Discovery of “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!*

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Abstract

Discovery of Bakken Petroleum System sweet-spots over the last 10 years has advanced by application of preceding paradigms to new areas. By contrast, each new sweet-spot represents a distinct combination of multiple play factors. Remaining open-minded to a variety of sweet-spot factors is fundamental to tight oil resource play exploration. Whiting’s position in North Dakota’s Sanish Field was based on regional mapping with a focus on the “B facies” of the middle Bakken juxtaposed to a thermally mature, lower Bakken Shale depocenter. Sanish and adjacent Parshall fields of Mountrail County, ND each represent giant oil fields producing from both the middle Bakken and Three Forks.

Our emphasis on core-based sedimentology and stratigraphy led us to refine our understanding of middle Bakken facies and recognize the significance of the 2nd-order regional angular unconformity separating the Three Forks and the lower Bakken Shale. Low-accommodation conditions succeeding this unconformity controlled depositional patterns of the entire lowstand (Pronghorn Member of Bakken) to transgressive (lower, middle, and upper Bakken) systems tracts, up to an MFS at the overlying Scallion Member of the Lodgepole. Regional, core-calibrated correlation in both the Pronghorn and the middle Bakken demonstrate that regional variations in siliciclastic and detrital dolomitic sediment supply and in carbonate productivity during this low accommodation LST-TST period critically impacted matrix reservoir quality.

Across the northern Williston Basin, the basal transgressive Pronghorn Member veneer (type-section being Antelope Field) has a northeastern-derived, siliciclastic provenance. By contrast, the southern Williston Basin was the locus of detrital dolomites derived from the Cedar Creek paleostructure. The Pronghorn Member extends well south of any preserved lower, middle, and upper Bakken deposits and is composed of a transgressive succession of restricted marine detrital dolomites capped by a locally preserved, burrowed limestone that represents open marine conditions prior to the restricted to anoxic episode marking lower Bakken deposition. Core-based definition of the Pronghorn Member’s varying provenance, coupled with core- and cuttings-calibrated resistivity mapping to confirm oil saturation, recently led to discovery of
significant new sweet-spots at Whiting’s “Pronghorn” and “Lewis and Clark” prospects in Stark, Billings, and southernmost McKenzie counties, ND.

References Cited


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Whiting Petroleum Corporation
Denver, Colorado  USA
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We thank Whiting management for permission to present this work, and of course all our Whiting colleagues of multiple disciplines who contributed immensely to turning the concepts described here into economic reality.

We are appreciative of the vast, unmatched core collection afforded by the North Dakota Geological Survey and to Julie LeFever and Kent Hollands of the ND Core Lab, in particular, for their support during our biannual “core trips” to Grand Forks, ND.
General Outline

1. Pre-discovery thinking
2. Play inception: correlating cores to subsurface
3. Sweetspot prediction and discovery
4. Regional stratigraphy and continued exploration implications
   • Mechanism for preservation within the Bakken Petroleum system of the Williston Basin
5. Conclusions
Summary

Remaining open-minded to a variety of sweet-spot factors is fundamental to tight oil exploration. Bakken Petroleum System sweet-spots:

- source rock quality & maturity
- reservoir matrix quality & saturation
- fractures, pressures, etc.

Low-accommodation setting following the 2nd-order angular unconformity (top Three Forks) controlled depositional and preservational patterns throughout the lowstand (Pronghorn Member of Bakken) to transgressive systems tracts of the lower, middle, and upper Bakken.

Regional log correlations, calibrated to core, are needed to adequately identify key surfaces and help demonstrate important provenance variation:

- Northern Williston Basin, the basal transgressive Pronghorn member veneer has a northeastern-derived, siliciclastic provenance.
- Southern Williston was the locus of detrital dolomite derived from the Cedar Creek paleostructure. Subtidal, detrital dolomites form the main reservoir across Whiting’s “Pronghorn” and “Lewis and Clark” Prospects.
New productive zone identified between Bakken and Three Forks
Structure contour map on base of Mississippian C.I. = 500 Feet

1. Nesson Anticline
2. Cedar Creek Anticline
3. Billings Anticline

After Meissner 1991
80’s (unstimulated) horizontal play - upper Bakken shale only

Early tests in ND Middle Bakken primarily tried to extend Elm Coulee trend and along the Nesson Anticline

Mixed economic results with completion practices and limitations of the time

Vertical Bakken Production
U. Bakken Shale Hz Production
M. Bakken Hz Production
Bakken Activity as of 10/1/12

- In 7+ years, play expanded to over 13,000 square miles
- Whiting currently at 20 rigs
- Whiting has operated 3.3 million linear feet of Bakken/Three Forks horizontal drilling and participated in another 1.9 million feet of non-op footage
- Whiting approaching 5 million linear feet of operated hz drilling by end of 2012
Whiting currently has over 1 million gross and 680,000 net acres - the majority of which are within the producing area of the Bakken petroleum system.

The colored map depicts the regional Hydrogen Index ("HI") of the upper Bakken Shale based on public domain data accessible from the USGS as compiled by the late Leigh Price, supplemented by in-house data. Hot colors are low HI values indicative of greater levels of thermal maturity; cooler colors are higher HI values indicative of lower thermal maturity.
Bakken petroleum system - the challenges of low accommodation...
“Sanish” Sand redefined as Pronghorn Mbr. by LeFever, 2011

Contact between base Sanish Sand and Three Forks facies

DUNCAN Rose #1
33-T152N-R94W

Lower Bakken
10,500

Three Forks
10,500

Core

Sanish - Good quality qtz.-dominated reservoir – but of limited extent!

Vertically oriented burrows – shallow, high energy marine

Clean well-sorted sand

Producible from "Sanish" Sand

Core photos from NDIC
Less than 1 foot of bioturbated Pronghorn Facies forms a patchy, thin veneer overlying the Three Forks at Sanish Field.
No Pronghorn beds present –
just rip-up clasts at
Lower Bakken Shale/
Three Forks contact

120 ft. of cumulative thickness found elsewhere
in the basin is missing at
this contact

PRODUCING FROM
“SANISH” SAND

DCR 43-28H
28-T154N-R92W

FIDELITY

GRL TVD PHN(TVD) GRL DCP PHN(DCP)
10030 2023 0.3 0.3
PHN(DCP)

CONTACT BETWEEN
Base Sanish Sand and Three Forks facies

LOWER BAKKEN
THREE FORKS

10 Ft
Bakken/Three Forks Core Control and the Challenges of Creating a Type Log

- Pronghorn Limestone
  - 10 Ft
- Upper Pronghorn
  - 10 Ft
- Lower Pronghorn
  - 10 Ft
- Lower Bakken Silt
  - 10 Ft

BAKKEN LIMIT

WELLS USED TO CREATE COMPOSITE LOG

All logs shown extend 5 feet above Upper Bakken and 30 feet below the Three Forks top.
<table>
<thead>
<tr>
<th>False Bakken</th>
<th>Lag deposits define key surfaces</th>
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<tbody>
<tr>
<td>Scallion</td>
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<td>Upper Bakken Shale</td>
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<td>Middle Bakken “A” Facies</td>
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<td>Middle Bakken “B” Facies</td>
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<td>Lower Bakken Anoxic Shale</td>
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<td>Lower Bakken Silt</td>
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<td>Pronghorn Limestone</td>
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<td>Pronghorn Member</td>
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<td>Three Forks Cycle 1</td>
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<td>Three Forks Cycle 2</td>
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Main focus on this interval
Middle Bakken Isopach with Bakken Hz. Wells Drilled prior to 2009

- Primary focus was for Middle Bakken
- Moderate to poor results and Middle Bakken only thinned to south – no additional industry interest for 4-5 years
- Several key cores were game changers
- Provided a new concept that ultimately ended up in a new focus area beyond where the Bakken was too thin and production was weak
Sadowsky 24-14H
14-T141N-R96W
Unexpected units identified in core...

Three Forks markers (green) already picked through most of the basin before seeing this core.

Below the limestone and above peritidal laminites of the Three Forks were diversely burrowed 1-3” storm beds—definitely NOT Three Forks!

open marine limestone below the Lower Bakken Shale with lag deposit at contact

Typical Three Forks

Contact with extra unit

Limestone

Lower Bakken Shale

CORE

UPPER BAKKEN SHALE

MIDDLE BAKKEN
ISOPACH OF NEW UNIT
C.I. = 5 Feet

“Sanish” Sand at Antelope Field

Sadowsky 24-14H
14-T141N-R96W

Isopach Interval

Thicker

Thinner

FED. 34-1
SADOWSKY 24-14H

10 Ft
DECREASING UPPER BAKKEN SHALE MATURATION

Less Mature
More Mature

Within this area the Upper Bakken Shale does not have any recognizable facies changes and originally had very high TOC values.

The Hydrogen Index map can then be used as a proxy for maturation.

Upper Bakken Hydrogen Index (Data points from USGS)
Pronghorn Member Isopach with Key Pre-Drill Geologic Criteria Noted to Identify 2009 Leasing Areas

DECREASING UPPER BAKKEN SHALE MATURATION

Federal 34-1 Dolomite reservoir full of oil!
Pronghorn Member Isopach with Early Results and Current Drilling Activity

- Initial 2 wells avg. IP - 2021 BOEPD
- Whiting has drilled over 80 wells on this concept to date
- Whiting is the main operator in this area with 5 rigs
- IP’s as high as 3611 BOEPD

ST. DEMETRIUS FIELD (mBK) AVG. IP: 278 BOEPD (2004-2008)
PRONGHORN FACIES

Significant flooding surface to open marine limestone at top of Pronghorn sequence

- Facies “A”
- Facies “B”
- Facies “C”
- Facies “D”
- Facies “E” (Pronghorn Lime)

- Skolithos
- Oblique Burrows
- Crinoids
- Brachiopods

Highest energy – vertical burrowing – best reservoir when found
Extensive bioturbation – good reservoir
Storm beds with limited bioturbation – good reservoir
Dominated by illite – very questionable reservoir
Open Marine Limestone
TWO MAIN INTERVALS OF PRONGHORN MBR CAN BE MAPPED AND SHOW NORTHWARD PROGRADING WEDGES INTO SUB-BASIN
Whiting focused leasing efforts in the thicker net/gross dolomite areas within the upper and lower Pronghorn intervals.

Proximal to distal facies changes within each of the two mapped Pronghorn intervals.

Increasing net/gross dolomite %

Legend:
- Yellow: Facies “A”
- Turquoise: Facies “C”
- Blue: Facies “E” (Pronghorn Lime)
- Red: Facies “B”
- Black: Facies “D”
- Green: Three Forks
Qemscan Mineral Map – Pronghorn B Facies
Detrital dolomite reservoir with quartz and illite

Minerals
- Quartz 12.3%
- Plagioclase
- Illite 15.9%
- Apatite
- Pyrite
- Dolomite 58.1%
- Others
- Unclassified
- K-Feldspar
- Fe - Bearing Dolomite (M)
Qemscan Mineral Map – Pronghorn D Facies
Muddy Dolomite/Dolomitic Mudstone w/ significantly poorer reservoir quality
Thin section and SEM image at same scale – bi-modal dolo with intercrystalline pores
Facies B
Facies C

3 inches

Pronghorn facies are detrital in origin
Cedar Creek high is likely source

Detrital dolomite cores
Zoned Dolomite
Quartz

25 μm
Changes in Source Area “Provenance”

Manitoba / E. North Dakota Quartz source area vs. Cedar Creek Anticline Dolomite source area

Antelope Field vs. Pronghorn Reservoir in Stark/Billings Co.
Pronghorn Interval Depositional Model

Three Forks, Nisku, Duperow and Interlake exposed during Pronghorn/Bakken time - Source for detrital dolomite

Core control:
- Bakken petroleum system
Regional Stratigraphic and Continued Exploration Implications

Low Accommodation Stratigraphic Mapping of the Greater Pronghorn Interval
LOWER BAKKEN SILT – Dark gray muddy siltstone, 1-5% TOC type III kerogen, localized basin.

LOWER BAKKEN SHALE - Anoxic kerogenous mudstone, dark brown to black, type I and II kerogen, TOC up to 20%.

PRONGHORN – Clay rich over much of the area, local isolated qtz rich in places with extensive dolomite in SW depocenter, NO TOC.

LOWER BAKKEN SHALE - Anoxic kerogenous mudstone, dark brown to black, type I and II kerogen, TOC up to 20%.

Separating sequences correctly matters.
Lower Bakken Silt C.I. = 5 Feet  0-37 Feet thick

AREA WITH ADDITIONAL LOW-GRADE SOURCE ROCK – FAULT CONTROL CREATING RHOMBIC SUB-BASIN
Mechanism for preservation within the Bakken Petroleum system of the Williston Basin:

Tectonics or salt dissolution?
Devonian Prairie Salt Isopach (0-650 Feet)

C.I. = 20 Feet

Map incorporates 1724 wells

Thicker

Thinner

PRAIRIE SALT ORIGINAL DEPOSITIONAL LIMIT (OGLESBY, 1988)

ISOLATED SALT DISSOLUTION HOLES

LOWE BAKKEN SALT MBR PRESERVED DEPOCENTER

PRONGHORN PRESERVATIONAL SUB-BASIN

BAKKEN/THREE FORKS
Qualitative eustatic sea-level curve for the Devonian and its relationship to Devonian conodont zones

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<th>CONODONT ZONES</th>
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<th>SEA-LEVEL CURVE</th>
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Multiple transgressive/regressive pulses have been documented in the western U.S. based on geology combined with conodont age dating. These sea-level pulses can significantly impact deposition and preservation – especially in a low-accommodation setting like the Bakken petroleum system within the Williston Basin.
Thicker

Thinner

Nisku Isopach C.I. = 5 Feet
0-183 Feet thick

- Broad open marine limestone with widespread preservation
- No obvious depo-center
Three Forks Isopach C.I. = 5 Feet
0-255 Feet thick

SE OF SWEETGRASS ARCH - RESTRICTED ENVIRONMENT - INTERLAYERED SHALES & DOLOMITES – ANHYDRITE PRESENT

DETONIAN SEA-LEVEL CURVE

JOHNSON ET AL 1985

100 FEET
MAPPED INTERVAL

TYPICAL THREE FORKS FROM CENTER OF BASIN

CEDAR CREEK ACTIVE

SWEETGRASS ARCH - ACTS AS SILL

MAN

MT.
ND

Thicker

Thinner

Composite Log

MAN
SASK
ND
MT

DEVONIAN SEA-LEVEL CURVE

STAGES
CONODONT ZONES

JOHNSON ET AL 1985
“Uppermost limestone bed of the Big Valley Fm. overlain with an erosional contact by a rubble deposit that grades upward into a silty and fossiliferous claystone. The claystone bed is sharply overlain by means of a pyritized lag deposit by the euxinic Lower Bakken/Exshaw Shale” (Meijer Drees & Johnston 1996)

Most marine transgressive pulse in the Bakken petroleum system
Pronghorn/Basal Big Valley Isopach C.I. = 5 Feet 0-114 Feet Thick

CEDAR CREEK ANTICLINE UPLIFTED AND DETRITAL DOLOMITES SHED INTO PRONGHORN SUB-BASIN

Detrital dolomite reservoir along SW side of sub-basin

Non-reservoir facies over majority of the preserved area
Qtz dominated facies rarely preserved in central and NE N. Dak.

Composite Log

DEVONIAN SEA-LEVEL CURVE

JOHNSON ET AL 1985

Qtz dominated facies rarely preserved in central and NE N. Dak.

Composite Log

DEVONIAN SEA-LEVEL CURVE

JOHNSON ET AL 1985

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Composite Log

DEVONIAN SEA-LEVEL CURVE

JOHNSON ET AL 1985

Qtz dominated facies rarely preserved in central and NE N. Dak.
Local preservational remnant

Much greater inferred original depositional extent because the Pronghorn lime represents open marine deposition over a vast, low-relief region.

Bakken/Three Forks core control used in mapping

Pronghorn/Crystal Limestone Isopach C.I. = 2 Feet

0-22 Feet thick
Lower Bakken Silt/Upper Big Valley Isopach
C.I. = 5 Feet  0-55 Feet thick

- Spotty preservation
- Downdropped graben/rhombochasm
- 1-5% TOC
- Muddy siltstone

Thicker

Thinner

EUXINIC LOWER BAKKEN SHALE

LOWER BAKKEN SILT

Bakken/Three Forks core control used in mapping
Thicker

Thinner

DEVONIAN SEA-LEVEL CURVE

JOHNSON ET AL 1985

Lower Bakken Shale Isopach C.I. = 5 Feet
0-87 Feet thick

- Preserved depocenter during Lower Bakken Shale time shifts back to Mountrail County
- Sweetgrass Arch active during and/or after Lower Bakken time - preserved thicknesses likely erosionally modified
- Sets the stage for Middle Bakken deposition

Bakken/Three Forks core control used in mapping

Lower Bakken Shale limit on S, SW and NE sides of Williston Basin erosionally modified

JOHNSON ET AL 1985

DEVONIAN SEA-LEVEL CURVE

STAGES

CONODONT ZONES

- Pre-Stephanian
- "a" Fenestrate
- "b" Angulate
- "c" Tonga
- "d" Tonga
- "e" Tonga
- "f" Tonga

Man	Sask	ND	MT
Conclusions

What is typically thought of as a well behaved and simple correlation scheme between Three Forks and Middle Bakken is anything but!

Regional mapping tied to core control is essential to recognizing what units should be expected.

In the case of the Pronghorn member, the intrigue of seeing an unexpected zone helped lay the bread crumbs leading to a new productive area.
WHITING
DRS Federal 24-24TFH

IP: 2898 BOEPD

Other Operator
Nearest Hz well
IP: 276 BOEPD

GEOLOGY MATTERS!

PRONGHORN BEST PRESERVED DOLOMITE QUALITY

PRONGHORN IMPROVING DOLOMITE %

PRONGHORN CLAY RICH

THREE FORKS TARGET

BAKKEN TARGET
THANK YOU!