Frontier Formation
of the
Powder River Basin
Frontier Formation of the Southwestern Powder River Basin

Overview

This study of the Frontier Formation of the Southwestern Powder River Basin examines the stratigraphy, sedimentology, petrography, and oil and gas potential of the Frontier sandstones in the southwestern part of the Powder River Basin. The study area covers approximately 180 townships and more than 6400 square miles. This report, representing four man-years of geologic research, provides the explorationist with a chronostratigraphic framework for the Cretaceous Frontier Formation and its members. The Frontier study in the southwestern part of the Powder River Basin, using 962 wells, 11 measured sections, and 51 cores, establishes a stratigraphic framework that is essential for explorationists in this play.

In this study, the Frontier Formation is divided into three members, the Belle Fourche, Emigrant Gap, and Wall Creek, in ascending order. Eighteen picks were carried within the Frontier. Most were correlated throughout the study area; a few were recognized only locally. The correlated picks use bentonite beds, the tops of coarsening-upward sequences, and regionally significant unconformities. Regional cross sections and maps document the distribution of stratigraphic intervals defined by these picks throughout the southwestern part of the Powder River Basin.

In this report, the Frontier Formation is subdivided into mappable, chronostratigraphic members, which are bounded by bentonite beds, disconformities, or unconformities. This chronostratigraphic methodology facilitated mapping of time-bounded lithofacies sequences and reconstruction of paleogeography through time. Physical correlations indicate there are three regionally significant unconformities within the Frontier Formation in this area of the Powder River Basin. Two bound the Emigrant Gap Member, and the third occurs within the upper part of the Belle Fourche Member. In addition to the unconformities, the Frontier includes numerous disconformities. These most commonly occur at the tops of upward-coarsening sequences and record post-depositional erosion associated with transgression. In many instances, the amount of erosion associated with these disconformities was slight. In other cases, particularly in areas underlain by active basement structures, the amount of erosion was substantial. Reworking of sediment on these transgressive disconformities is responsible for the formation of some of the principle reservoir sandstones.

The Frontier play consists of three principal reservoir sandstone types consisting of shoreface, transgressive lags, and reworked shelf sand bodies, including prodelta "plumes." The origins and distributions of these sandstone types are portrayed within the context of the complicated transgressive-regressive history of the Frontier. The analysis of the stratigraphy, sedimentology, and petrographic characteristics in this report is designed to assist exploration and production geologists in understanding the complex stratigraphic
relationships, reservoir sandstone geometries, diagenetic history, and hydrocarbon production within the Frontier play trend. The study discusses the potential for Frontier reservoirs throughout the southwestern part of the Powder River Basin.

**Database**

- 962 - Study Wells
- 18 - Regional Stratigraphic Markers Correlated
- 11 - Outcrops Measured
- 51 - Cores Described
- 100 - Thinsections (Petrographic Study)

**Maps**

- **Regional Maps (1:96,000) (1:250,000)**
  - Isopach Maps
  - Net Sandstone Map
  - Structure Map
  - Study well Map
- **Field Study maps (1:96,000)**
  - Isopach Maps
  - Net Sandstone Maps
  - Porosity Maps
  - Structure Maps

**Cross Sections**

- 4 - Regional Stratigraphic Sections
- 2 - Field Cross Sections

**Field Studies**

Finley Draw, Crawford Draw, Spearhead Ranch, Powell, Billy Creek/Trabing

**Report Contents**

TEXT AND FIGURES - This extensively illustrated report includes discussions, figures, and color plates on: Executive Summary, Depositional Setting, Lithofacies, Stratigraphy, Depositional History, Petrography, Field Studies, Synthesis, and Exploration Potential.
CORES AND OUTCROP DESCRIPTIONS - This appendix contains descriptions of 51 cores from the study area. It also contains descriptions of 11 outcrop localities along the southwestern margin of the Powder River Basin.

STRATIGRAPHIC DATA - This file contains the stratigraphic data (9 formation tops and stratigraphic markers, and net sandstone values) and isopach values, as well as information on well name, operator, location, API number, completion date, datum, and production status for the 962 study wells.

MAPS AND CROSS SECTIONS - These appendices contain the 26 regional maps and 8 field study maps. This includes isopach maps, structure maps, net sandstone maps, and a study well map. They also include the 4 regional and 2 field cross sections.
Frontier Formation of the Powder River Basin
Frontier Formation
of the
Powder River Basin

Study
Table of Contents
TABLE OF CONTENTS
Frontier Formation - Powder River Basin

Table of Contents................................................................................................................ i
List of Maps and Cross Sections............................................................ iv
Acknowledgements..................................................................................... vi

Executive Summary

Chapter 1
Introduction.......................................................................................................................... 1-1
Depositional Setting................................................................................................. 1-1
Tectonic Setting........................................................................................... 1-2
Sea Level..................................................................................................... 1-3
Hydrographic Regime.................................................................................. 1-4
Waves and Currents............................................................................. 1-4
Tidal Range...................................................................................... 1-5
Salinities........................................................................................ 1-6
General Stratigraphy.............................................................................. 1-6
Cenomanian-Turonian Wedge..................................................................... 1-7
Turonian-Coniacian Wedge......................................................................... 1-8

Chapter 2
Procedures.......................................................................................................................... 2-1
Data Acquisition............................................................................................... 2-1
Study Wells.............................................................................................................. 2-1
Measured Outcrop Sections.................................................................................... 2-1
Cores....................................................................................................................... 2-1
Petrography............................................................................................................. 2-2
Downhole Picks....................................................................................................... 2-2
Calculation of Gross Sandstone.............................................................................. 2-2
Determination of Net Porous Sandstone................................................................. 2-3
Regional Maps......................................................................................................... 2-4
Regional Cross Sections.......................................................................................... 2-4
Detailed Study Area Maps and Cross Sections....................................................... 2-4

Chapter 3
Depositional Facies and Facies Sequences........................................................................ 3-1
Depositional Facies...................................................................................................... 3-1
Shale Lithofacies.......................................................................................... 3-2
Interbedded Sandstone and Shale Lithofacies....................................................... 3-2
Amalgamated Hummocky-Bedded Sandstone Lithofacies........................................ 3-5
Cross-Bedded Sandstone Lithofacies.......................................................... 3-7
Trough Cross-Stratified Sandstone Subfacies....................................................... 3-7
Tabular Cross-Bedded Sandstone Subfacies....................................................... 3-8
Conglomerate and Pebbly Sandstone Lithofacies............................................... 3-9
Poorly-Organized Conglomerate Subfacies....................................................... 3-10
Well-Organized Conglomerate Subfacies....................................................... 3-11
<table>
<thead>
<tr>
<th>Field/Field Trend</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crawford Draw Field</td>
<td>6-5</td>
</tr>
<tr>
<td>Ormsby Draw Field</td>
<td>6-5</td>
</tr>
<tr>
<td>Bobcat Creek Field</td>
<td>6-5</td>
</tr>
<tr>
<td>Finley Draw Trend</td>
<td>6-6</td>
</tr>
<tr>
<td>Bozeman Trail Field</td>
<td>6-6</td>
</tr>
<tr>
<td>Taylor Field</td>
<td>6-7</td>
</tr>
<tr>
<td>Moore Field</td>
<td>6-7</td>
</tr>
<tr>
<td>Avery Draw Field</td>
<td>6-8</td>
</tr>
<tr>
<td>Snake Charmer Field</td>
<td>6-8</td>
</tr>
<tr>
<td>Sand Dunes Field</td>
<td>6-9</td>
</tr>
<tr>
<td>Cole Northeast Field</td>
<td>6-10</td>
</tr>
<tr>
<td>Spearhead Ranch Trend</td>
<td>6-10</td>
</tr>
<tr>
<td>Spearhead Ranch Field</td>
<td>6-11</td>
</tr>
<tr>
<td>Phillips Creek and South Spearhead Ranch Fields</td>
<td>6-12</td>
</tr>
<tr>
<td>Powell Trend</td>
<td>6-12</td>
</tr>
<tr>
<td>BuckDraw/Moyer Draw/Nine Mile Fields</td>
<td>6-12</td>
</tr>
<tr>
<td>Powell Field</td>
<td>6-13</td>
</tr>
</tbody>
</table>

**Chapter 7**

**Synthesis**                                                                 | 7-1  |
**Frontier Depositional History**                                               | 7-1  |
**Mowry-Belle Fourche Transgression**                                           | 7-1  |
**Belle Fourche Regressions**                                                    | 7-2  |
**Late Cenomanian Transgression**                                               | 7-7  |
**Late Cenomanian Unconformity**                                                | 7-8  |
**H Sandstone Regression**                                                       | 7-9  |
**Middle Turonian Unconformity**                                                | 7-10 |
**Emigrant Gap Transgression and Regression**                                   | 7-10 |
**Wall Creek Member**                                                            | 7-11 |
**Late Turonian Unconformity**                                                   | 7-13 |
  **D Sandstone Unit**                                                           | 7-13 |
  **C Sandstone Unit**                                                           | 7-15 |
  **B Sandstone Unit**                                                           | 7-17 |
  **A Sandstone Unit**                                                            | 7-18 |
**Exploration Concepts**                                                         | 7-20 |
**Belle Fourche Member**                                                         | 7-22 |
**Emigrant Gap Member**                                                          | 7-24 |
**Wall Creek Member**                                                            | 7-24 |
  **D Sandstone Unit**                                                           | 7-25 |
  **C Sandstone Unit**                                                           | 7-26 |
  **B Sandstone Unit**                                                           | 7-29 |
  **A Sandstone Unit**                                                            | 7-29 |

**Bibliography**
LIST OF MAPS AND CROSS SECTIONS

Regional Maps - 1:96 000

Wall Creek Member
1. Gross Sandstone Isopach: A-C Interval (A sandstone unit) (1-3)
2. Gross Sandstone Isopach: C-D Interval (C sandstone unit) (1-3)
3. Gross Sandstone Isopach: D-F Interval (D sandstone unit) (1-3)

Emigrant Gap Member
1. Gross Sandstone Isopach: F-H Interval (1-3)

Belle Fourche Member
1. Gross Sandstone Isopach: H-I Interval (H sandstone unit) (1-3)
2. Gross Sandstone Isopach: L-M Interval (L sandstone unit) (1-3)
3. Gross Sandstone Isopach: N-O Interval (N sandstone unit) (2,3)
4. Gross Sandstone Isopach: O-P Interval (O sandstone unit) (2,3)

Regional Maps - 1:250 000

Wall Creek Member
1. Interval Isopach: A-C Interval
2. Gross Sandstone Isopach: A-C Interval (A sandstone unit)
3. Interval Isopach: C-D Interval
4. Gross Sandstone Isopach: C-D Interval (C sandstone unit)
5. Interval Isopach: D-F Interval
6. Gross Sandstone Isopach: D-F Interval (D sandstone unit)

Emigrant Gap Member
1. Interval Isopach: F-H Interval
2. Gross Sandstone Isopach: F-H Interval

Belle Fourche Member
1. Interval Isopach: H-I Interval
2. Gross Sandstone Isopach: H-I Interval (H sandstone unit)
3. Interval Isopach: I-K Interval
4. Interval Isopach: K-M Interval
5. Gross Sandstone Isopach: L-M Interval (L sandstone unit)
6. Interval Isopach: M-P Interval
7. Gross Sandstone Isopach: N-O Interval (N sandstone unit)
8. Gross Sandstone Isopach: O-P Interval (O sandstone unit)
9. Interval Isopach: P-Q Interval
10. Interval Isopach: Q-R Interval
General
1. Structure: Bentonite Datum within lower Cody Shale

Wall Creek Member
1. Gross Sandstone Isopach: A-B Subinterval
2. Net Porous Sandstone Isopach: A-B Subinterval
3. Isopach: B-C Subinterval
4. Gross Sandstone Isopach: B-C Subinterval
5. Net Porous Sandstone Isopach: B-C Subinterval
6. Net Porous Sandstone Isopach: C-D Subinterval

Emigrant Gap Member
1. G-H Interval Isopach

Regional Cross Sections
1. ACHK
2. BCD
3. EGJ
4. FGHI

Detailed Study Area Cross Sections
1. X-X’
2. Y-Y’
Frontier Formation of the Powder River Basin

Selected Figures from the Study
Figure 1.3. Isopach map of Upper-Cretaceous strata in the central and northern Rocky (Mountain regions. (Modified from McGookey, 1972.)
Figure 4.16. Exposure of L sandstone unit of the Belle Fourche Member near Kaycee (Arndt Draw section; sec. 34, T.44N., R. 82W.). The L sandstone typically weathers back to form light gray rilled slopes. This unit is capped by a transgressive lag containing pebbles of andesite porphyry, which is unique among Frontier sandstones.

Figure 4.17. Exposure of the L sandstone unit along the Bighorn Mountain front. This unit is the major producer at Salt Creek field.
Figure 4.38. Representative log showing the two upward-coarsening sequences present within the D-F interval in the southwestern portion of the study area. A third isolated upward-coarsening sequence is present within the D-F interval in the northwestern portion of the study area.
Figure 5.16A. SEM photomicrograph of authigenic kaolinite within an intergranular area.

Figure 5.16B. Enlarged view of an area in Figure 5.16A, showing the occurrence of mixed-layer illite-smectite on the surface of the kaolinite platelets. Many of the kaolinite platelet are ragged and may have undergone minor dissolution prior to the development of illitic clay. Sample from log depth 7889 in the Federal 9-19 well (ne sw sec. 19. T.32 N., R.84 W.)
Example of a Core Description

OPERATOR: [Name]
WELL NAME: [Name]
LOCATION: [Location]
API#: [API Number]
REPORTED CORE INTERVAL: 15315-15591, 15591-15604
LOG INTERVAL: 15315-15591, 15591-15604
PRODUCING INTERVAL: 15504-15517, 15555-15586
2753 BOPD
STUDY:
FIELD:
APPROX. FEET RECOVERED: 289'
CORE TYPE: SF SWC CP
QUALITY: EGF FP
SOURCE:

DESCRIBED BY:
PAGE 3 OF 5

LOG DEPTH = CORE DEPTH + *

*CORED INTERVAL CLOSELY APPROXIMATES LOG INTERVAL; MISSING CORE PROHIBITS ACCURATE ADJUSTMENT

SEDIMENTARY TEXTURES AND STRUCTURES

CARBONATES

CLASTICS

TEST
G, P, C, M, F, V, D, CLAY

SANDY BED FORMS

THALMOID SCOUR POOL

ACTIVE CHANNEL FILL

PASSIVE CHANNEL FILL

UPPER POINT BAR

RED BED FORMS

STORY SURFACE

SANDY BED FORMS

SANDY BED FORMS

INTERPRETED DEPOSITIONAL ENVIRONMENT

NOTES

PLANAR/WAVY TO STRUCTURELESS, CARBONACEOUS DEBRIS, STICKS, CHERT CLASTS

MOSTLY STRUCTURELESS WITH DISSOCIATED ORGANICS AND CHARCOAL, ABUNDANT PYRITE

CROSSBEDDED TO CONFORMED FLAT BEDS, CHARCOAL, DEBRIS, P RIZED CARBONACEOUS DEBRIS, YELLOW HALOS AROUND PYRITE

COARSE TO PEBBLE-SIZED SANDSTONE CLASTS, VAGUELY BEDDED

MATRIX SUPPORTED SHALE CLASTS

DISSOCIATED CARBONACEOUS DEBRIS ALONG FORESETS, SWELLING CLAYS

CORE MISSING

CORE MISSING

CORE MISSING

POORLY SORTED SHALE CLASTS

CORE MISSING
Example of a Measured Outcrop Section

NAME:

LOCATION:

GAMMA RAY

CARBONATES

SEDIMENTARY & DIAGENETIC TEXTURES & STRUCTURES

M \ F \ VF \ SILT \ AVERAGE \ BULK SIZE

PALAEODIOGEOGRAPHY

BASIC ROCK TYPE

STONE TYPE

CORED \ DUG \ INTERPRETED

APPROXIMATE ENVIRONMENT

NOTES

Offshore to Transition Zone

Msta; dk gy; lam; fissile; crsn up into thinly interbedd vfg ss and &nbsp;msln.

Fluvial Suspension Load

Thinly interbedd ss and &nbsp;msln. Ss; vfg-fg; thin bdd; &nbsp;wavy/planar bdd. Msta; dk gy-brown black; carbonaceo&mash;e; rooted; sparse &nbsp;mod Planoform, Arenicolites.

Fluvial Bed Load

Ss; buff-lan; vfg-wg; 6-16" trough &nbsp;x-strat. beds; grades up into thinly interbedd &nbsp;fgr ss and carb msta; interval is lenticular &nbsp;(approx 1/2 mile wide and up to 40' thick) and along strike cuts out and replaces underlying marine ss; erosional lower contact.

Shoreface

Ss; buff-lan; vfg-fg; massive; relict her lam and HCS grades up into amalgamated HCS and trough x-strat.; &nbsp;and intense bioturbation; interval thickness varies from 6-30' along strike due to erosional upper contact.

Lower Shoreface

Msta; dk gy; grades up into bioturbated sltn and vfg ss; intensely bioturbated; relict storm sands; her lam, HCS; erosional lower contact.

Offshore Marine L-Tusc

Transition to Lower Shoreface

Interbedd vfg ss and msta; &nbsp;crsn up sequence; beds 4-12" thick; her lam.

Offshore Marine

Msta; dk gy; crsn up into interbedd, lenticular vfg ss and msta; sparse &nbsp;Planoform, Arenicolites; benthicites at 0.4', 19.5' and 12'; erosional lower contact.

Offshore Marine

Clyst; dk black; fissile. Thermopolis Shale.