Work

The Spearfish Formation was first identified by Darton (1899) based on the red outcrops near Spearfish, South Dakota. Dow (1964) provided the first detailed study of the Spearfish Formation and identified 3 distinct units: (1) lowermost gray shale and red siltstone unit (lower shale/Belfield Member), (2) a middle salt unit (Pine Member), and (3) uppermost red siltstone, shale and fine-grained sandstone unit (Saude Member). For the purposes of this study, only the Saude Member is discussed as the Belfield and Pine Members are restricted to the deeper portions of the basin in North Dakota and are not present in any of the logs or cores discussed in this study.

Figure 1. Reference map showing the extent of the study area within North Dakota. The location of cored wells used in the core workshop is represented by light blue circles. The yellow circle represents the type log location shown in Figure 2. The blue line denotes the location of the cross section shown in Figure 3.
Interpretations regarding the depositional environment of the Spearfish have evolved over the years. McCabe (1956) described the depositional setting as terrestrial, while LeFever and LeFever (1991) advocated for a complex depositional system of both marine and terrestrial environments. Several others have concluded that the Spearfish Formation was deposited along the gently-dipping eastern margin of the Williston basin in a tidal flat environment during a transgression of the Triassic sea (Husain, 1991; Musial, 1995; Sebade, 2014). Hansen (1987) compared the depositional environment of the lower Amaranth (Spearfish equivalent in Canada) to the modern, tide-dominated Colorado River delta in the Gulf of California where sediments are deposited on tidal flats. Husain (1991) concluded that the sandstones were subtidal deposits, while the siltstone and mudstones were intertidal and supratidal, respectively.

Core Observations

Four cores were described, analyzed and discussed for the core workshop (see Appendix 1). The cores were selected based on several criteria including, among others: available core analysis data, spatial diversity, producing formation and cored interval. An attempt was made during core selection to provide a representative sample of the Spearfish formation in Bottineau County, North Dakota.

Examinations of the cores presented in the workshop show a common trend for the Spearfish interval in this study area. Generally, the Spearfish interval is best described as a silty sandstone that was deposited over the Madison unconformity (Figure 2A). Sediments are typically reddish in color indicating intermittent exposure causing oxidation of the iron associated with the formation’s clay minerals. Summarized core descriptions, lithology and wireline logs are available in Appendix 1.

Figure 2. Examples of sedimentary structures viewed in core. A) Madison unconformity (dashed black line) with rip up clasts outlined in yellow; B) Laminar bedding with oil staining; C) Wavy bedding of interbedded sands and silt; D) Flaser bedding in sandstone; E) Anhydrite nodules and mottled siltstone texture in the upper shale.
The lower two thirds of the interval contain up to four, fining-upwards, sheet-like sandstone packages interbedded with siltstones (Figure 3). The sands within the Spearfish can be difficult to visually identify in core as they are typically poorly sorted and contain substantial quantities of anhydrite, silt, clay and very fine grained sands. However, the base of several of the sands observed contained small quantities of medium- to coarse-grained sand and were interpreted by Sebade (2014) as tidal channel lag deposits. Identification of these sand packages is most easily done using wireline logs in conjunction with core description and analysis.

![Figure 3. Stratigraphic column and type log with lithology and general description of the Spearfish Formation (Saude Member) (Murphy, et al., 2009).](image)

The cleanest sands are most often found directly overlying the Madison Group carbonates. Laminar bedding and oil staining is common in the sands directly overlying the Madison unconformity in the cores observed (Figure 2B). The sand packages that are not in direct contact with the Madison Group are poorly sorted and variable in color from light pink to a deep reddish-brown. Wavy bedding was the dominant sedimentary structure observed with a few occurrences of climbing ripples, flaser bedding, laminar bedding and channel lag deposits (Figures 2C and 2D). Anhydrite is present throughout the Spearfish in both cement and nodular form suggesting periods of exposure during deposition.

The upper third of the Spearfish is primarily a siltstone with a mottled texture (Figure 2E). Due to the high abundance of silt and clay, the upper section has not been targeted as a hydrocarbon reservoir. This study found no oil staining or other evidence that would suggest that the upper third of the Spearfish would be a viable reservoir. Thus, the following section will focus on the stratigraphy of the lower hydrocarbon-bearing portion of the formation.
Stratigraphy

The lower two thirds of the Saude Member of the Spearfish Formation in north-central North Dakota can be subdivided into sand packages (Figure 3) using gamma ray (GR) logs and core analysis. This section contains up to four separate sand packages that have been mapped across the study area (Figure 4). Sands A and B (also referred to as A Sand and B Sand; e.g. Husain, 1991; Sebade, 2014) are present in all cores and wireline logs reviewed in this study (Figure 3). Both are poorly sorted sandstones that fine upwards and prograde basinward (Figure 4). Sand C (also referred to as the “water sand”; e.g. Husain, 1991; Sebade, 2014) exhibits similar characteristics to the overlying Sand A and B when not in direct contact with the underlying Madison Group (i.e. poorly sorted and fining upwards). When Sand C is observed directly overlying the Madison, the sandstone is typically well sorted with very little silt or clay. Sand D (also referred to as the basal sand or main sand; e.g. Husain, 1991; Sebade, 2014) is well sorted with better definition of sedimentary structures such as cross-bedding and laminar bedding. Similarly, Sand D fines upwards and progrades basinward.

Most of the initial development came from wells targeting both Sand D and the underlying Madison Group as a commingled play. More recently, the Spearfish has been targeted as a standalone play. Operators in the standalone play have focused on Sands A and B while avoiding the lowermost Sand C due to its proximity to the Madison and the potential for high water production if Madison aquifers are stimulated with hydraulic fractures (Birchard, 2014).

Figure 4. Stratigraphic cross-section of the Spearfish Formation (Saude Member) from west (A) to east (A’) showing continuous sand packages prograding across the study area from the basin margin in the east to the deeper portions of the basin in the west. Note that both Sands C and D pinch out to the east. In our study area (Figure 1), the Spearfish Formation (Saude Member) thickens from approximately 90 feet in the eastern portion of the study to over 300 feet in the west (Figure 3).
References


Summary

Based on previous work and observations made from core and wireline log analysis, this study supports the interpretation that the Spearfish was deposited in a tidal flat environment during a transgression in the Triassic. Oxidized sediments, giving the formation its distinct reddish color, and abundant anhydrite are representative of periods of exposure during deposition and likely accumulated in an arid climate on a broad, gently-dipping plain in a shallow, restricted, hypersaline sea. Laterally continuous sands in the lower two thirds of the Spearfish with observable changes from lenticular to wavy bedding suggest that sediments were deposited in subtidal to intertidal environments (Reineck and Wunderlich, 1968). The mottled siltstones in the upper third of the Spearfish are interpreted to be supratidal deposits (Sebade, 2014).

Hydrocarbons have been produced from the Spearfish only in a very small area of the Williston Basin in North Dakota. The first production from the Spearfish was a commingled stream with Sand D and the underlying Madison carbonates. The more recent standalone Spearfish play has seen Sands A and B primarily targeted. While this may be the only commercially productive part of the basin for the Spearfish, no data are available for its potential in other parts of North Dakota. Future work will seek other potentially productive areas with North Dakota’s portion of the Williston Basin.
Appendix 1

Core 1 – Scout Ticket

NDIC File No: 21504  API No: 33-009-02246-00-00  County: BOTTINEAU
Well Type: OG  Well Status: IA  Status Date: 4/15/2018  Wellbore type: HORIZONTAL
Location: SWNW 31-164-76  Latitude: 48.990014  Longitude: -100.576056
Current Operator: CRESCENT POINT ENERGY U.S. CORP.
Original Operator: LEGACY OIL & GAS ND, INC.
Current Well Name: LEGACY ET AL BERGE 5-31H
Original Well Name: LEGACY ET AL BERGE 5-31H
Elevation(s): 1,794 KB; 1,780 GL  Total Depth: 7,010’ MD  Field: NORTH SOURIS
Spud Date(s): 1/20/2012

Formation Tops

K-P: 286’ MD;  K-GH: 1,712’ MD;  K-M: 1,960’ MD;  K-IK: 2,106’ MD;  J-S: 2,439’ MD

Casing String(s):

8.625” – 657’MD
5.5” – 7,010’ MD

Completion Data

Pool: SPEARFISH  Perfs: 3,801’-6,869’ MD  Comp Dt: 4/9/2012

Cumulative Production Data (Pool: Spearfish)

Cum Oil: 37,174 Bbls  Cum Gas: 6,932 Mcf  Cum Water: 401,390 Bbls

Production Test Data

IP Test Date: 4/12/2012  Pool: SPEARFISH  IP Oil: 126 Bbls  IP MCF: 0  IP Water: 157 Bbls

Cores and Samples View

Type: DC  Top: 2,400’ MD  Bottom: 4,140’ MD
Type: DC  Top: 4,140’ MD  Bottom: 6,450’ MD
Type: DC  Top: 5,850’ MD  Bottom: 7,110’ MD
Type: LS  Top: 3,030’ TVD  Bottom: 3,044’ TVD  Formation: T-S
Type: LS  Top: 3,044’ TVD  Bottom: 3,149’ TVD  Formation: T-S
Core 1 – Box Photographs

API No: 33-009-02246-00-00
NDIC File No: 21504
Core Interval: 3,030’ – 3,136’

Sand A
Sand B
Sand C
Sand D – not present
Core 1 – Wireline Log with Core Description

Core 1
NDIC: 21504
Interval Cored: Spearfish/Madison

Siltslime, red, anhydrite nodules

Silty Sandstone, light red, wavy bedding, some FG sand lenses, anhydrite nodules

Red, siltic laminations, anhydrite nodules

Low angle, trough cross-bedding, light red

Fine-grained, light red, trace anhydrite

Red, siltic laminations, wavy bedding, anhydrite nodules/lenses

Poorly sorted, very fine-to-coarse sand, anhydrite nodules

Light grey to white, medium-to-coarse-grained, rip-up clasts from underlying limestone

Limestone, massive, light grey to white, fine-grained, anhydrite beds with anhydrite filling fractures
Core 2 – Scout Ticket

NDIC File No: 10452  API No: 33-009-01629-00-00  County: BOTTINEAU
Well Type: OG  Well Status: DRY  Status Date: 7/11/1986  Wellbore type: VERTICAL
Location: NENW 29-163-77  Latitude: 48.920846  Longitude: -100.678475
Current Operator: DORCHESTER EXPLORATION, INC.
Original Operator: DORCHESTER EXPLORATION, INC.
Current Well Name: MCDONALD 21-29
Original Well Name: MCDONALD #21-29
Elevation(s): 1,527' KB  Total Depth: 4,150' TVD  Field: WILDCAT
Spud Date(s): 12/6/1983

Formation Tops

K-GH: 1,530' TVD  K-M: 1,778' TVD  K-IK: 1,956’ TVD  J-S: 2,344’ TVD
T-S: 2,904’ TVD  M-MDUN: 3,006’ TVD  M-MDTI: 3,139’ TVD  M-MDLP: 3,301’ TVD
MD-B: 3,886’ TVD  D-TF: 3,914’ TVD  D-BB: 3,955’ TVD  D-DP: 4,056’ TVD

Casing String(s):

8.625” – 266’ TVD
4.5” – 2,999’ TVD

Completion Data

Pool: SPEARFISH  Perfs: 2,955’-2,978’ TVD  Comp Dt: 7/11/1986

Cumulative Production Data (Pool: Spearfish)
Cum Oil: 456 Bbls  Cum Gas: 0  Cum Water: 0

Production Test Data
DST: 3,107’-3,140’ TVD  Recovery: 490' MC Water, 1,704' Salt Water - Sampler: 2,160 CC Water

Cores and Samples

Type: DC  Top: 1’ TVD  Bottom: 3,170’ TVD
Type: DC  Top: 3,170’ TVD  Bottom: 4,150’ TVD
Type: LS  Top: 2,945’ TVD  Bottom: 3,035’ TVD  Formation: T-S
Type: RS  Top: 2,945’ TVD  Bottom: 3,005’ TVD  Formation: T-S
Type: RS  Top: 3,005’ TVD  Bottom: 3,035’ TVD  Formation: M-MD
Core 2 – Box Photographs

API No: 33-009-01629-00-00
NDIC File No: 10452
Core Interval: 2,945’ – 3,035’

Sand A
Sand B
Sand C
Sand D – not present
Core 2 – Wireline Log with Core Description

Core 2
NDIC: 10452
Interval Cored: Spearfish/Madison

Silty Sandstone, light red-gray, very fine-grained, faint wavy bedding, anhydrite nodules

Light red with some dark red-brown silty laminations, very fine-grained, wavy bedding, anhydrite nodules

Light red, very fine-to fine-grained sand, wavy bedding, anhydrite nodules

Light red with some dark red-brown silty laminations, very fine-grained, wavy bedding, anhydrite nodules

Light red very fine-to medium-grained sand, wavy bedding, anhydrite nodules

Dolomite, gray to greenish gray, mauve to red, mottled, very anhydritic

Anhydrite, gray, sucrosic

Dolomite, buff gray
Core 3 – Scout Ticket

NDIC File No: 1978     API No: 33-009-00325-00-00     County: BOTTINEAU
Well Type: OG     Well Status: A     Status Date: 9/6/1958     Wellbore type: VERTICAL
Location: SESE 4-161-79     Latitude: 48.7936     Longitude: -100.90864
Current Operator: ENDURO OPERATING, LLC
Original Operator: THE CALIFORNIA CO.
Current Well Name: NEWBURG-SPEARFISH-CHARLES UNIT P-718
Original Well Name: ROLAND HENRY #6
Elevation(s): 1,475’ KB     Total Depth: 3,412’ TVD     Field: NEWBURG
Spud Date(s): 8/20/1958

Formation Tops

   K-GH: 1,724’ TVD     K-M: 1,993’ TVD     K-IK: 2,185’ TVD
   J-S: 2,436’ TVD     T-S: 3,187’ TVD     M-MDUN: 3,354’ TVD

Casing String(s):

   10.75” – 221’ TVD
   5.5” – 3,412’ TVD

Completion Data


Cumulative Production Data (Pool: Spearfish/Charles)

   Cum Oil: 375,027 Bbls     Cum Gas: 14,808 Mcf     Cum Water: 701,575 Bbls

Production Test Data

   IP Test Date: 9/6/1958     Pool: SPEARFISH/CHARLES     IP Oil: 61 Bbls     IP MCF: 0     IP Water: 0

Cores and Samples

   Type: C     Top: 3,331’ TVD     Bottom: 3,354’ TVD     Formation: T-S
   Type: C     Top: 3,354’ TVD     Bottom: 3,381’ TVD     Formation: M-MD
   Type: DC     Top: 320’ TVD     Bottom: 1,200’ TVD
   Type: DC     Top: 1,200’ TVD     Bottom: 3,250’ TVD
   Type: DC     Top: 3,250’ TVD     Bottom: 3,410’ TVD
Core 3 – Box Photographs

API No: 33-009-00325-00-00
NDIC File No: 1978
Core Interval: 3,330’ – 3,381’
Core 3 – Wireline Log with Core Description

Core 3
NDIC: 1978
Interval Cored: Spearfish/Madison

UWI: 33009003250000
T16N R79W S4
KB: 1,475

Silty Sandstone, very fine- to fine-grained, light red, anhydrite nodules

Grey, wavy bedding, anhydrite nodules

Light red, fine- to coarse-grained, wavy bedding, anhydrite nodules

Limestone, fine grained, light grey, anhydrite nodules

Fine grained, tan, anhydrite nodules

Fine grained, light grey, anhydrite nodules
Core 4 – Scout Ticket

NDIC File No: 10845  API No: 33-009-01655-00-00  County: BOTTINEAU
Well Type: OG  Well Status: A  Status Date: 3/15/2018  Wellbore type: VERTICAL
Location: NENW 8-160-78  Latitude: 48.703556  Longitude: -100.767734
Current Operator: 31 OPERATING, LLC
Original Operator: TURTLE MOUNTAIN GAS & OIL, INC.
Current Well Name: CHRISTENSON 1
Original Well Name: CHRISTENSON 1
Elevation(s): 1,462’ KB  Total Depth: 3,333’ TVD  Field: SOUTHWEST STARBUCK
Spud Date(s): 5/8/1984

Formation Tops
K-GH: 1,671’ TVD  K-M: 1,934’ TVD  K-IK: 2,113’ TVD  J-S: 2,416’ TVD
T-S: 3,125’ TVD  M-MDUN: 3,292’ TVD

Casing String(s):
8.625” – 323’ TVD
4.5” – 3,333’ TVD

Completion Data

Cumulative Production Data (Pool: Spearfish)
Cum Oil: 12,351 Bbls  Cum Gas: 0  Cum Water: 649 Bbls

Production Test Data
IP Test Date: 11/25/1984  Pool: SPEARFISH  IP Oil: 6 Bbls  IP MCF: 0  IP Water: 0

Cores and Samples
Type: LS  Top: 3,258’ TVD  Bottom: 3,288’ TVD  Formation: T-S
Type: RS  Top: 3,258’ TVD  Bottom: 3,278’ TVD  Formation: T-S
Type: RS  Top: 3,278’ TVD  Bottom: 3,288’ TVD
Core 4 – Box Photographs

API No: 33-009-01655-00-00
NDIC File No: 10845
Core Interval: 3,258’ – 3,288’
Core 4 – Wireline Log with Core Description

Core 4
NDIC: 10845
Interval Cored: Spearfish/Madison

Silty Sandstone, light red, anhydrite nodules
Light red, wavy bedding, anhydrite nodules
Red-brown, wavy bedding, anhydrite nodules
Light red-grey, wavy bedding, anhydrite nodules
Light red-grey, low angle laminar bedding, prevalent oil staining, trace anhydrite
Light red-grey, wavy bedding, anhydrite nodules
Limestone, light grey, anhydrite nodules