[AV]The Giant Continuous Oil Accumulation in the Bakken Petroleum System, Williston Basin*

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Conclusions

- A "giant" continuous accumulation is present in the Bakken and Three Forks of the Williston Basin.
- Sophisticated completion technology and geological factors have a large impact on productivity.
- Sweetspots influenced by hydrocarbon generation, pore overpressure, inferred oil saturations and productivity, net pay, facies, natural fractures, etc.
- Optimal completion design depends on area and field maturity:
  - 40-stage completions may not be economic in low-productivity areas.
  - Simpler (cheaper) completions may be preferable for infill wells at late development stage.
- Multistage hydraulic fracturing and horizontal drilling are game changers for tight oil systems.

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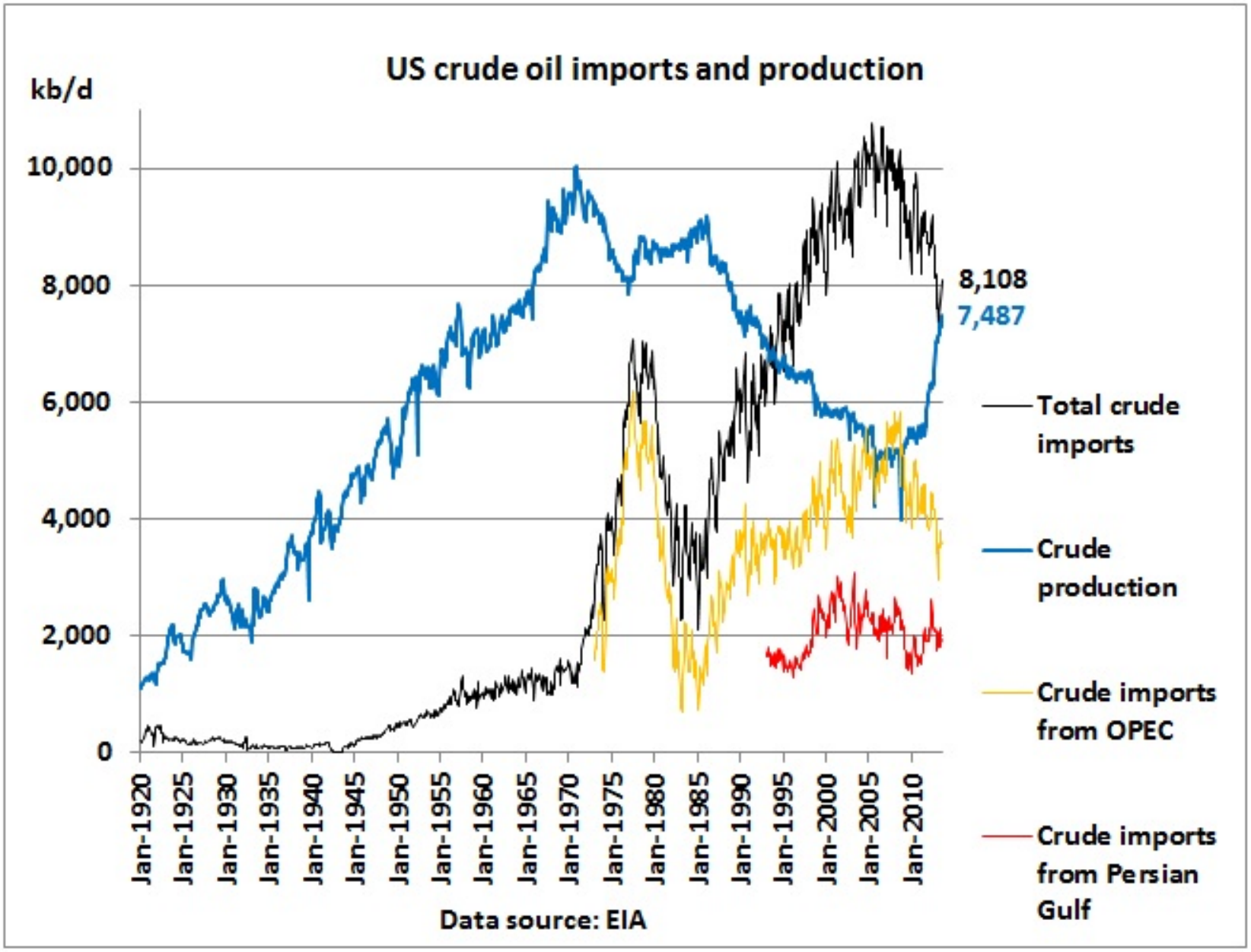
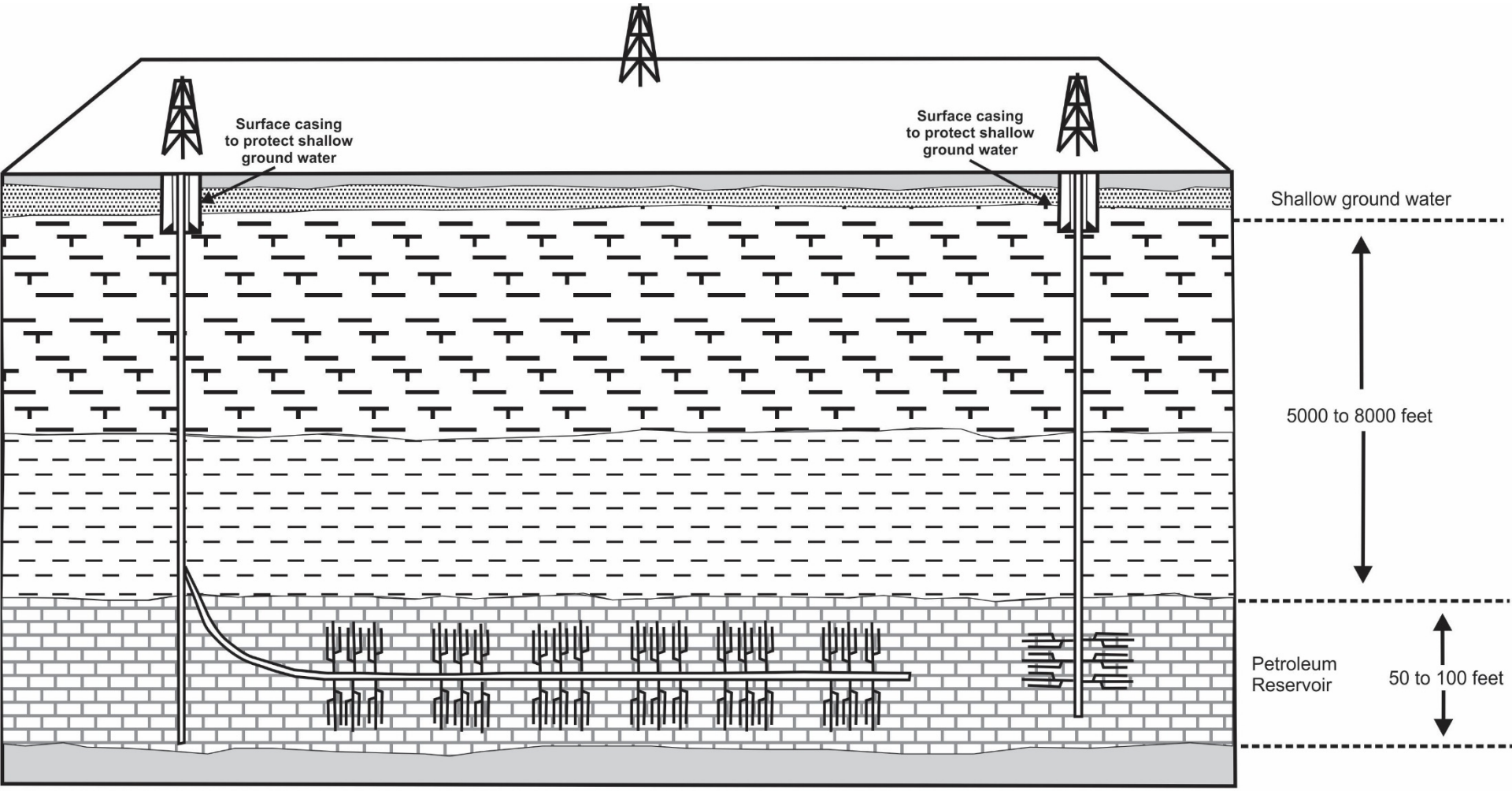
Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011


US crude oil imports and production
kb/d
10,000
8,000
6,000
4,000
2,000
0
8,108
7,487
Total crude imports
Crude production
Crude imports from OPEC
Crude imports from Persian Gulf
Jan-1920
Jan-1925
Jan-1930
Jan-1935
Jan-1940
Jan-1945
Jan-1950
Jan-1955
Jan-1960
Jan-1965
Jan-1970
Jan-1975
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Data source: EIA



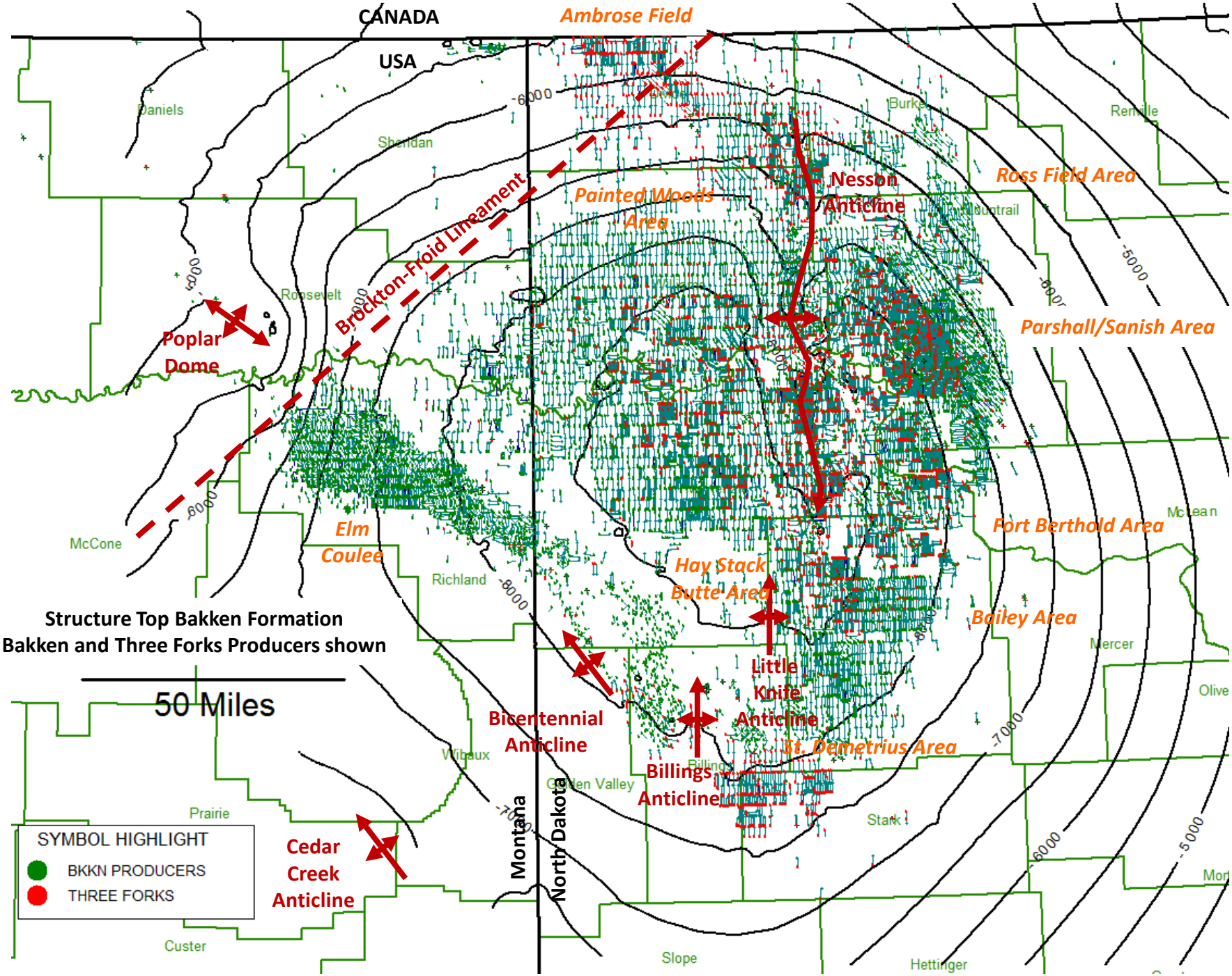
Horizontal well with multistage
hydraulic fracture stimulation

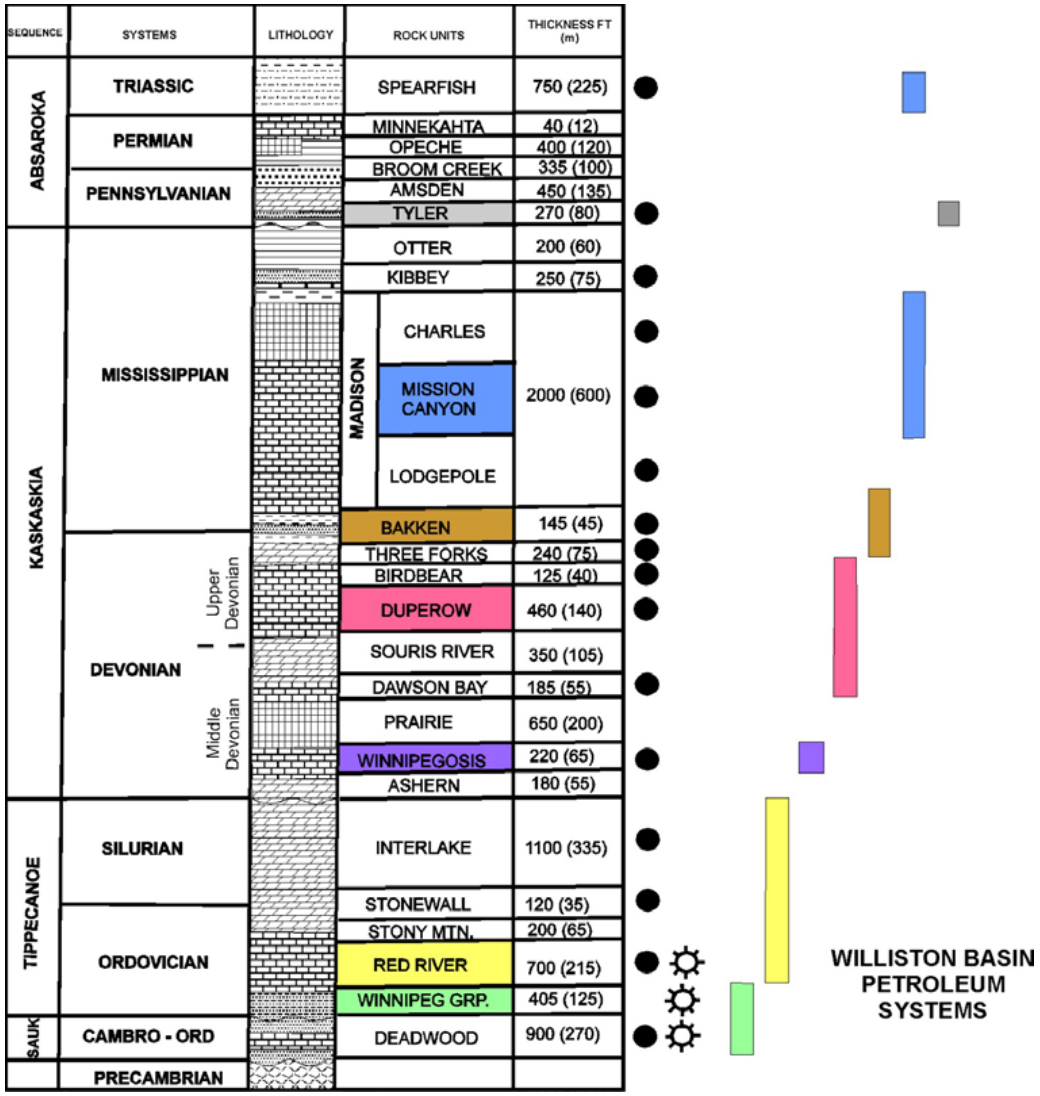
Typical vertical well
with hydraulic fracture stimulation

Horizontal versus Vertical Wells
Highly diagramatic

Meissner, 1978

"Relationship between source-rock maturity, hydrocarbon generation, geopressuring and fracturing suggest an opportunity in exploration for unrecognized and unlooked-for "unconventional" accumulations of potentially very large regional extent"


CANADA
USA
Ambrose Field
Daniels
Sheridan
Burke
Renville
Ross Field Area
Painted Woods Area
Nesson Anticline
Brockton-Froid Lineament
Roosevelt
Poplar Dome
Parshall/Sanish Area
McCone
Elm Coulee
Richland
Fort Berthold Area
McLean
Hay Stack Butte Area
Bailey Area
Mercer
Olive
Little Knife Anticline
St. Demetrius Area
Bicentennial Anticline
Billings Anticline
Wibaux
Golden Valley
Billings
Stark
Prairie
Cedar Creek Anticline
Montana
North Dakota
Custer
Slope
Hettinger
Structure Top Bakken Formation
Bakken and Three Forks Producers shown
50 Miles
SYMBOL HIGHLIGHT
BKKN PRODUCERS
THREE FORKS



Modified from LeFever 1992; Anna, 2009

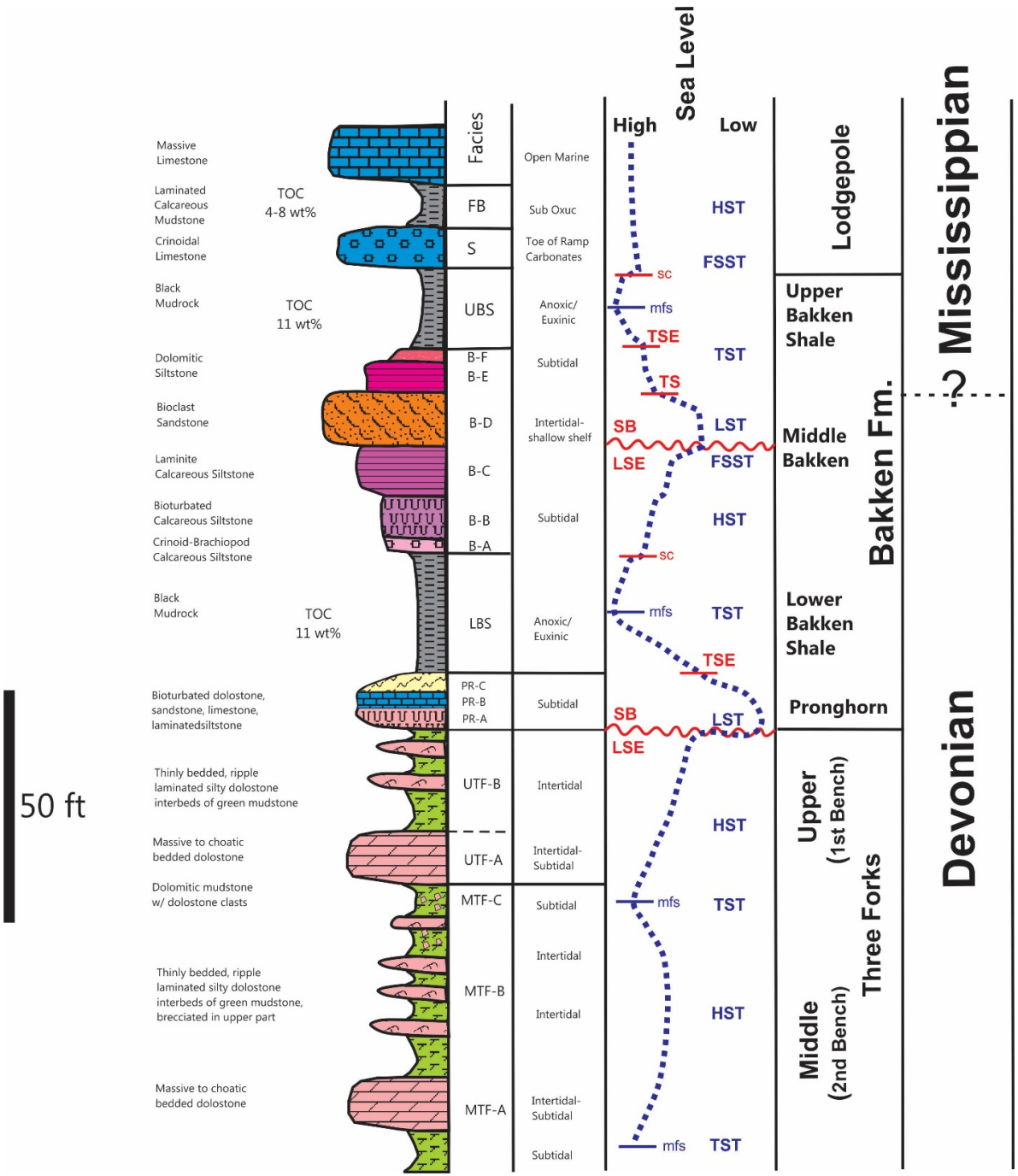
USGS 2013 Bakken PS Assessment

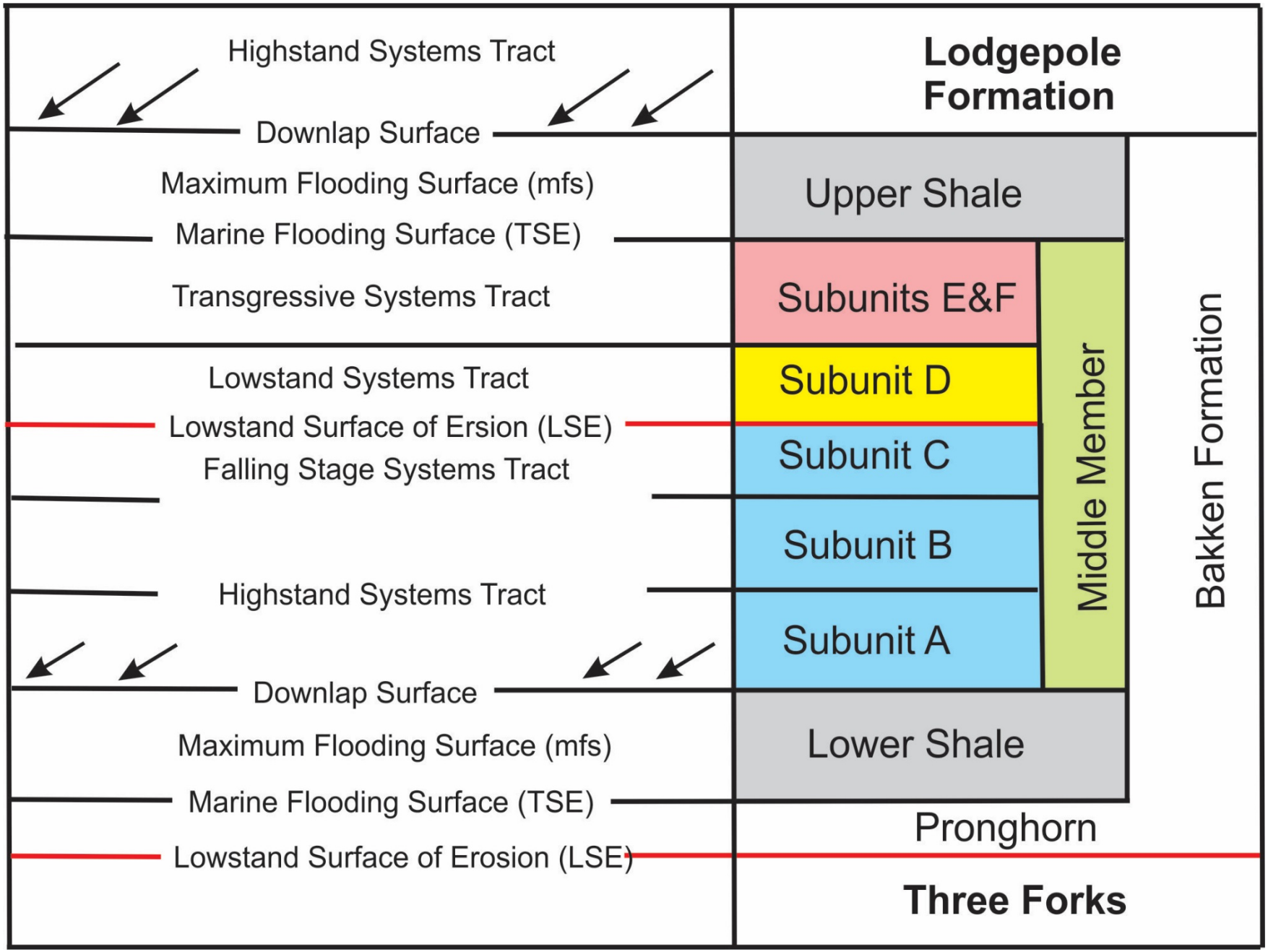
7.4 BBO

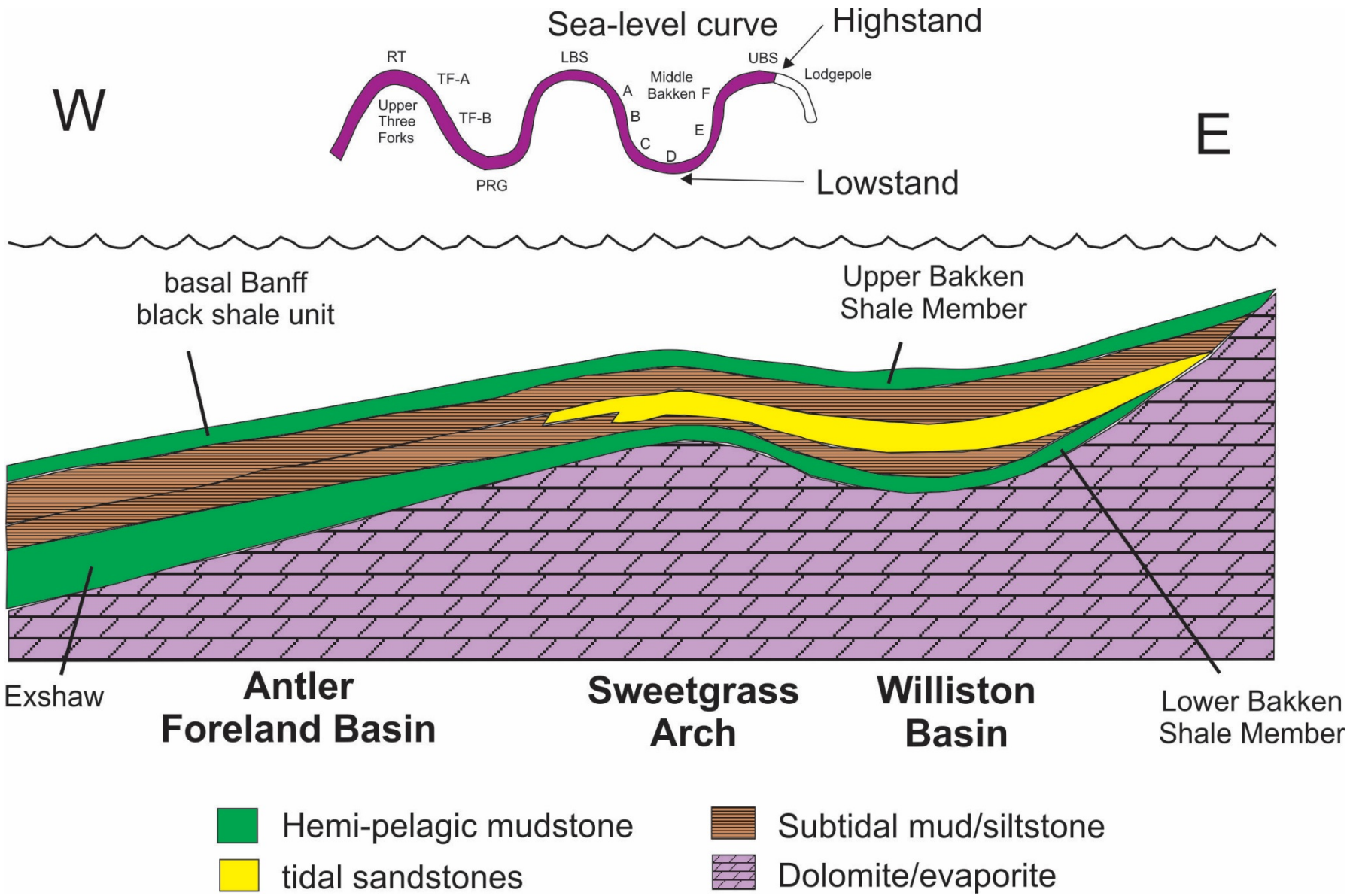
6.7 TCFG

Unconventional, Continuous Tight Oil Accumulations

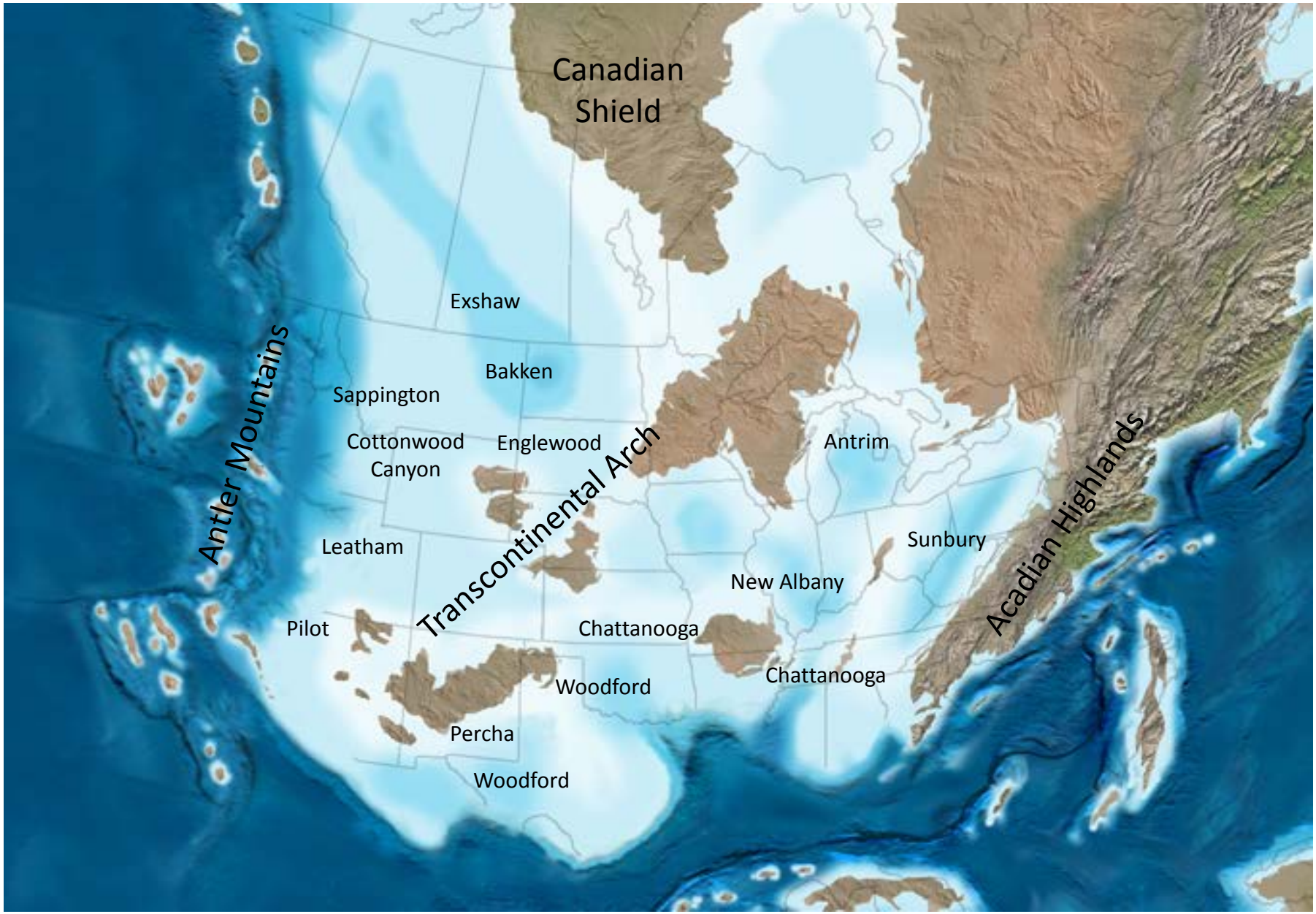
- Pervasive accumulations that are hydrocarbon-saturated
- Not localized by buoyancy
- Abnormally pressured (high or low)
- Commonly lack downdip water
- Updip contact with regional water saturation
- Low-permeability and low-matrix porosity reservoirs
- Reservoirs may be single or vertically stacked
- Commonly enhanced by fracturing
- Associated with mature source rocks that are either actively generating or have recently ceased generation
- Hydrocarbons of thermal origin
- Fields have diffuse boundaries
- Inverted Petroleum Systems


Massive Limestone
Laminated Calcareous Mudstone
Crinoidal Limestone
Black Mudrock
Dolomitic Siltstone
Bioclast Sandstone
Laminite Calcareous Siltstone
Bioturbated Calcareous Siltstone
Crinoid-Brachiopod Calcareous Siltstone
Black Mudrock
Bioturbated dolostone, sandstone, limestone, laminatedsiltstone
Thinly bedded, ripple laminated silty dolostone interbeds of green mudstone
Massive to choatic bedded dolostone
Dolomitic mudstone w/ dolostone clasts
Thinly bedded, ripple laminated silty dolostone interbeds of green mudstone, brecciated in upper part
Massive to choatic bedded dolostone
TOC 4-8 wt%
TOC 11 wt%
TOC 11 wt%
50 ft
Facies
FB
S
UBS
B-F
B-E
B-D
B-C
B-B
B-A
LBS
PR-C
PR-B
PR-A
UTF-B
UTF-A
MTF-C
MTF-B
MTF-A
Open Marine
Sub Oxuc
Toe of Ramp Carbonates
Anoxic/ Euxinic
Subtidal
Intertidal-shallow shelf
Subtidal
Anoxic/ Euxinic
Subtidal
Intertidal
Intertidal-Subtidal
Subtidal
Intertidal
Intertidal
Intertidal-Subtidal
Subtidal
Sea Level
High
Low
HST
FSST
sc
mfs
TSE
TST
TS
SB
LST
LSE
FSST
HST
sc
mfs
TST
TSE
SB
LST
LSE
HST
mfs
TST
HST
mfs
TST
Lodgepole
Upper Bakken Shale
Middle Bakken
Lower Bakken Shale
Pronghorn
Upper (1st Bench)
Middle (2nd Bench)
Three Forks
Bakken Fm.
Mississippian
Devonian


Highstand Systems Tract
Lodgepole Formation
Downlap Surface
Maximum Flooding Surface (mfs)
Upper Shale
Marine Flooding Surface (TSE)
Transgressive Systems Tract
Subunits E&F
Middle Member
Bakken Formation
Lowstand Systems Tract
Subunit D
Lowstand Surface of Ersion (LSE)
Subunit C
Falling Stage Systems Tract
Subunit B
Highstand Systems Tract
Subunit A
Downlap Surface
Maximum Flooding Surface (mfs)
Lower Shale
Marine Flooding Surface (TSE)
Pronghorn
Lowstand Surface of Erosion (LSE)
Three Forks



Modified from Smith et al., 1995

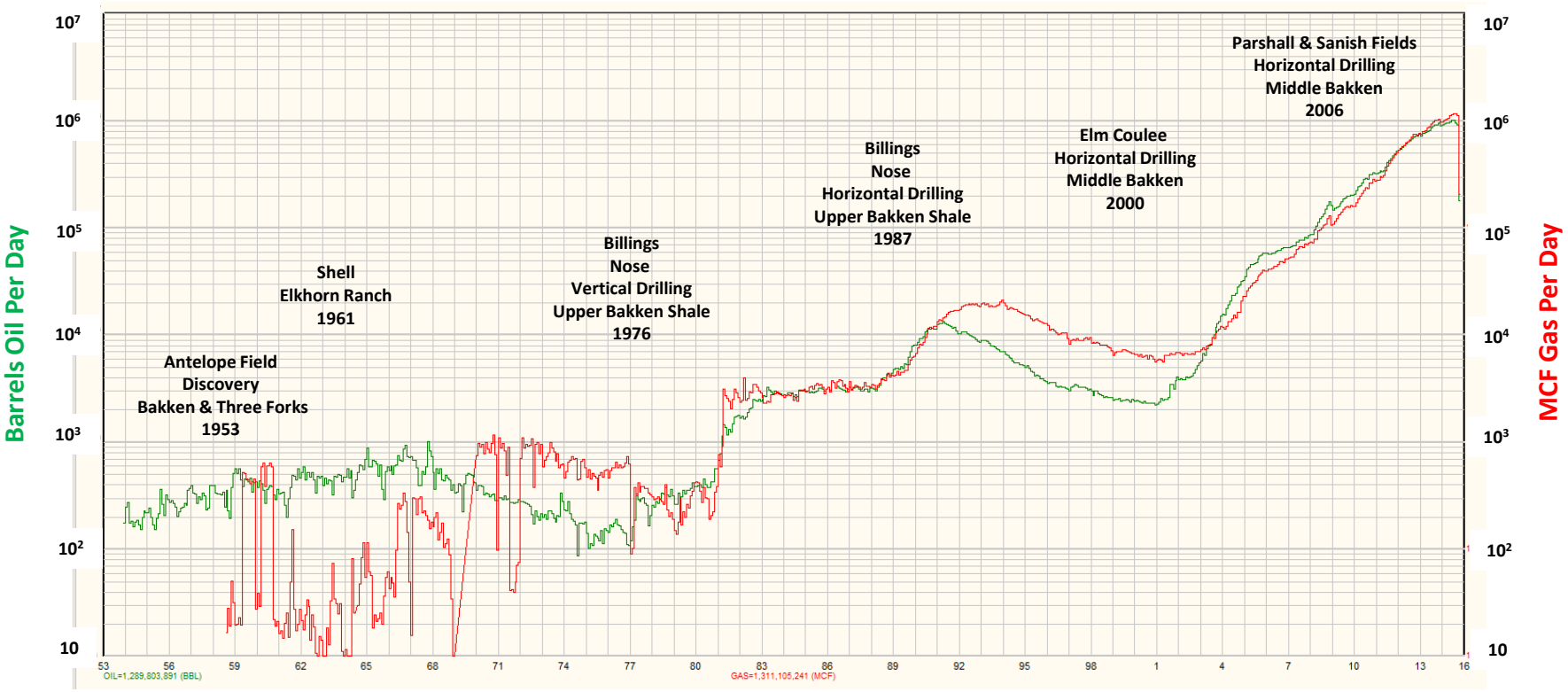


Late Devonian-Early Mississippian black shales (360 Ma)

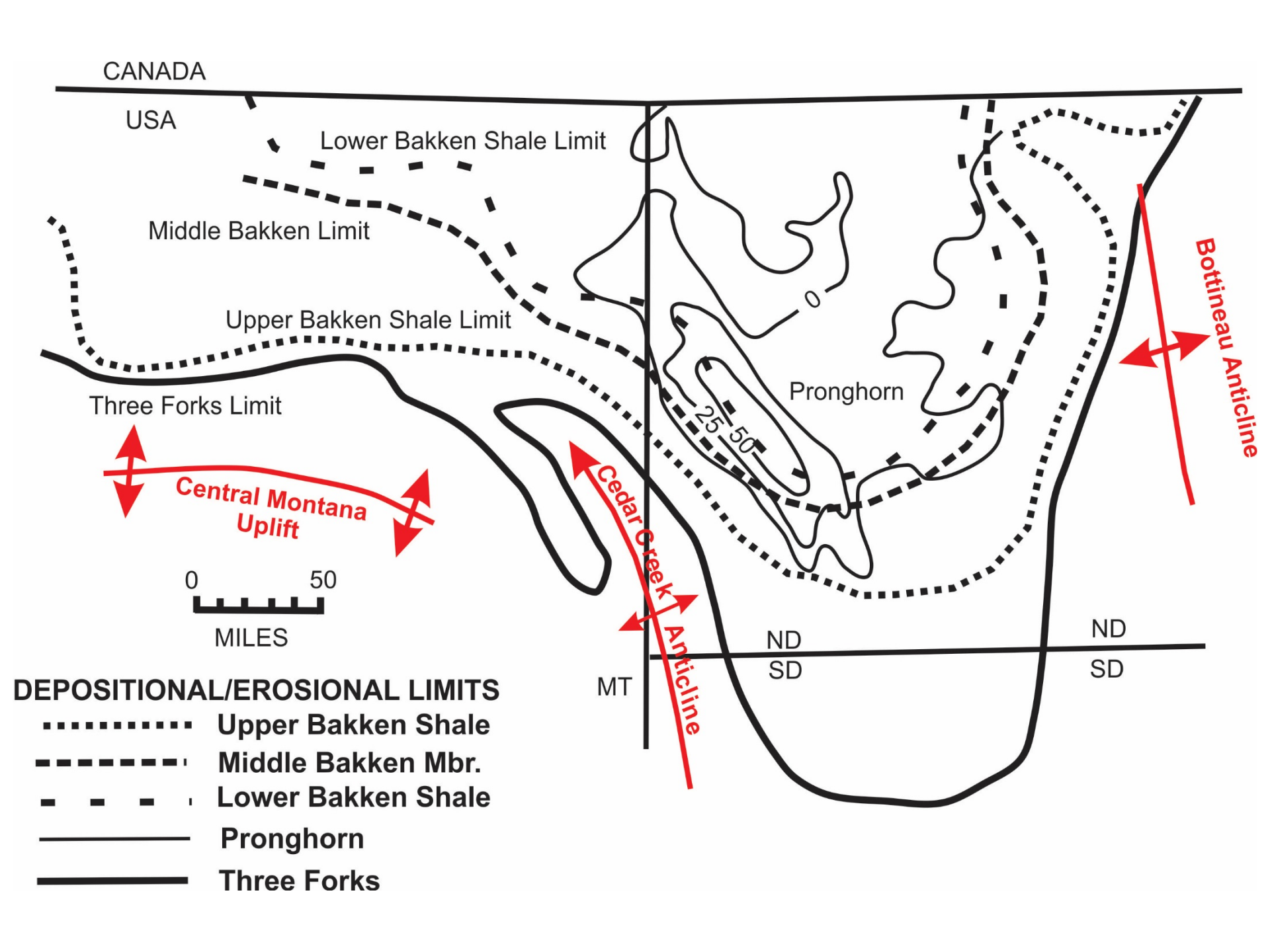
Blakey, 2007, <http://jan.ucc.nau.edu/~rcb7/namD360.jpg>

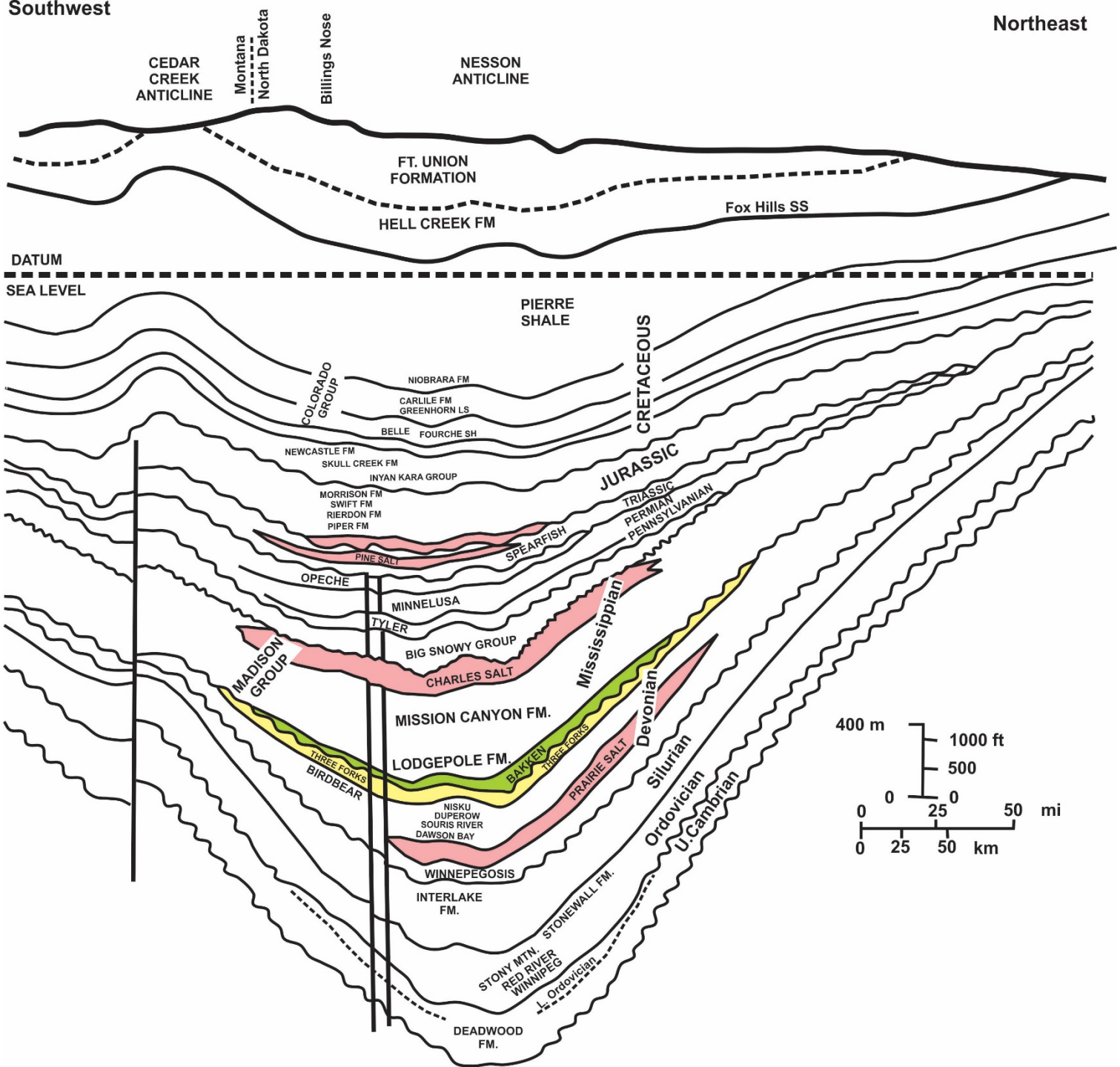
Bakken Petroleum System Basics

- Upper & lower black shales
  - 'World Class' Source Rocks
    - Hard, siliceous, pyritic, fissile, organic-rich
    - TOC's average wt. 11%
    - High OM indicates anoxic conditions (amorphous-sapropelic OM)
    - HC Generation: 10 to 400 B bbl oil
- Middle member (target of horizontal drilling)
  - Dolomitic siltstone to a silty dolomite
  - Low porosity and permeability
- Upper & Middle Three Forks dolostones (target of horizontal drilling)
- Pronghorn dolostones (new target!)
- Abnormal pressure and hydrocarbon generation (> 0.5 psi/ft)



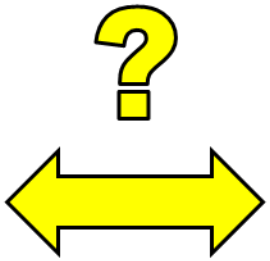
Total US Williston Basin
Bakken and Three Forks
1,289,803,891 BO
1,311,105,241 MCFG


CANADA
USA
Lower Bakken Shale Limit
Middle Bakken Limit
Upper Bakken Shale Limit
Three Forks Limit
0
25
50
Pronghorn
Central Montana Uplift
Cedar Creek Anticline
Bottineau Anticline
0
50
MILES
ND
SD
ND
SD
MT
DEPOSITIONAL/EROSIONAL LIMITS
Upper Bakken Shale
Middle Bakken Mbr.
Lower Bakken Shale
Pronghorn
Three Forks


Southwest
Northeast
CEDAR CREEK ANTICLINE
Montana
North Dakota
Billings Nose
NESSON ANTICLINE
FT. UNION FORMATION
HELL CREEK FM
Fox Hills SS
DATUM
SEA LEVEL
PIERRE SHALE
CRETACEOUS
COLORADO GROUP
NIOBRARA FM
CARLILE FM
GREENHORN LS
BELLE
FOURCHE SH
NEWCASTLE FM
SKULL CREEK FM
INYAN KARA GROUP
JURASSIC
MORRISON FM
SWIFT FM
RIERDON FM
PIPER FM
TRIASSIC
PERMIAN
PENNSYLVANIAN
SPEARFISH
PINE SALT
OPECHE
MINNELUSA
TYLER
BIG SNOWY GROUP
CHARLES SALT
MADISON GROUP
Mississippian
MISSION CANYON FM.
LODGEPOLE FM.
THREE FORKS
BAKKEN
THREE FORKS
BIRDBEAR
Devonian
PRAIRIE SALT
NISKU
DUPEROW
SOURIS RIVER
DAWSON BAY
Silurian
Ordovician
U.Cambrian
WINNEPEGOSIS
INTERLAKE FM.
STONEWALL FM.
STONY MTN.
RED RIVER
WINNIPEG
L. Ordovician
DEADWOOD FM.
400 m
1000 ft
500
0
0
0
25
50
mi
0
25
50
km

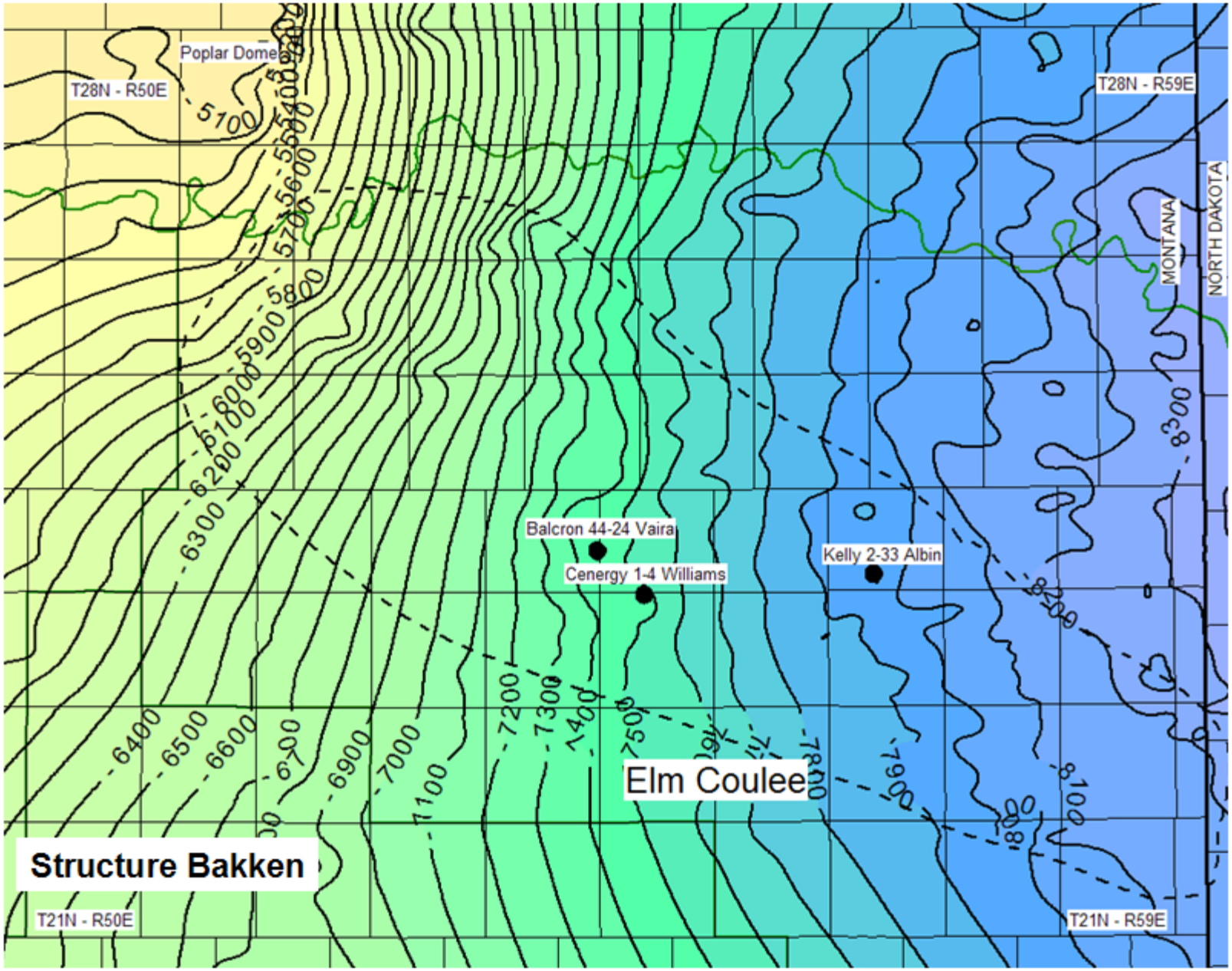
What factors influence productivity?

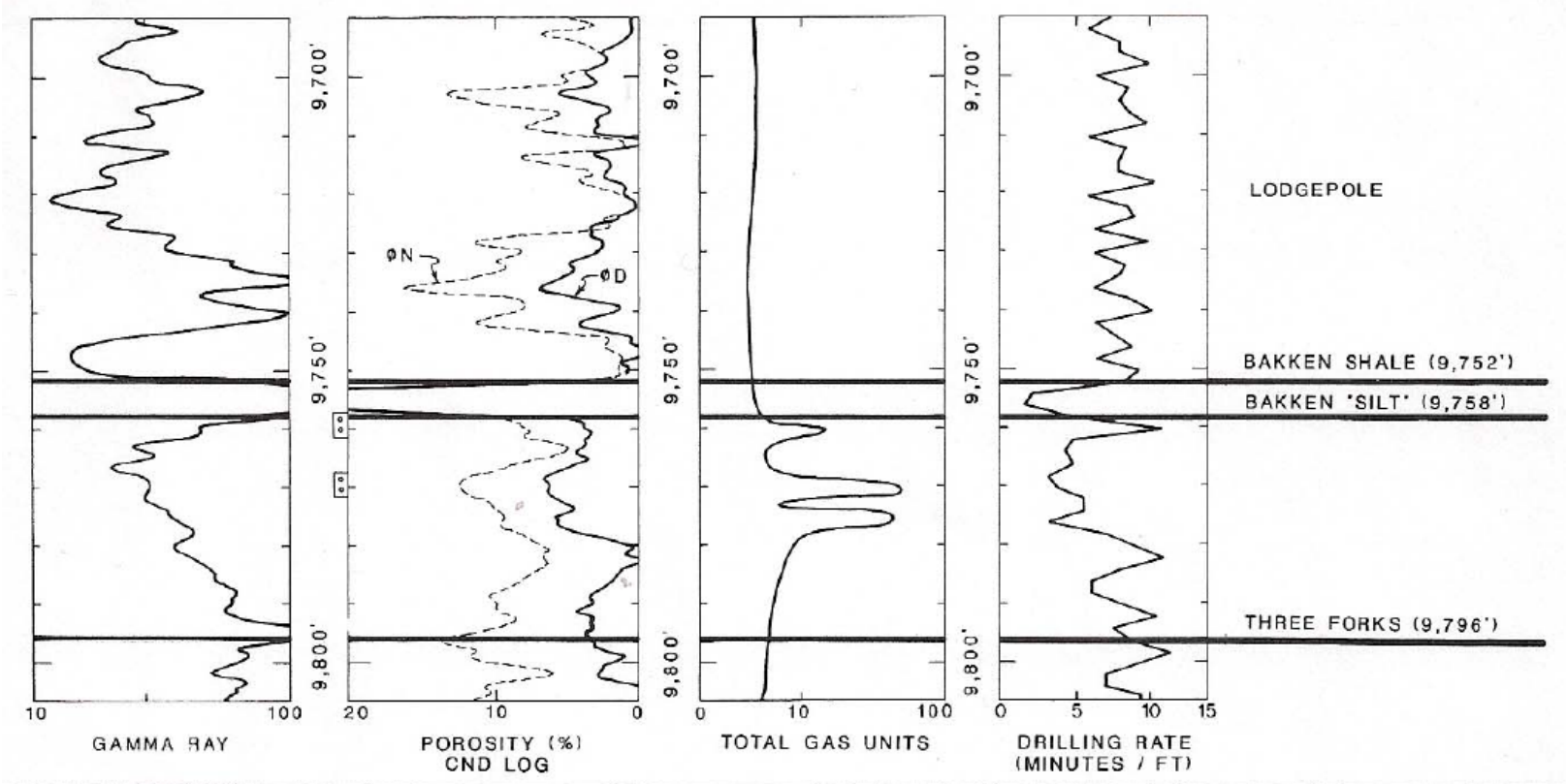
GEOLOGY	TECHNOLOGY
• Reservoir quality	• Well type
• Reservoir thickness	• Lateral length
• Oil & water saturations	• No. of hyd. fracturing stages
• HC generation potential	• Proppant volume & type
• Maturity	• Proppant loading
• Overpressure	• Fluid volume & type
• Structure and lineaments	• Fluid / proppant ratio
• Regional stress regime	• Injection rate
• Mechanical stratigraphy	• Treatment pressure
• Natural fractures	• Choke size
• Migration	• Plug & perf; sliding sleeves
• Traps	• Well spacing



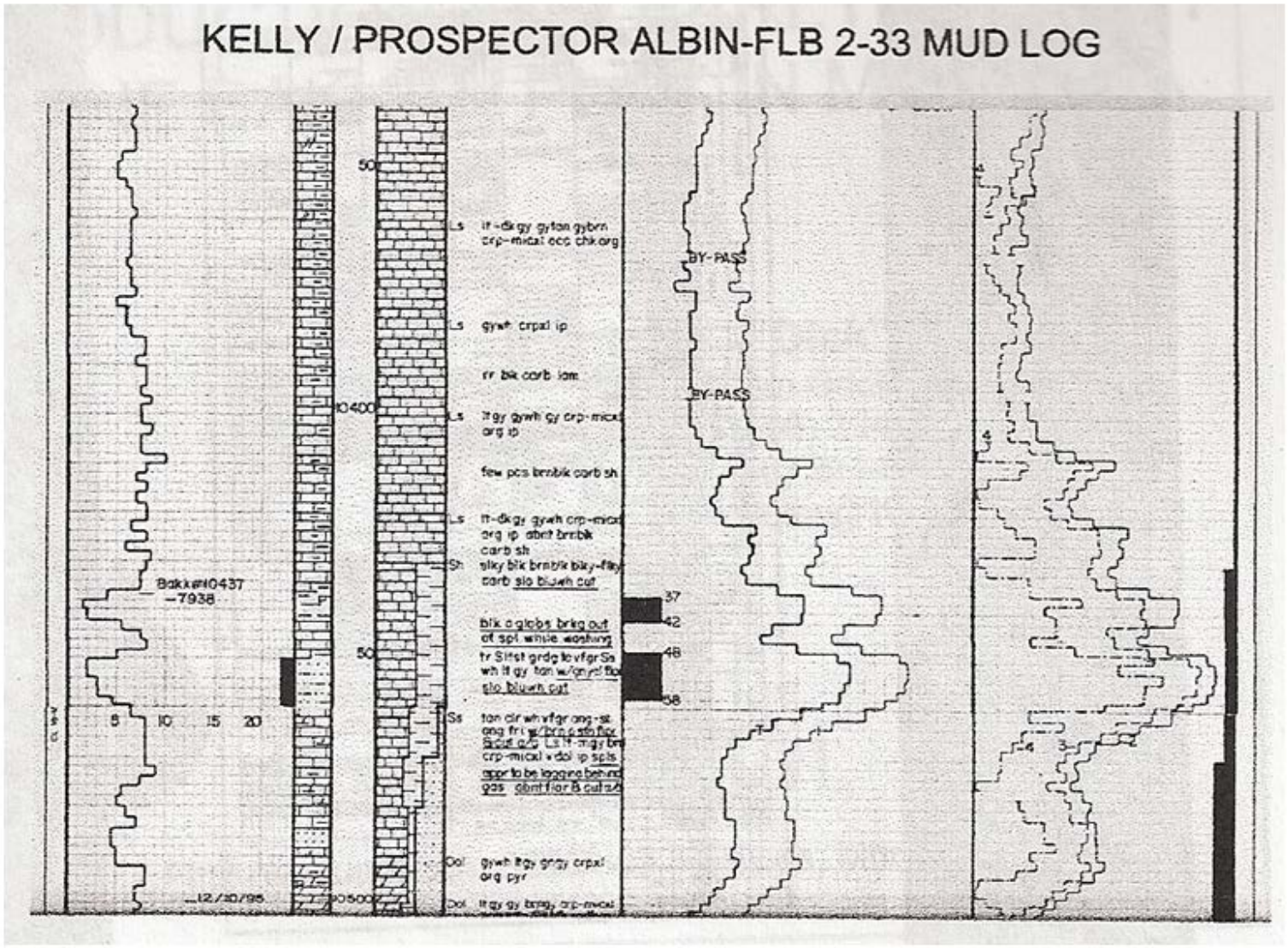
Theloy, 2013

Elm Coulee

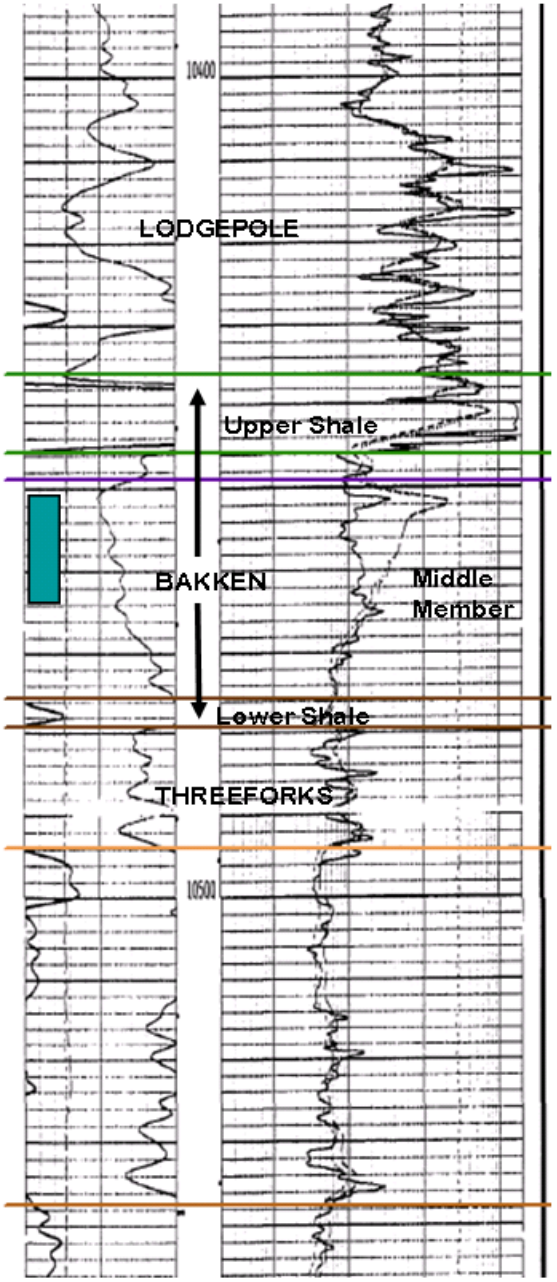

Poplar Dome
T28N - R50E
T28N - R59E
MONTANA
NORTH DAKOTA
Balcron 44-24 Vaira
Cenergy 1-4 Williams
Kelly 2-33 Albin
Elm Coulee
Structure Bakken
T21N - R50E
T21N - R59E



Log suite, BN 9-27, Richland Co., MT (Cramer, 1991)
Note mud log shows in Middle Bakken.



From Findley, 2005

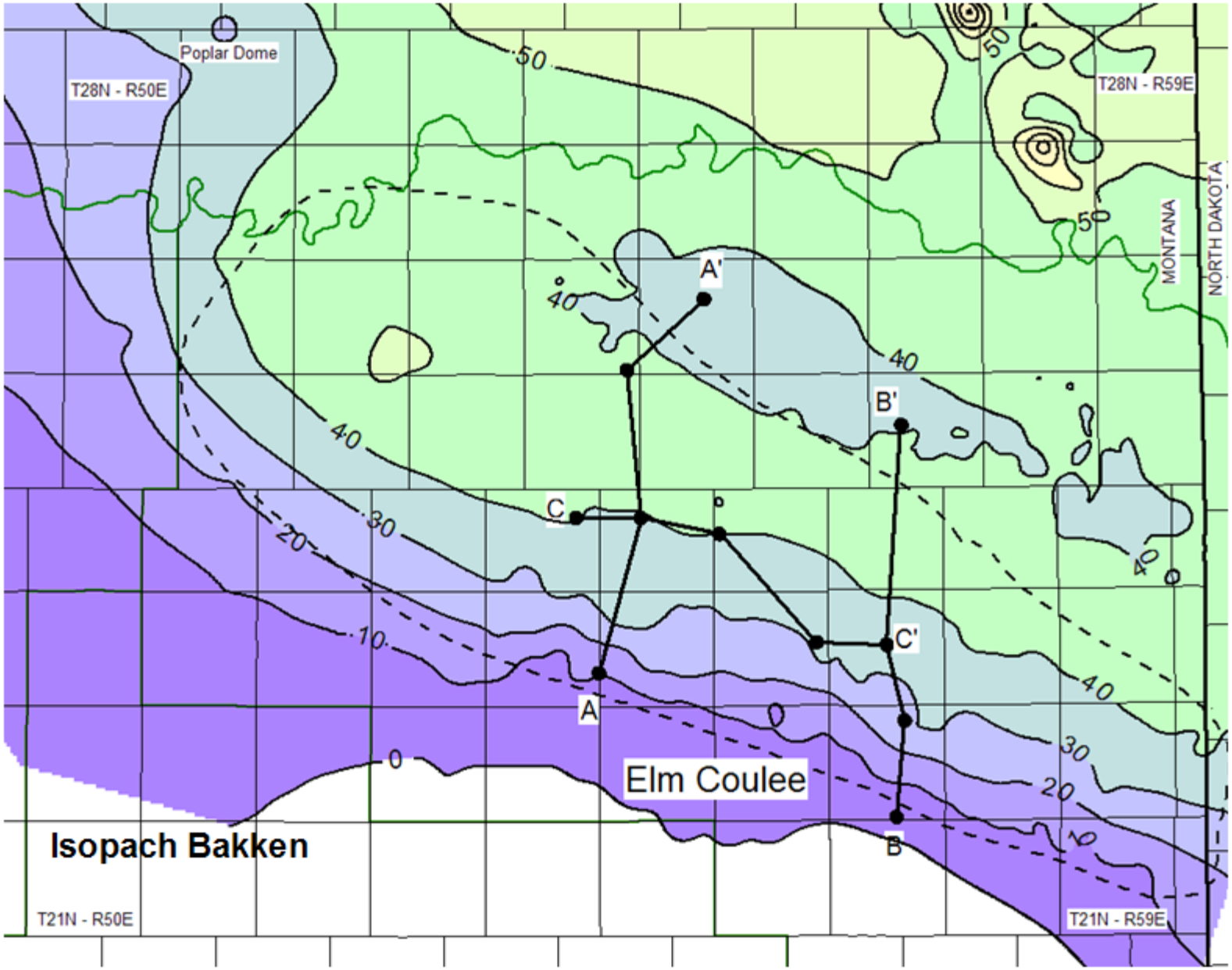


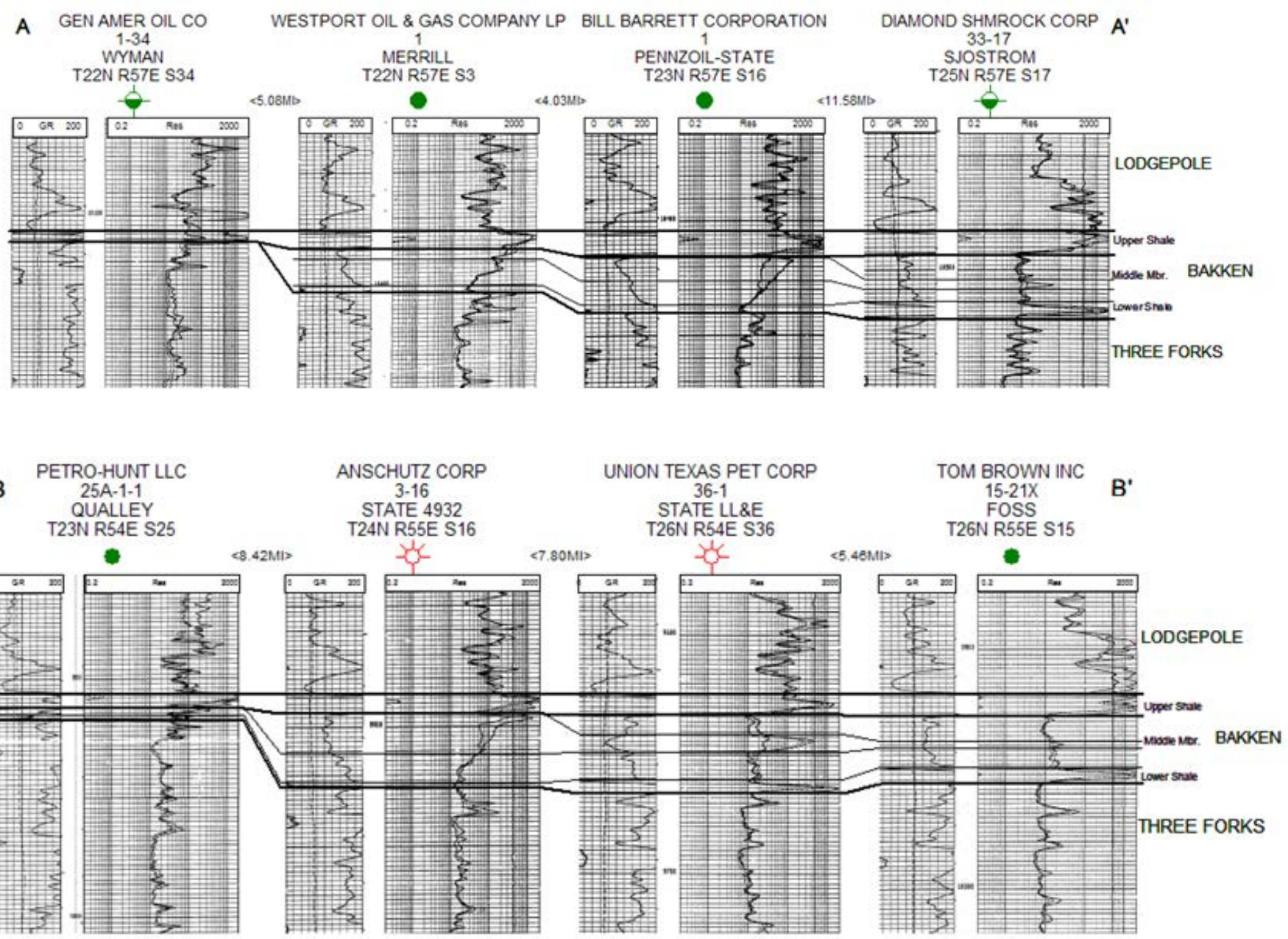
Kelly/Prospector
(Enerplus Resources)
Albin Flb 2-33
Sec. 33-24N-57E

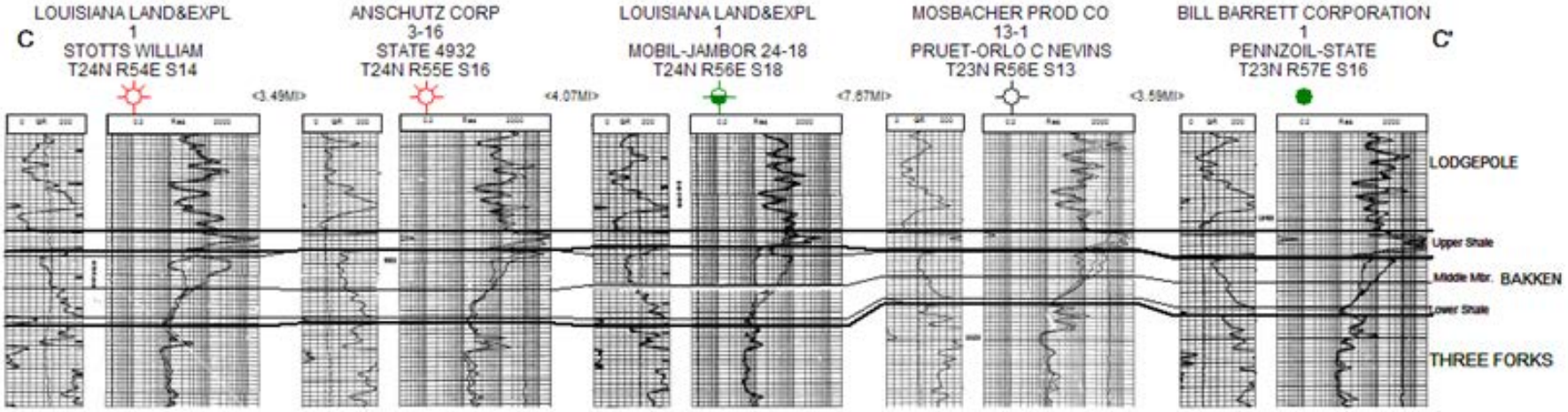
Pfs: 10,451-463
IP: 73 BOPD
Flowed 2,191 barrels oil in the first 30 days beginning March 20, 1996

Treatment:
Water sand frac with 80,260 gallons water & 151,800 lbs sand

Cum: Cum:
92,119 BO; 56,607 MCFG; 10,674 BW


Poplar Dome
T28N - R50E
T28N - R59E
MONTANA
NORTH DAKOTA
50
40
30
20
10
0
A'
B'
C
C'
A
B
Elm Coulee
Isopach Bakken
T21N - R50E
T21N - R59E


A
GEN AMER OIL CO
1-34
WYMAN
T22N R57E S34
<5.08MI>
WESTPORT OIL & GAS COMPANY LP
1
MERRILL
T22N R57E S3
<4.03MI>
BILL BARRETT CORPORATION
1
PENNZOIL-STATE
T23N R57E S16
<11.58MI>
DIAMOND SHMROCK CORP
33-17
SJOSTROM
T25N R57E S17
A'
LODGEPOLE
Upper Shale
Middle Mbr.
BAKKEN
Lower Shale
THREE FORKS
B
PETRO-HUNT LLC
25A-1-1
QUALLEY
T23N R54E S25
<8.42MI>
ANSCHUTZ CORP
3-16
STATE 4932
T24N R55E S16
<7.80MI>
UNION TEXAS PET CORP
36-1
STATE LL&E
T26N R54E S36
<5.46MI>
TOM BROWN INC
15-21X
FOSS
T26N R55E S15
B'
LODGEPOLE
Upper Shale
Middle Mbr.
BAKKEN
Lower Shale
THREE FORKS


C
LOUISIANA LAND&EXPL
1
STOTTS WILLIAM
T24N R54E S14
<3.49MI>
ANSCHUTZ CORP
3-16
STATE 4932
T24N R55E S16
<4.07MI>
LOUISIANA LAND&EXPL
1
MOBIL-JAMBOR 24-18
T24N R56E S18
<7.67MI>
MOSBACHER PROD CO
13-1
PRUET-ORLO C NEVINS
T23N R56E S13
<3.59MI>
BILL BARRETT CORPORATION
1
PENNZOIL-STATE
T23N R57E S16
C'
LODGEPOLE
Upper Shale
Middle Mbr.
BAKKEN
Lower Shale
THREE FORKS

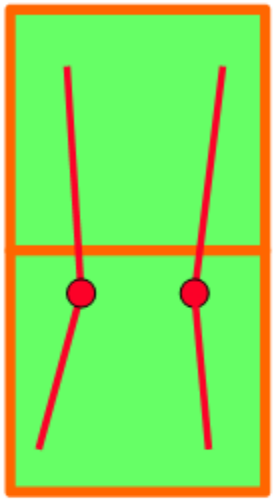
Middle Bakken Reservoir Data

• Formation type:	Fractured Silty Dolomite
• Vertical Depth:	8,500' to 10,500'
• Vertical thickness:	8' to 14'
• Porosity:	8 to 10%
• Permeability:	0.05 md average
• Oil Saturation:	75% average
• Spacing Units:	Primarily 640 to 1280 acres
• Stimulation:	Gelled water, sand frac
• Initial Production:	200 to 1900 BOPD; 100 to 900 Mcfd
• Oil Gravity:	42º API @ 60ºF
• Bottom hole temp:	240ºF
• GOR:	500 CFG/Bbl
• Oil in Place (BO/section):	5,000 MBO
• Primary Recovery Factor:	10%
• Primary Oil Recovery:	500 MBO
• Well Cost:	~ $4,500,000

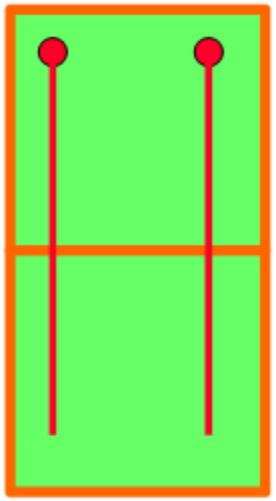
Walker, 2006

Well Spacing Units & Patterns

1280s

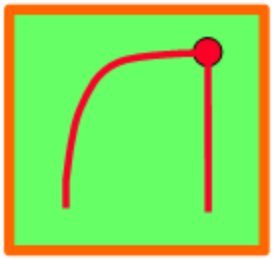


"Bow tie"
Dual laterals

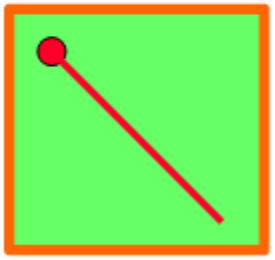


Long single
laterals

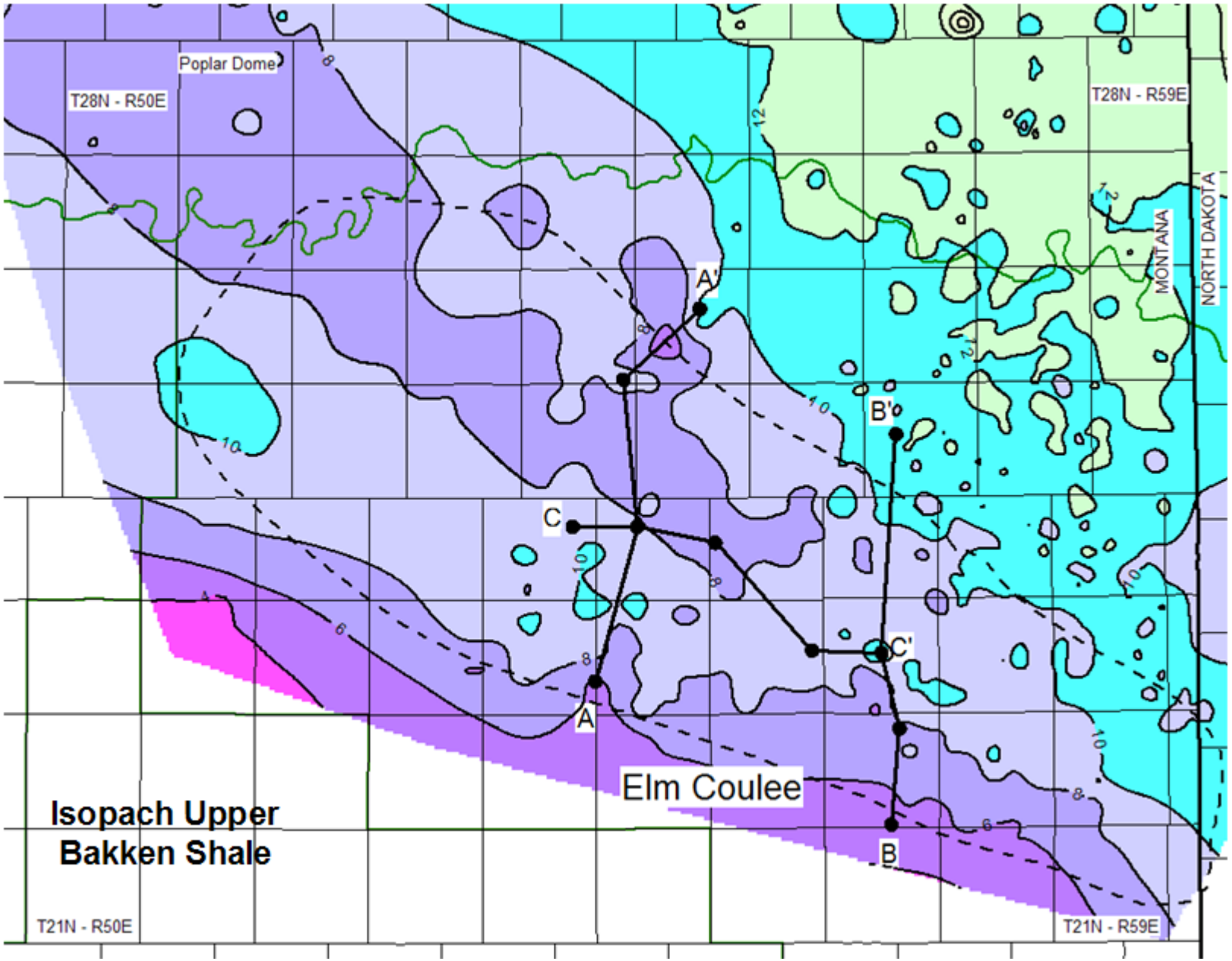
640s

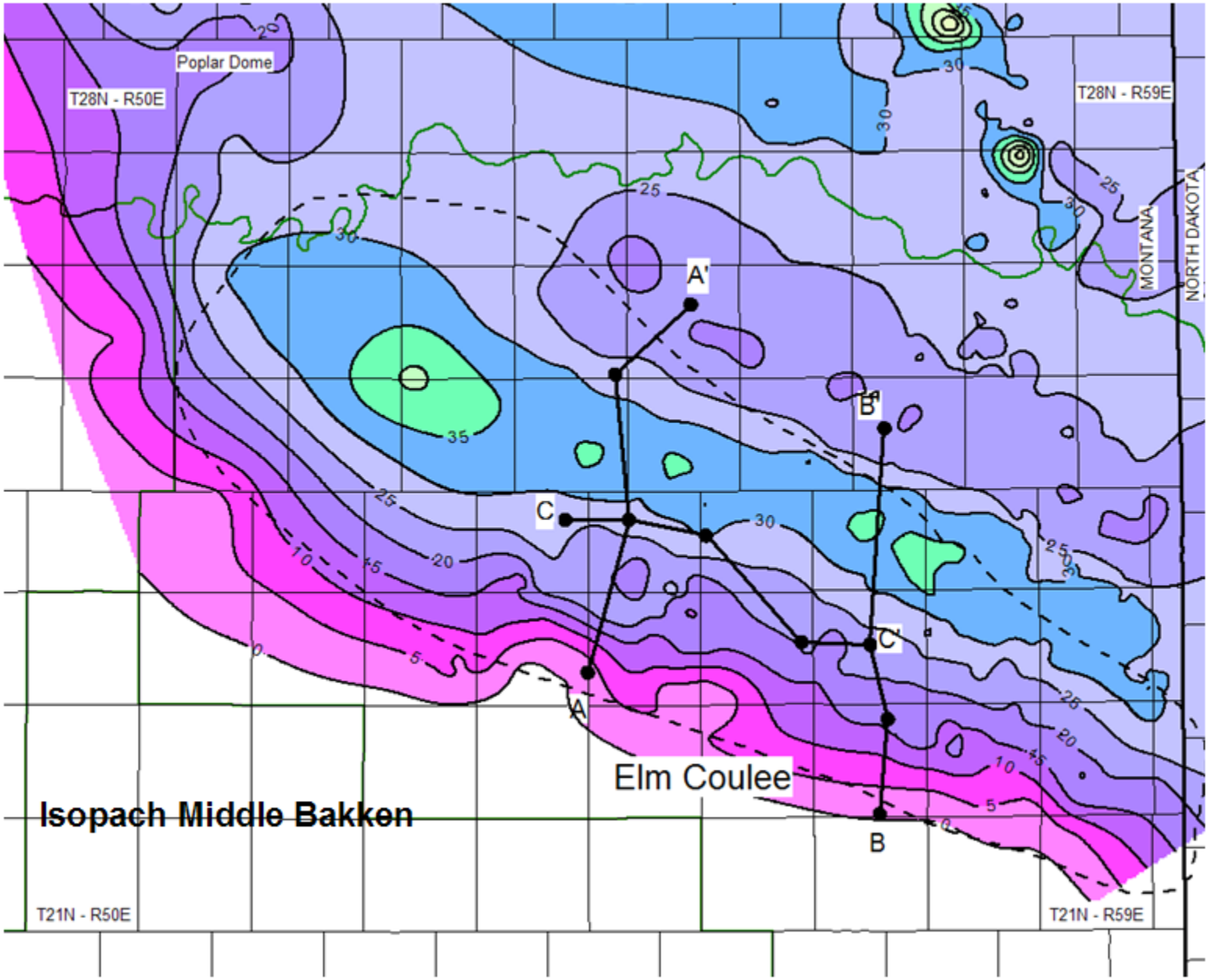


"Bird foot"
Dual laterals

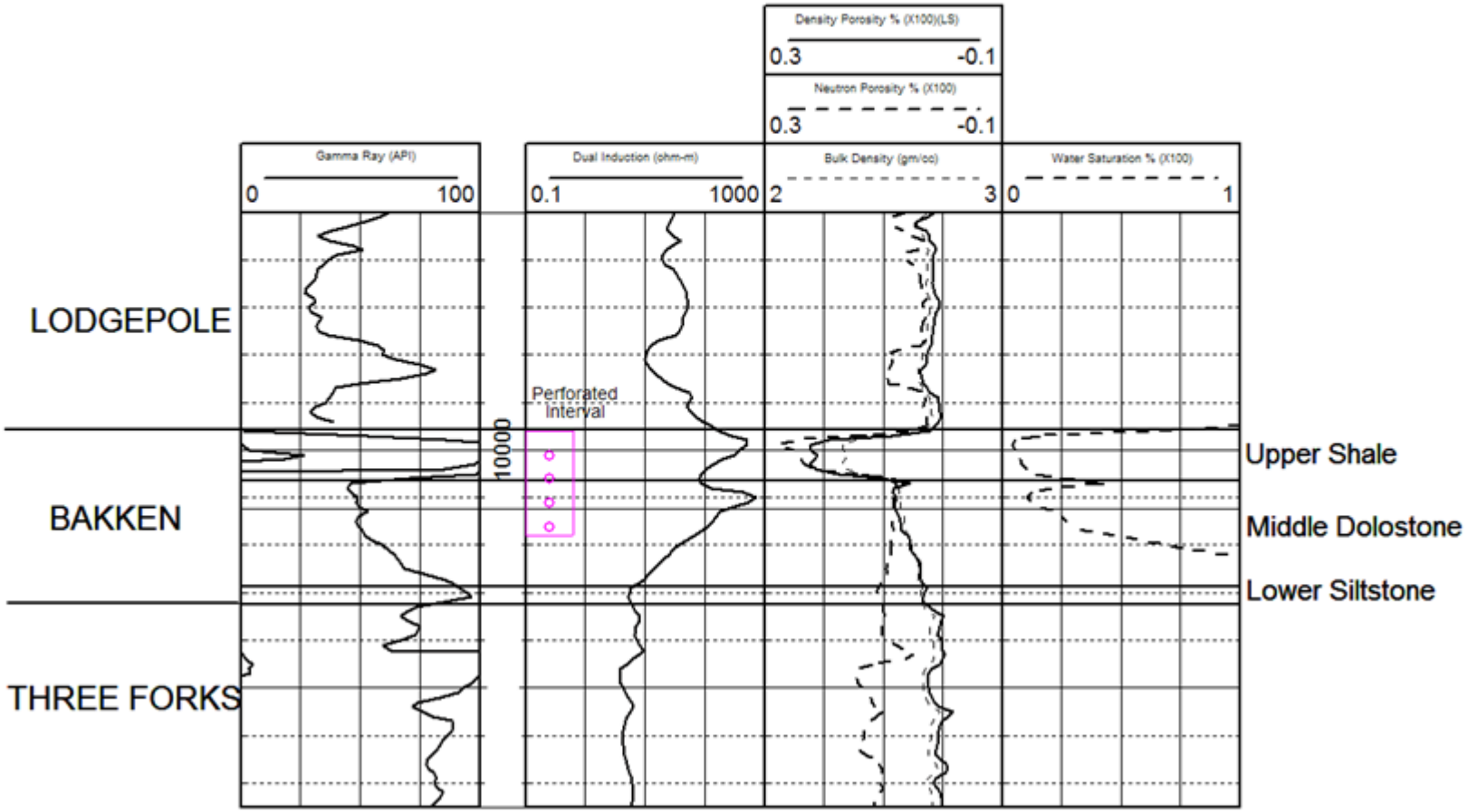


Single
section
laterals


Poplar Dome
T28N - R50E
T28N - R59E
MONTANA
NORTH DAKOTA
A'
B'
C
C'
A
B
Elm Coulee
Isopach Upper
Bakken Shale
T21N - R50E
T21N - R59E

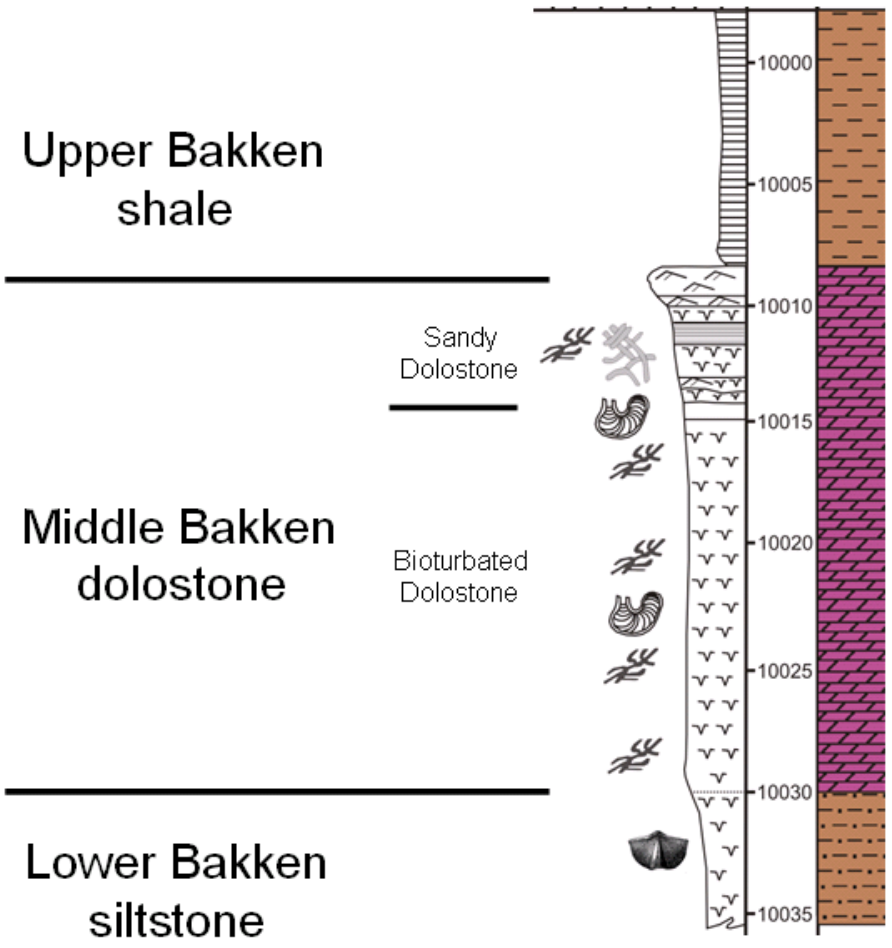

Poplar Dome
T28N - R50E
T28N - R59E
MONTANA
NORTH DAKOTA
A'
B'
C
A
B
C
Elm Coulee
Isopach Middle Bakken
T21N - R50E
T21N - R59E
35
30
25
20
15
10
5
0

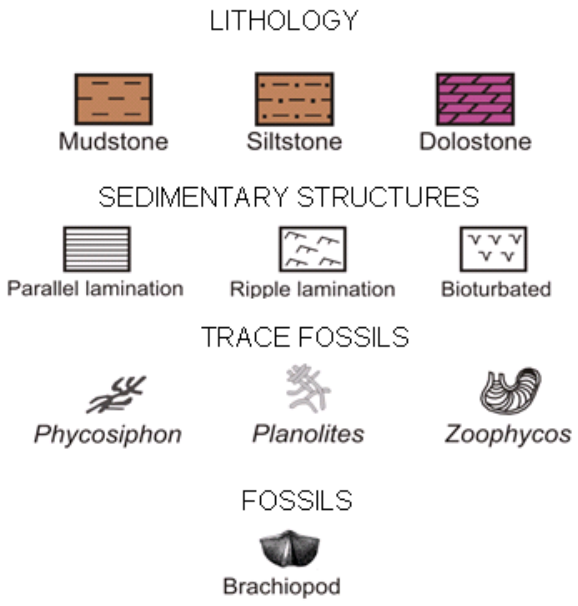
Balcron 44-24 Vaira
(Sec. 24-T24N-R54E, Richland County, Montana)

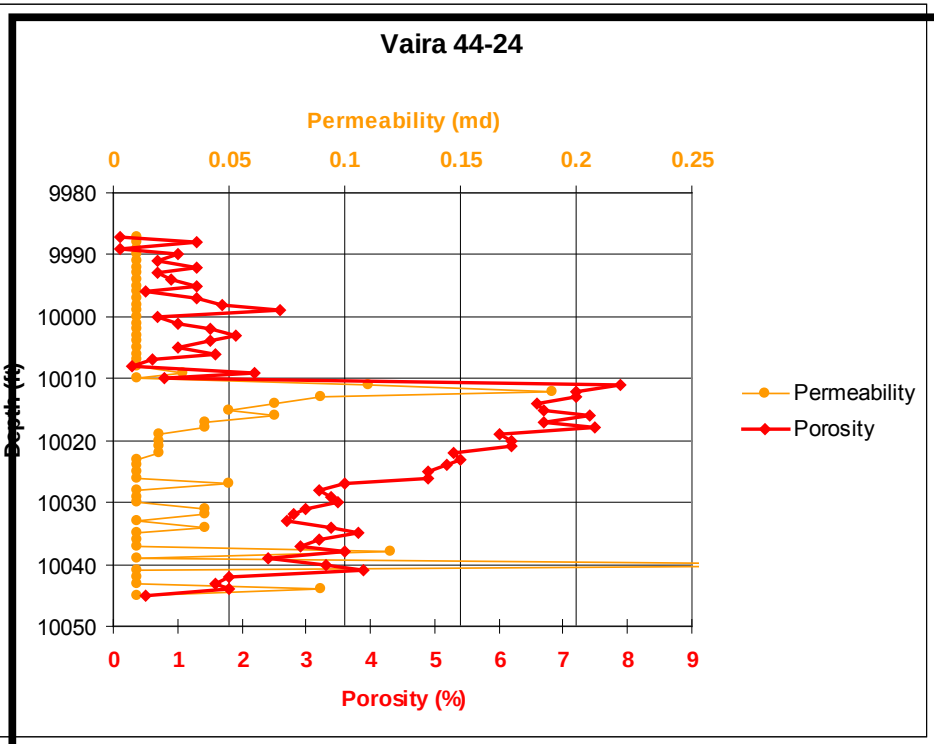


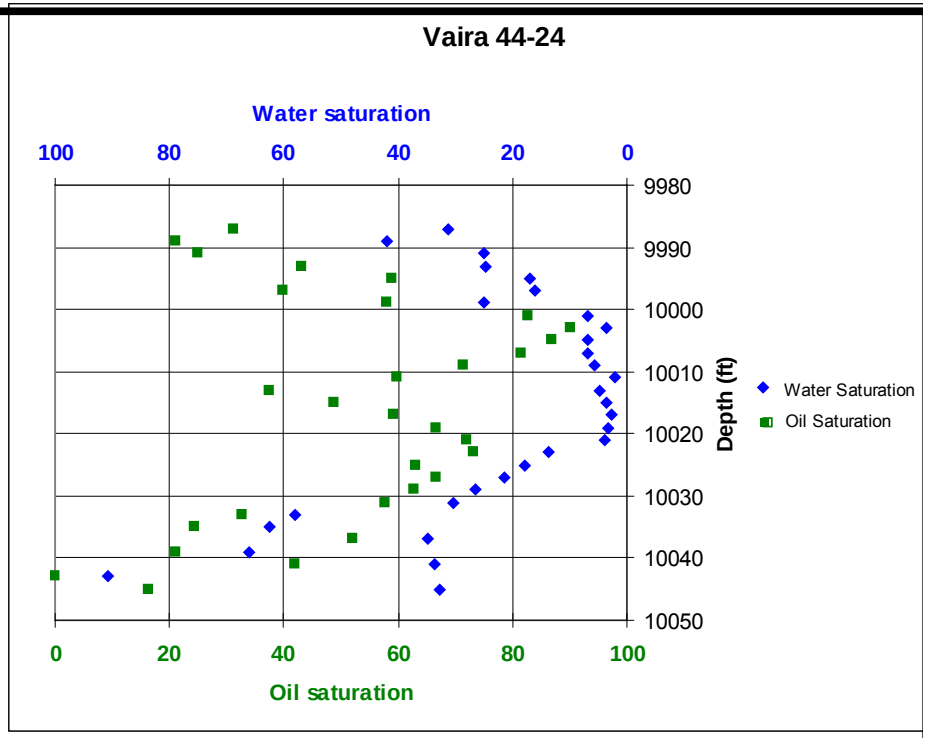
IP: 83 BOPD and 61 MCFD

Core description of the Balcron #44-24 Vaira

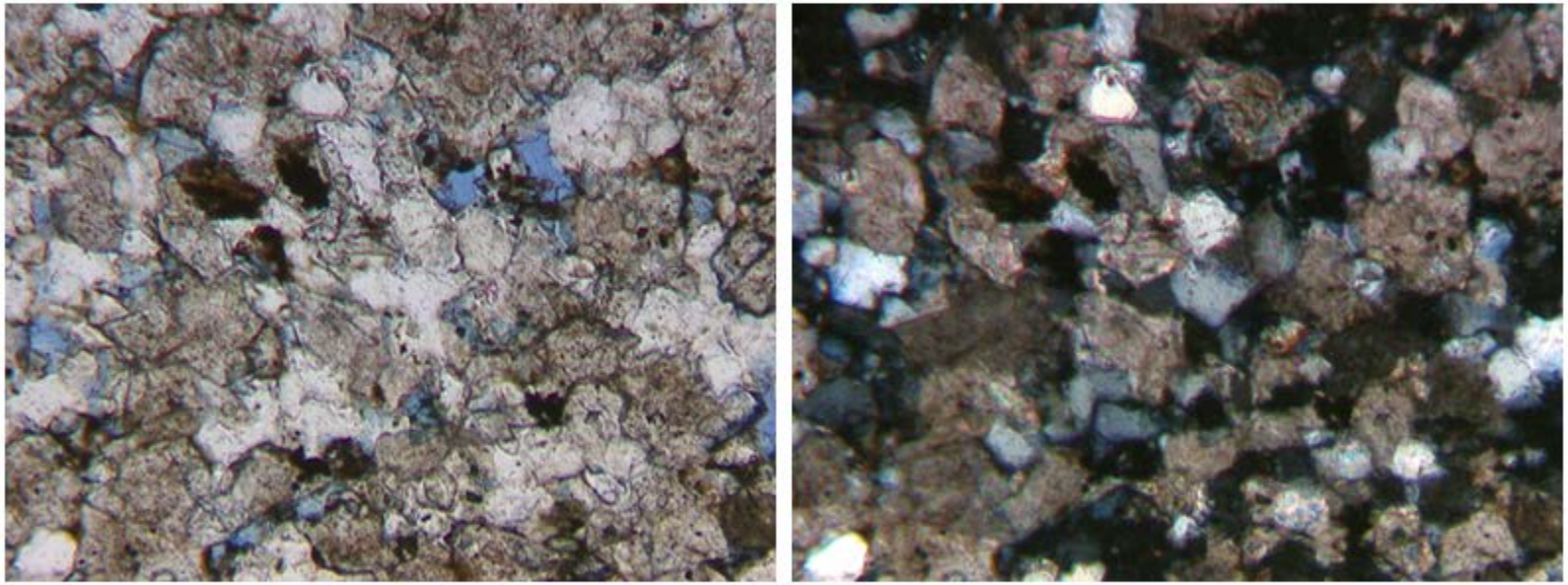





Vaira 44-24
Permeability (md)
0
0.05
0.1
0.15
0.2
0.25
9980
9990
10000
10010
10020
10030
10040
10050
Depth (ft)
0
1
2
3
4
5
6
7
8
9
Porosity (%)
Permeability
Porosity

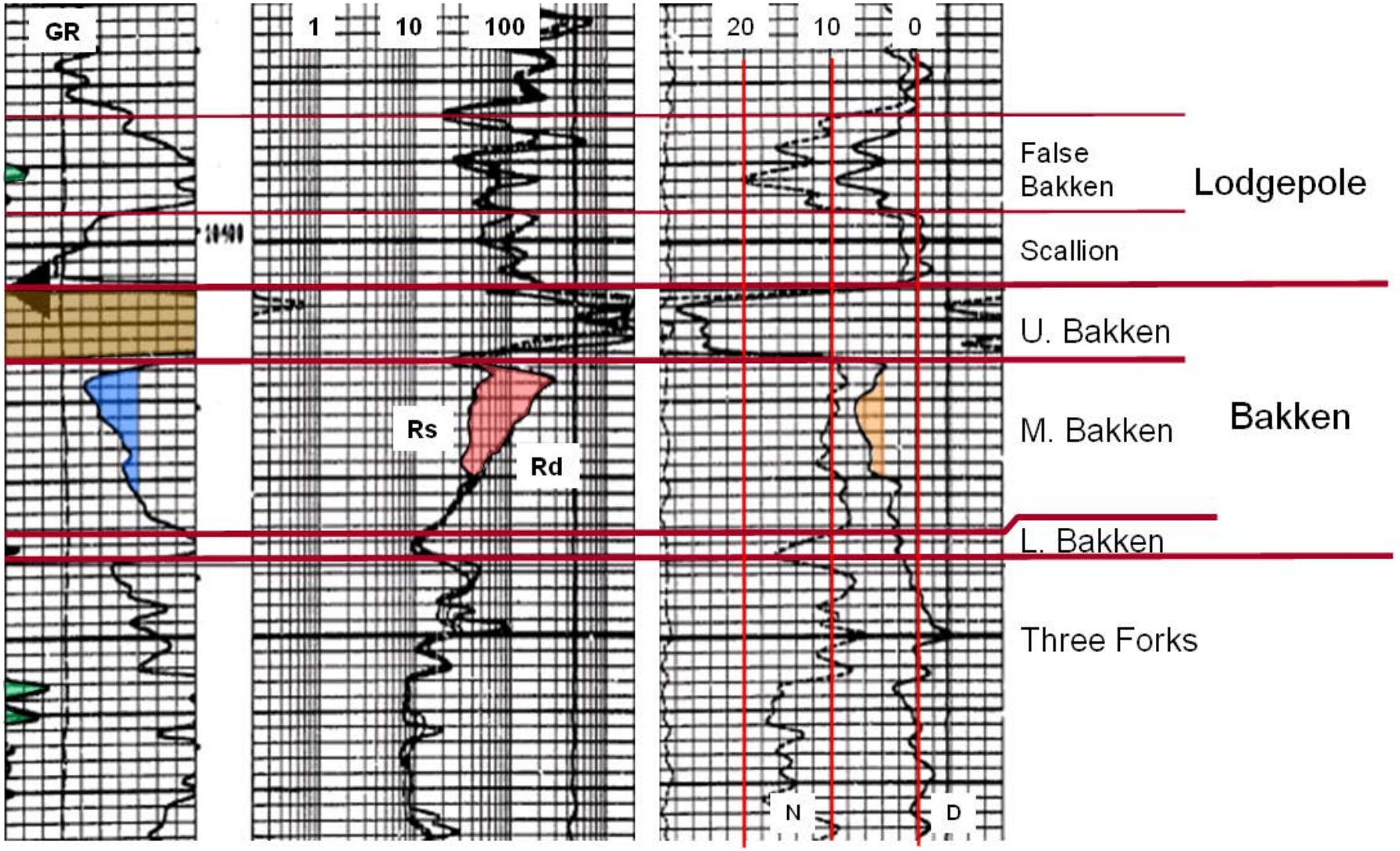

Vaira 44-24
Water saturation
100
80
60
40
20
0
9980
9990
10000
10010
10020
10030
10040
10050
Depth (ft)
0
20
40
60
80
100
Oil saturation
Water Saturation
Oil Saturation

Vaira - 10011

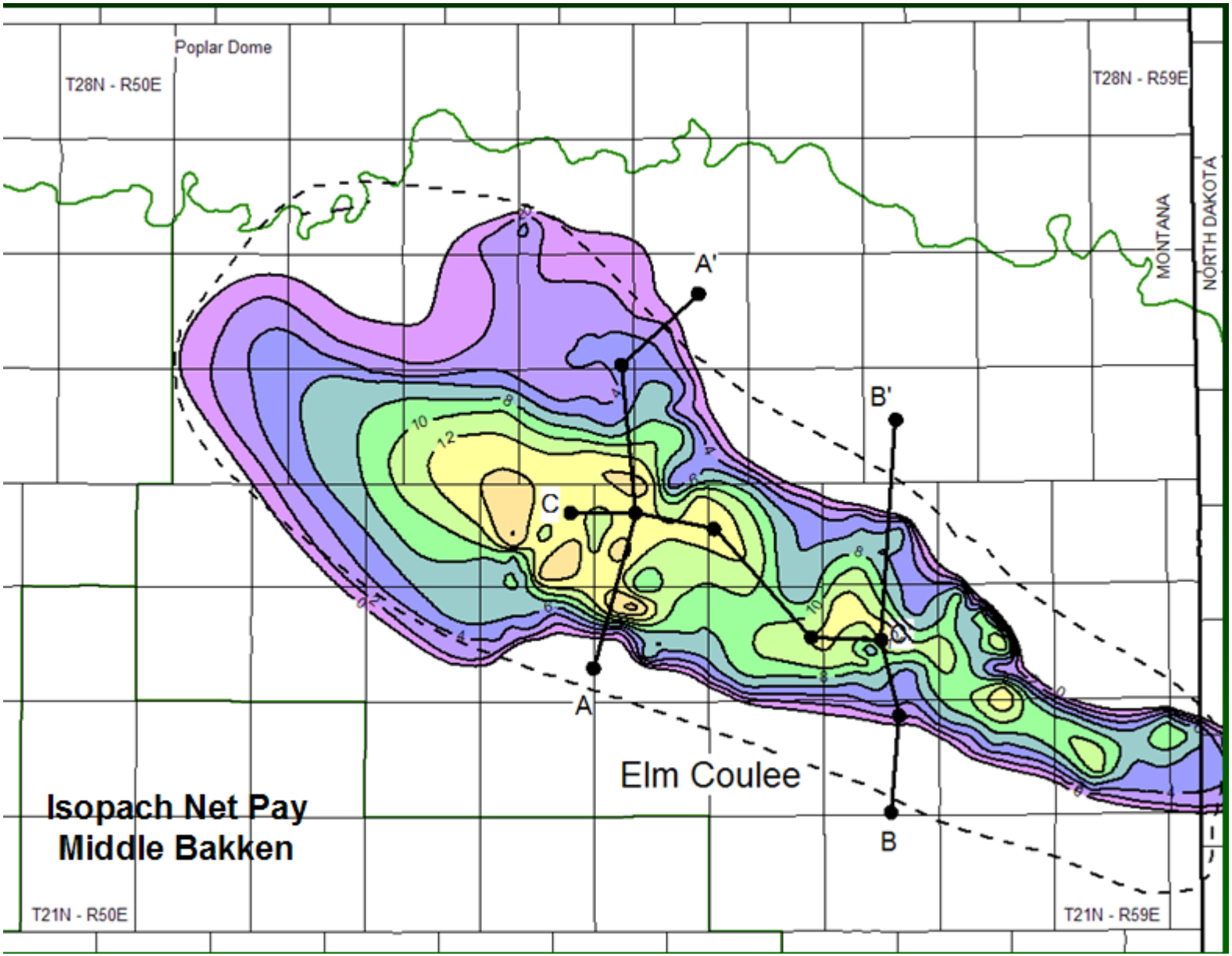


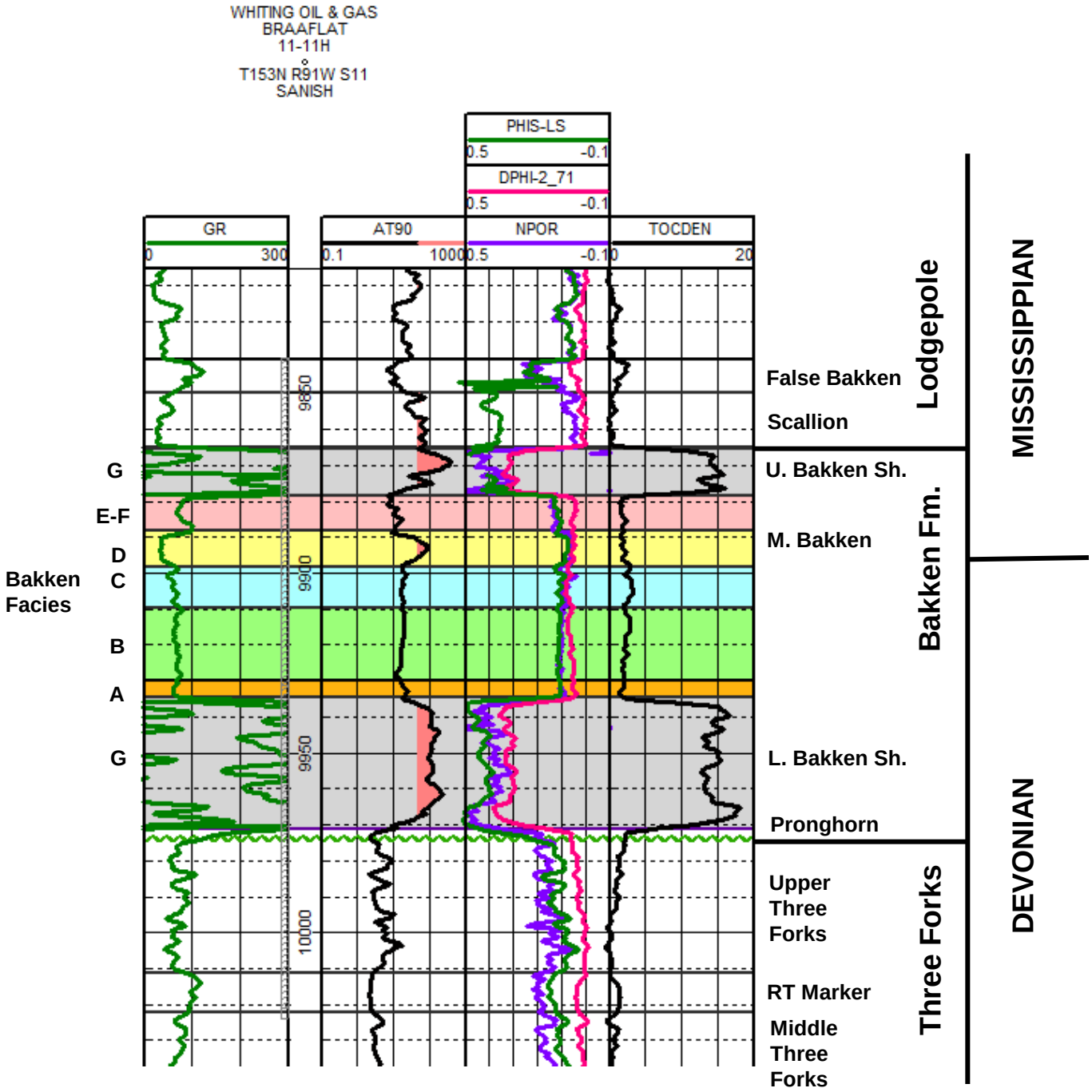
O.5 MM

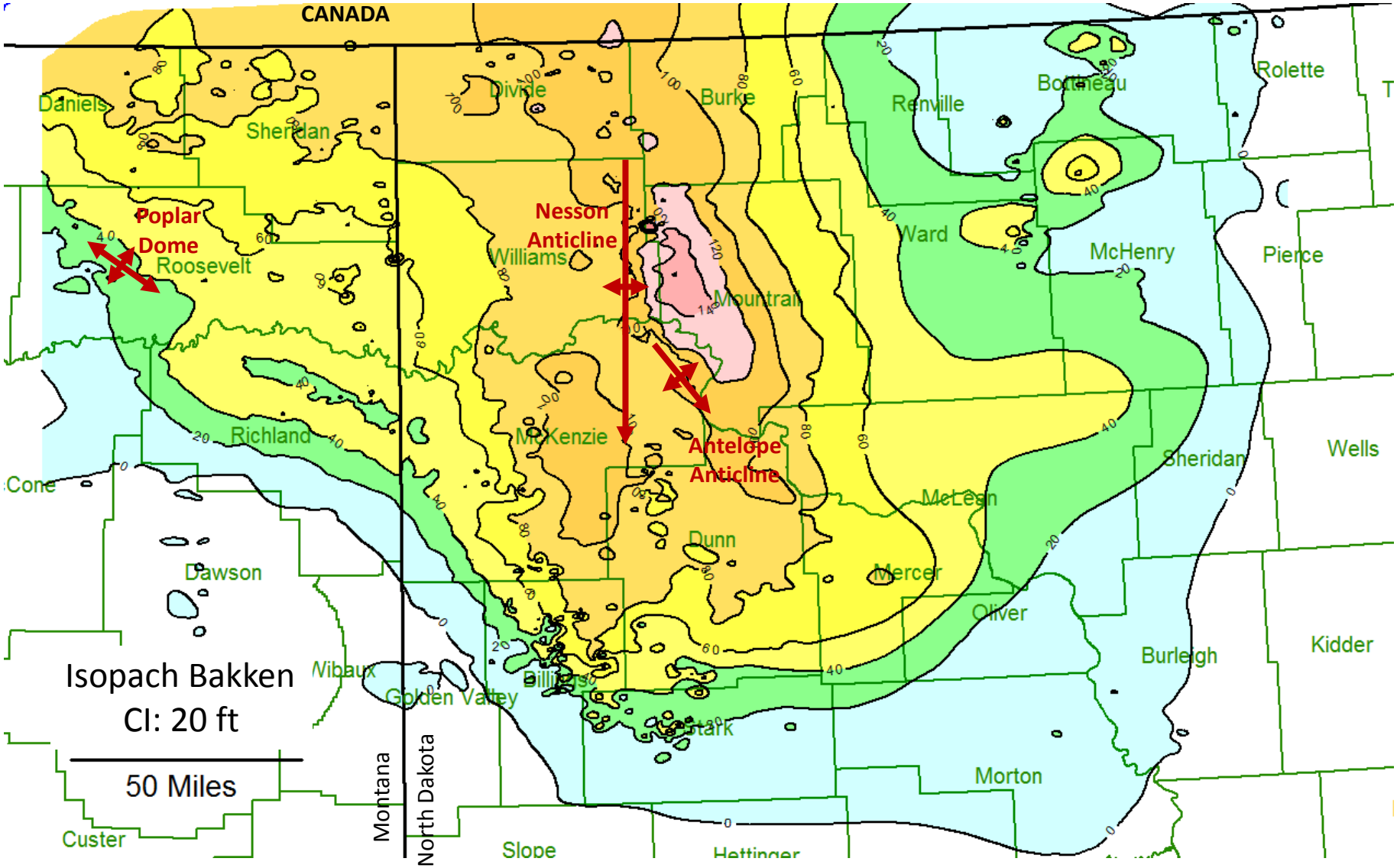
Bakken Type Log
Richland County, Montana
Sec. 16-T23N-R57E

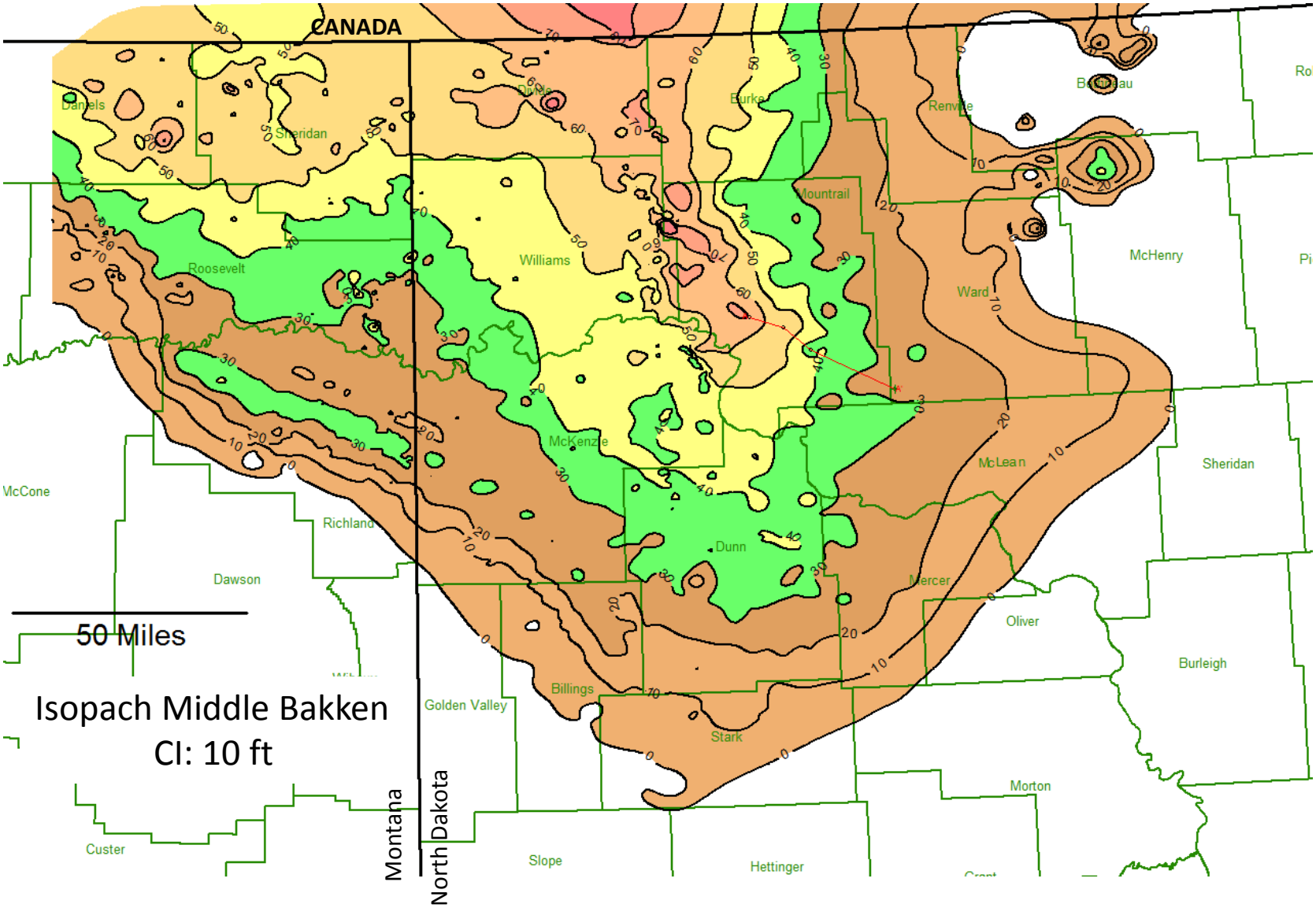


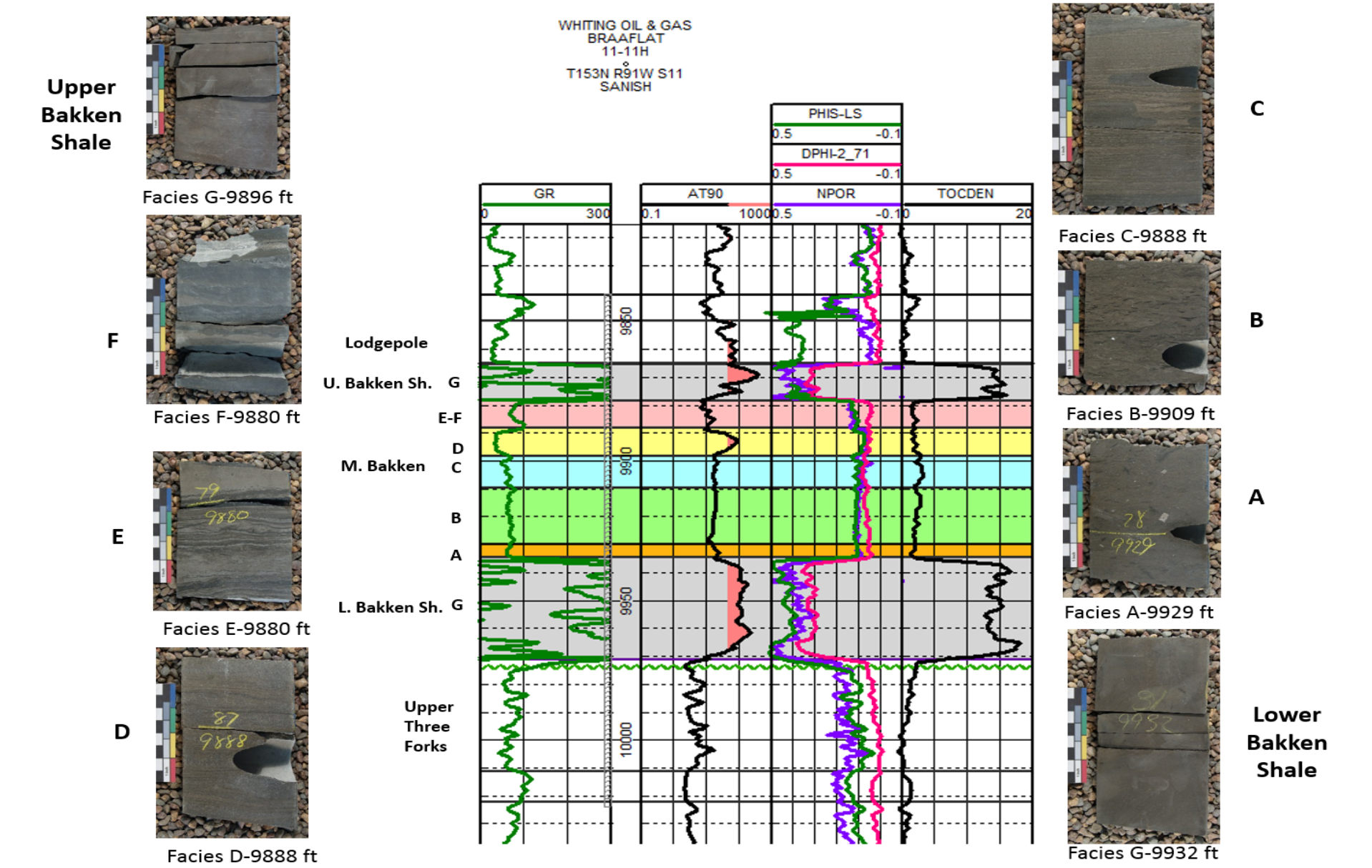
SAS, 2004

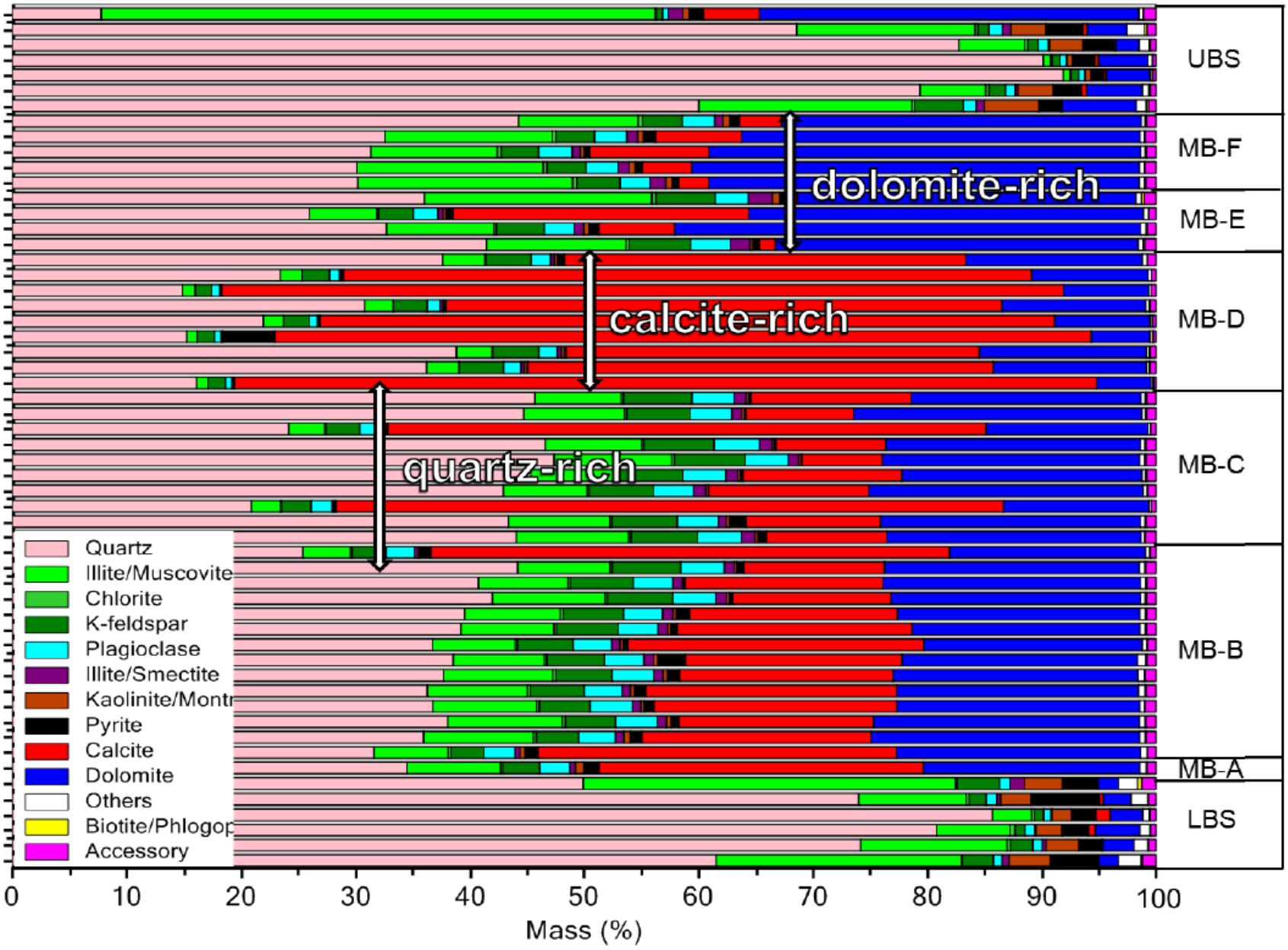

Poplar Dome
T28N - R50E
T28N - R59E
MONTANA
NORTH DAKOTA
A'
B'
C
C'
A
B
Elm Coulee
Isopach Net Pay
Middle Bakken
T21N - R50E
T21N - R59E


WHITING OIL & GAS
BRAAFLAT
11-11H
T153N R91W S11
SANISH
PHIS-LS
0.5 -0.1
DPHI-2_71
0.5 -0.1
GR
0 300
AT90
0.1 1000
NPOR
0.5 -0.1
TOCDEN
0 20
9850
9900
9950
10000
Bakken Facies
G
E-F
D
C
B
A
G
False Bakken
Scallion
U. Bakken Sh.
M. Bakken
L. Bakken Sh.
Pronghorn
Upper Three Forks
RT Marker
Middle Three Forks
Lodgepole
Bakken Fm.
Three Forks
MISSISSIPPIAN
DEVONIAN


CANADA
Daniels
Sheridan
Divide
Burke
Renville
Bottineau
Rolette
Poplar
Dome
Roosevelt
Nesson
Anticline
Williams
Mountrail
Ward
McHenry
Pierce
Richland
McKenzie
Antelope
Anticline
Sheridan
Wells
Cone
McLean
Dunn
Dawson
Mercer
Oliver
Burleigh
Kidder
Nibaux
Billings
Golden Valley
Stark
Morton
Isopach Bakken
CI: 20 ft
50 Miles
Montana
North Dakota
Custer
Slope
Hettinger


CANADA
Daniels
Sheridan
Burke
Renville
Bottineau
Mountrail
Williams
Roosevelt
McHenry
Ward
McKenzie
McLean
Sheridan
McCone
Richland
Dawson
Dunn
Mercer
Oliver
Burleigh
Billings
Golden Valley
Stark
Morton
Custer
Slope
Hettinger
50 Miles
Isopach Middle Bakken
CI: 10 ft
Montana
North Dakota

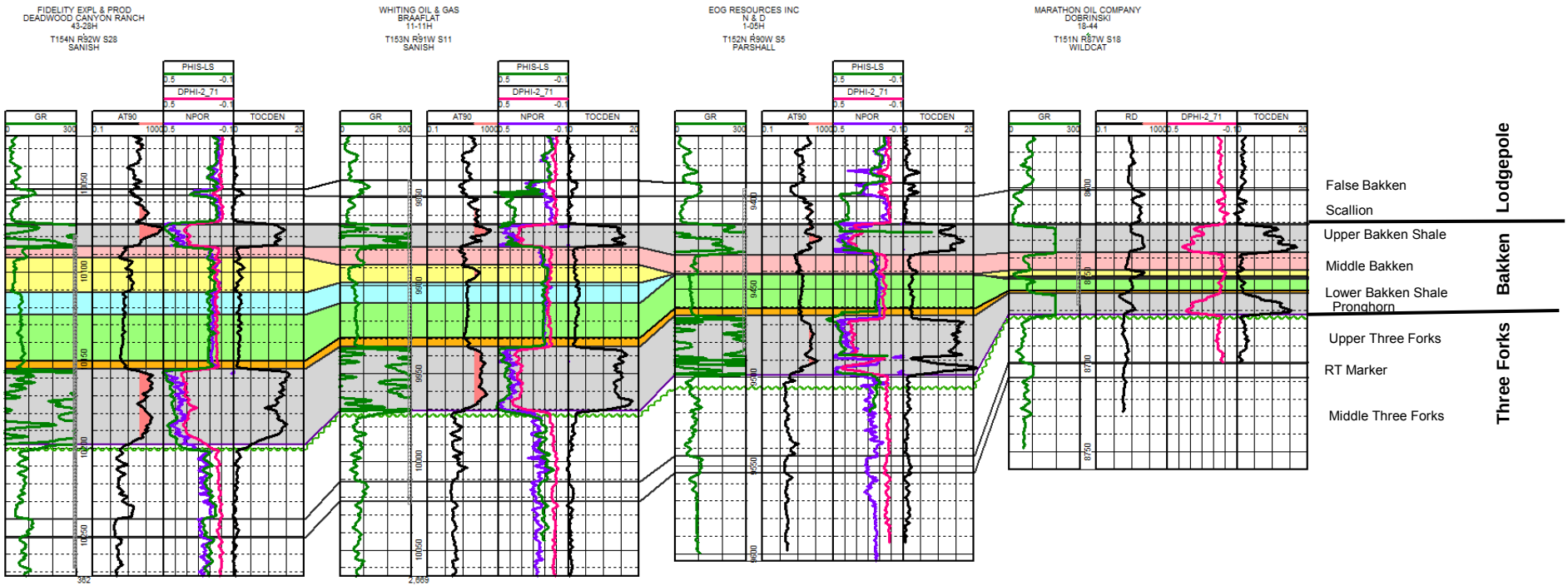

Upper Bakken Shale
Facies G-9896 ft
F
Facies F-9880 ft
E
Facies E-9880 ft
D
Facies D-9888 ft
WHITING OIL & GAS
BRAAFLAT
11-11H
T153N R91W S11
SANISH
PHIS-LS
0.5 -0.1
DPHI-2_71
0.5 -0.1
GR
0 300
AT90
0.1 1000
NPOR
0.5 -0.1
TOCDEN
0 20
9850
9900
9950
10000
Lodgepole
U. Bakken Sh.
G
E-F
D
M. Bakken
C
B
A
L. Bakken Sh.
G
Upper Three Forks
C
Facies C-9888 ft
B
Facies B-9909 ft
A
Facies A-9929 ft
Lower Bakken Shale
Facies G-9932 ft


UBS
MB-F
MB-E
MB-D
MB-C
MB-B
MB-A
LBS
dolomite-rich
calcite-rich
quartz-rich
Quartz
Illite/Muscovite
Chlorite
K-feldspar
Plagioclase
Illite/Smectite
Kaolinite/Montr
Pyrite
Calcite
Dolomite
Others
Biotite/Phlogop
Accessory
0
10
20
30
40
50
60
70
80
90
100
Mass (%)

Sanish Field

Parshall Field

Non-productive



Source Beds:
Mature

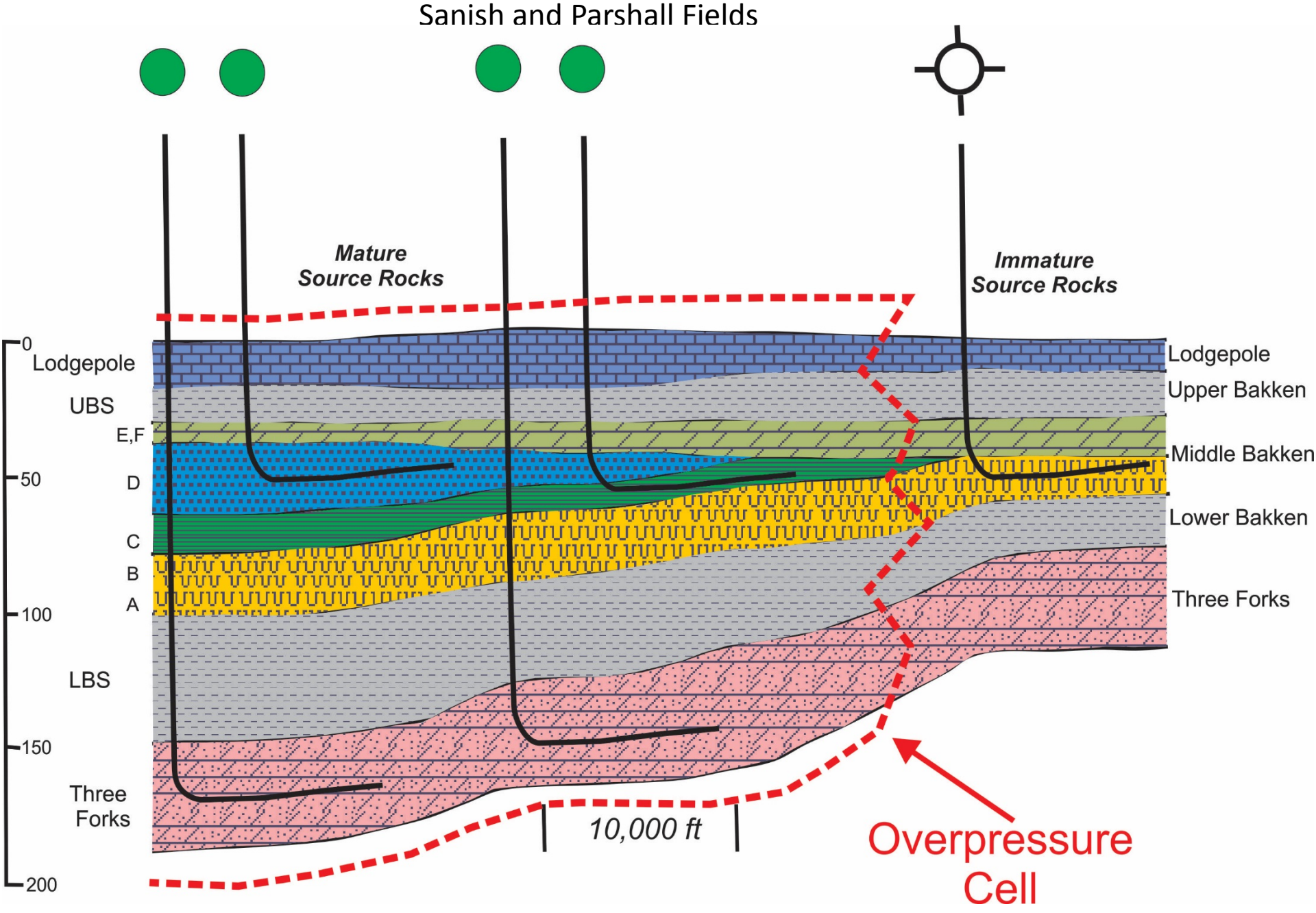
Overpressured

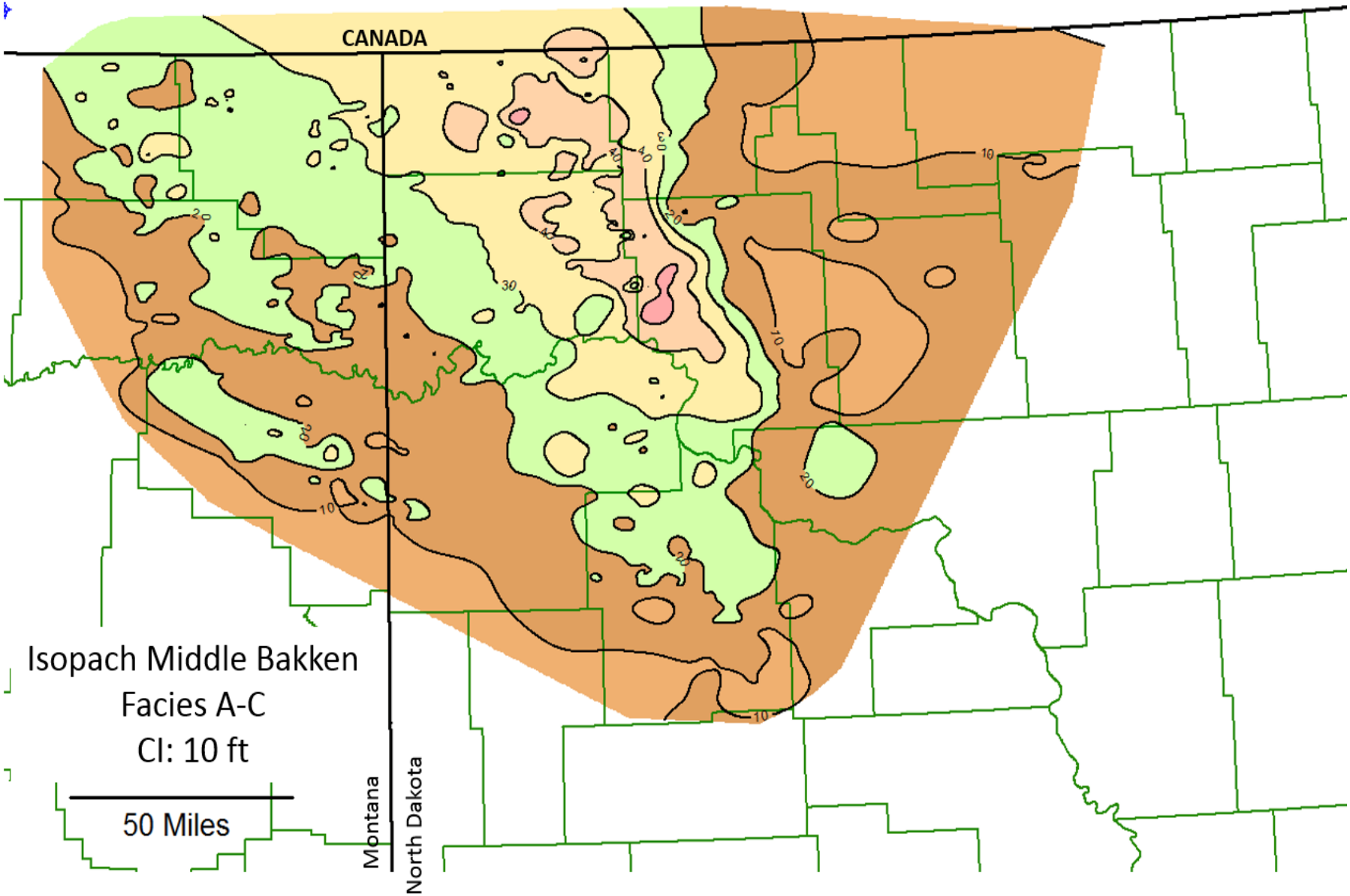
Source Beds:
Marginally mature

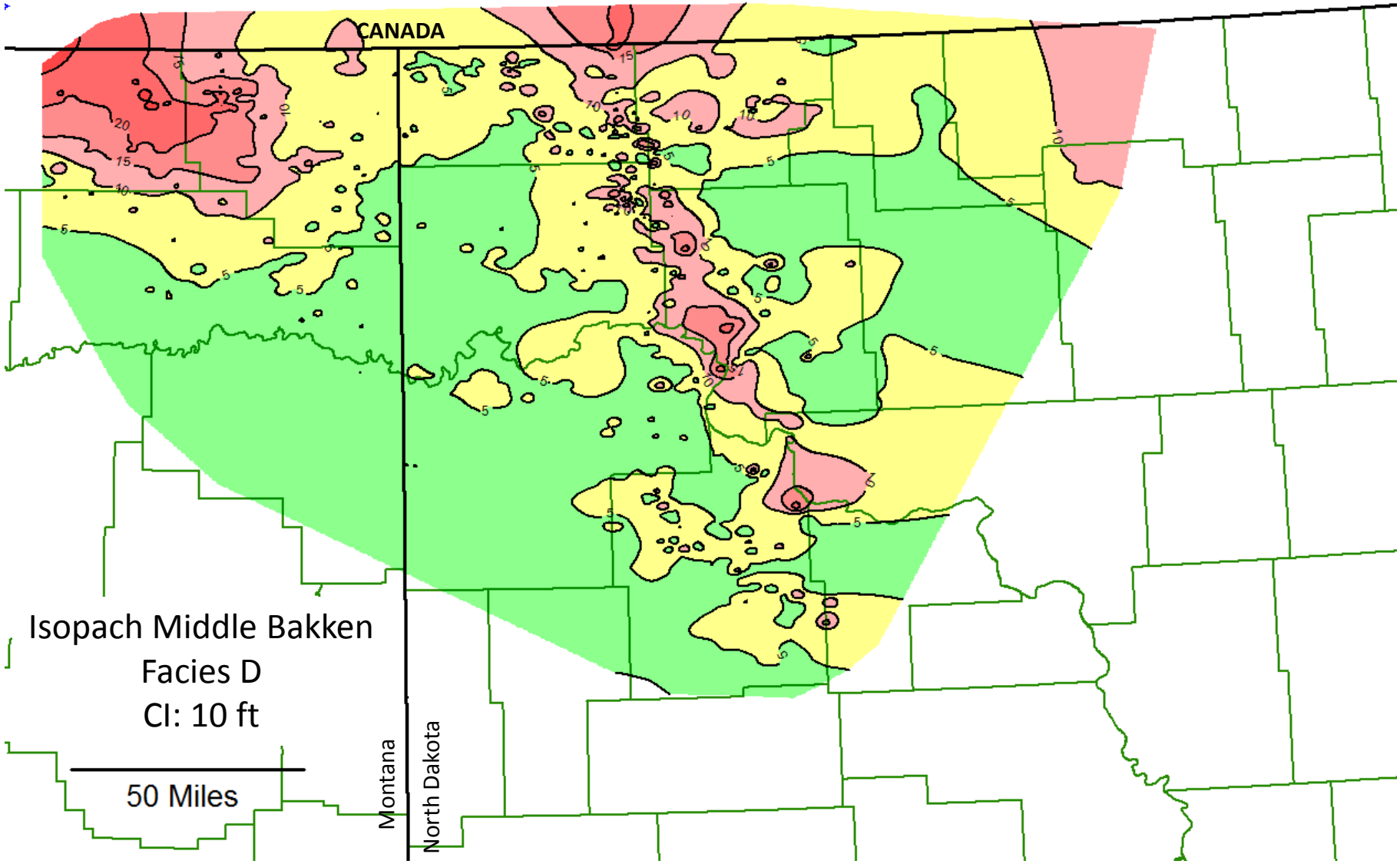
Highly over3pressured

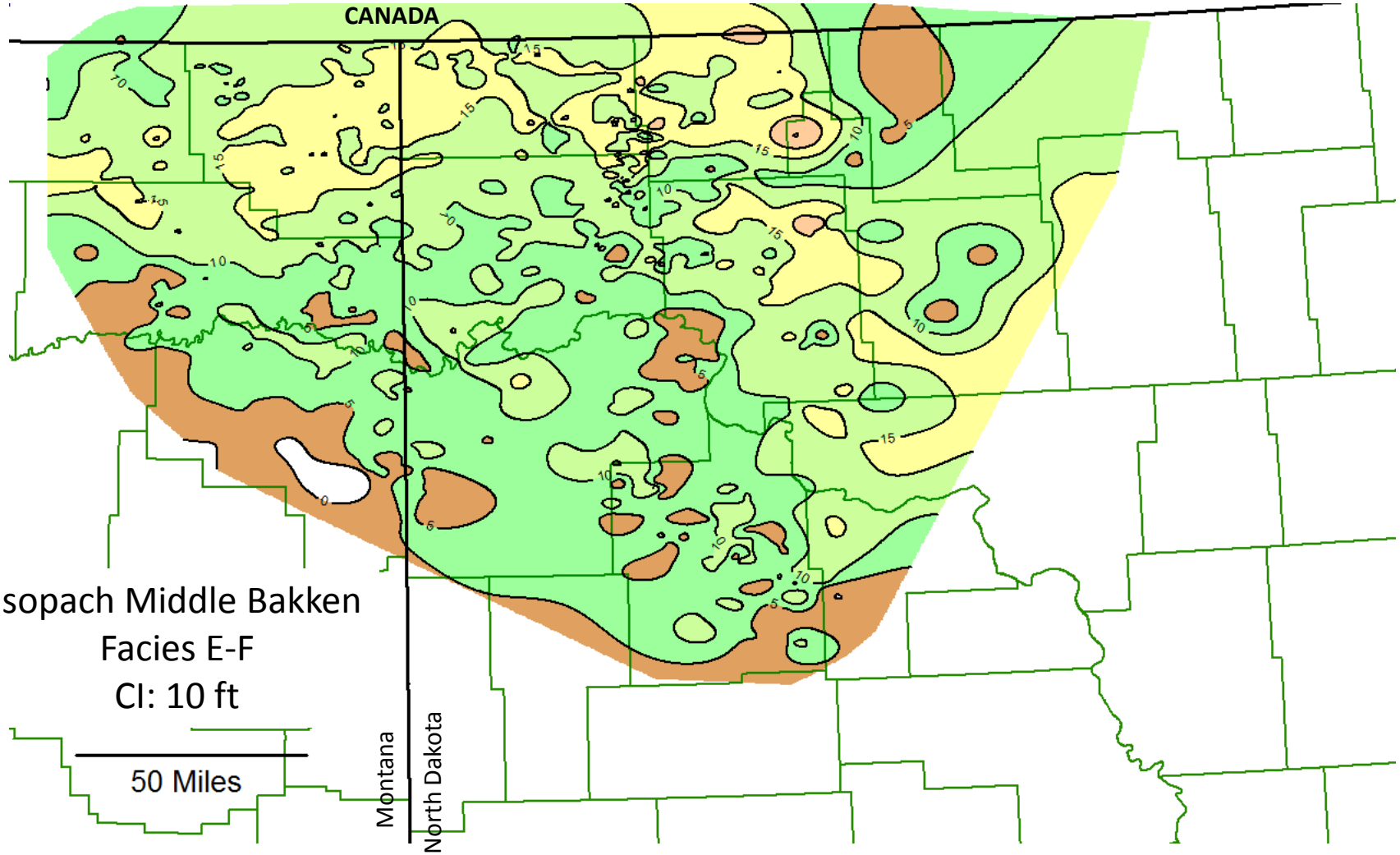
Source Beds:
Immature

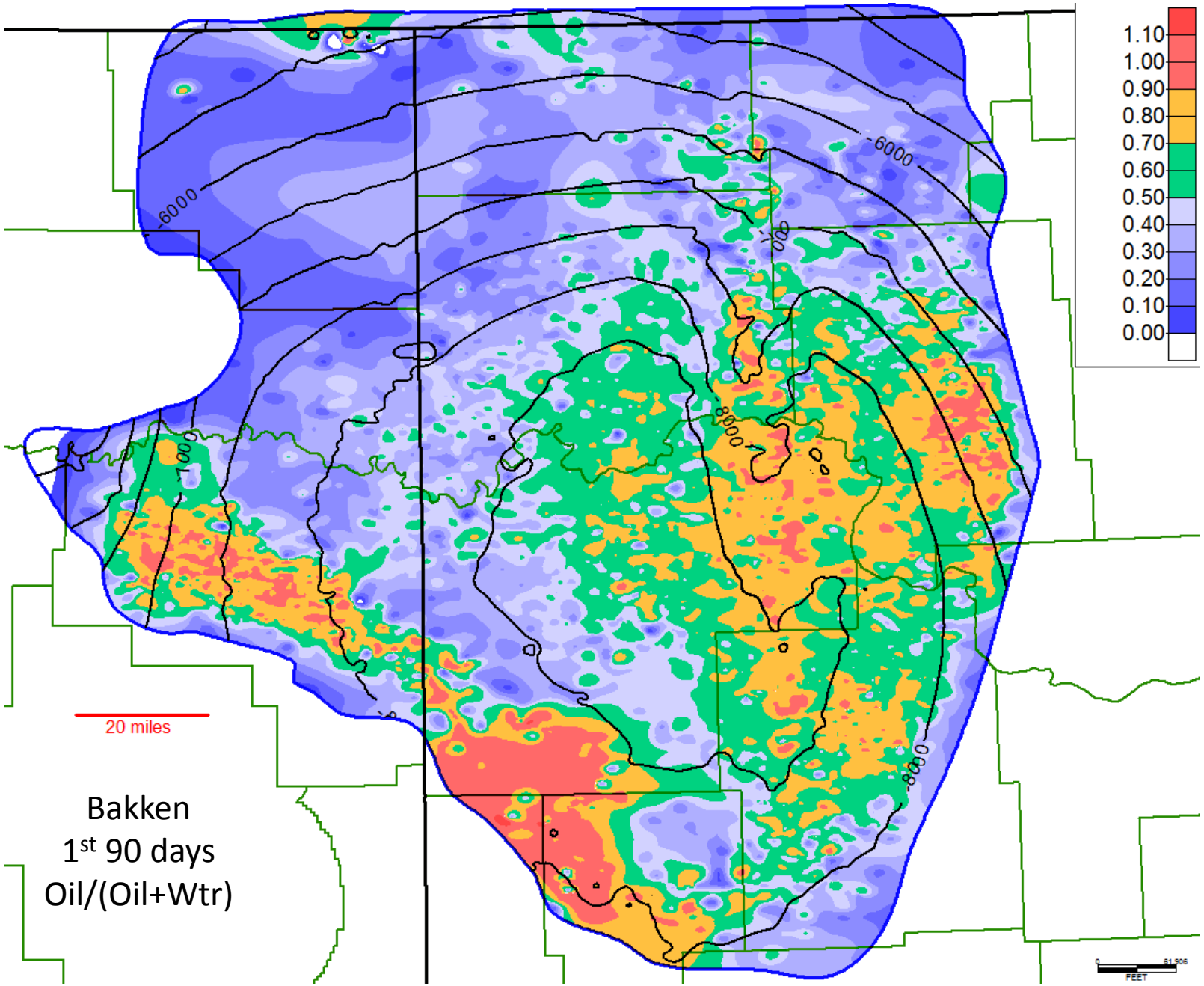
Normally pressured

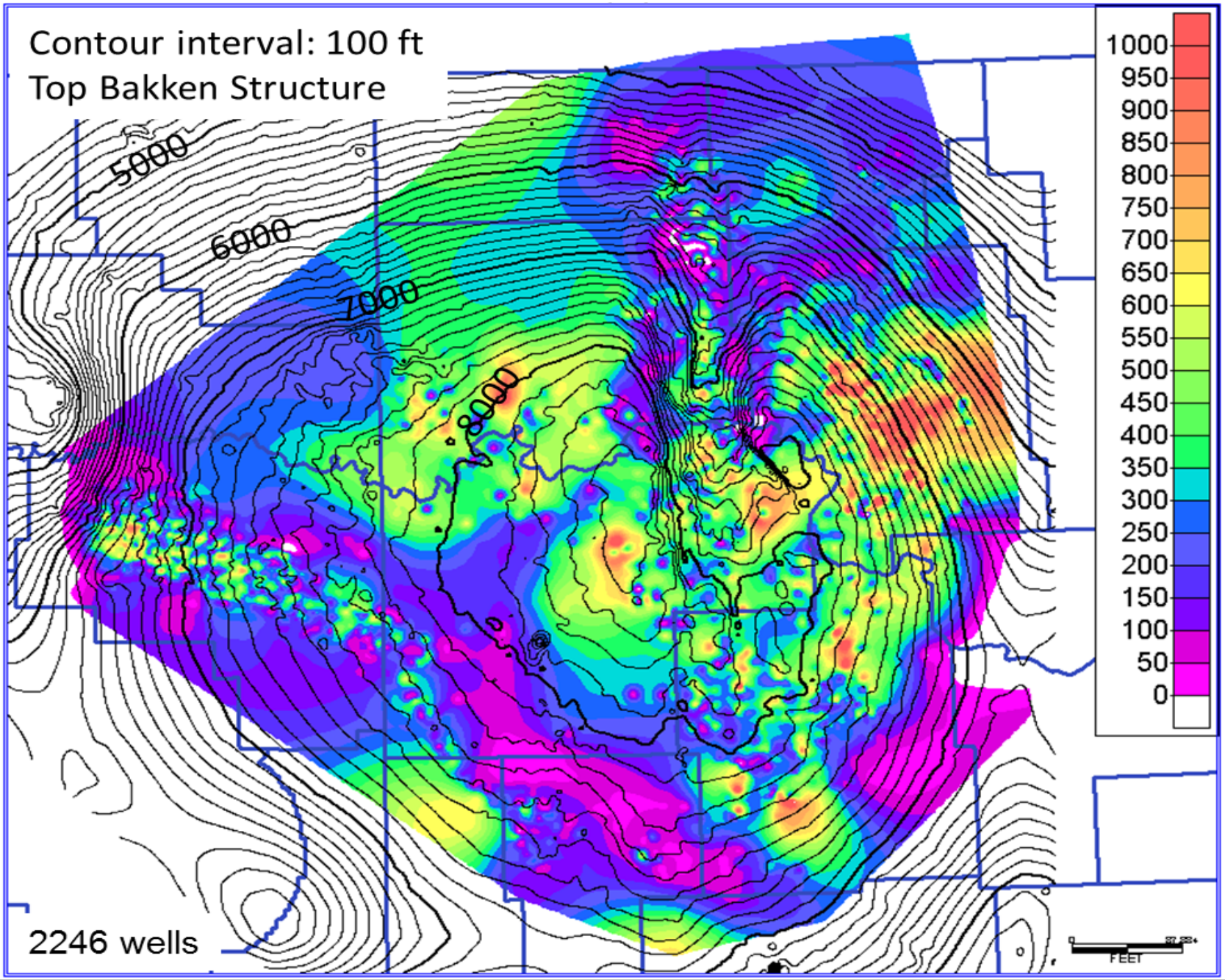

Sanish and Parshall Fields
Mature
Source Rocks
Immature
Source Rocks
0
50
100
150
200
Lodgepole
UBS
E,F
D
C
B
A
LBS
Three
Forks
Lodgepole
Upper Bakken
Middle Bakken
Lower Bakken
Three Forks
10,000 ft
Overpressure
Cell


CANADA
Isopach Middle Bakken
Facies A-C
CI: 10 ft
50 Miles
Montana
North Dakota

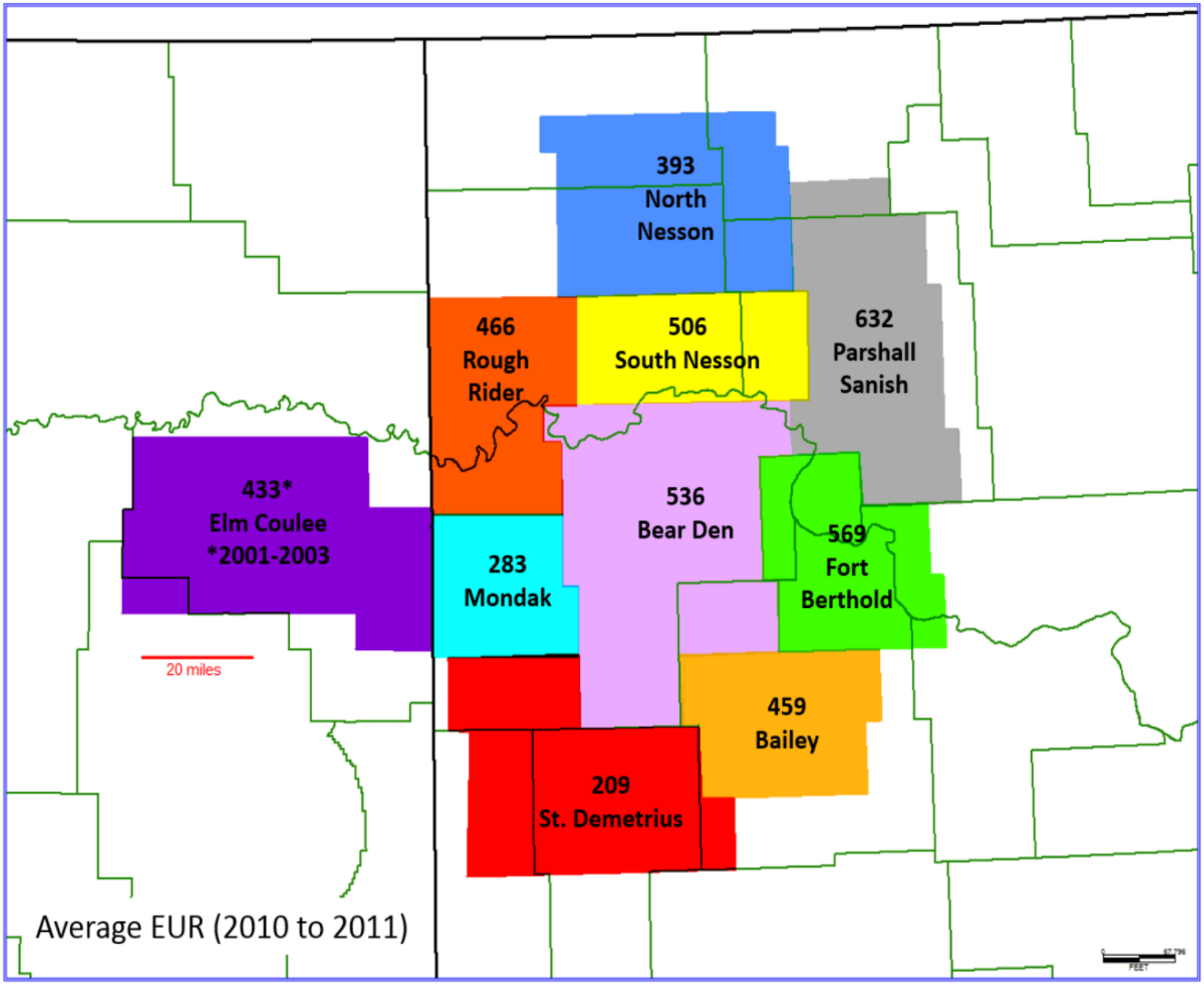

CANADA
Isopach Middle Bakken
Facies D
CI: 10 ft
50 Miles
Montana
North Dakota


CANADA
Isopach Middle Bakken
Facies E-F
CI: 10 ft
50 Miles
Montana
North Dakota

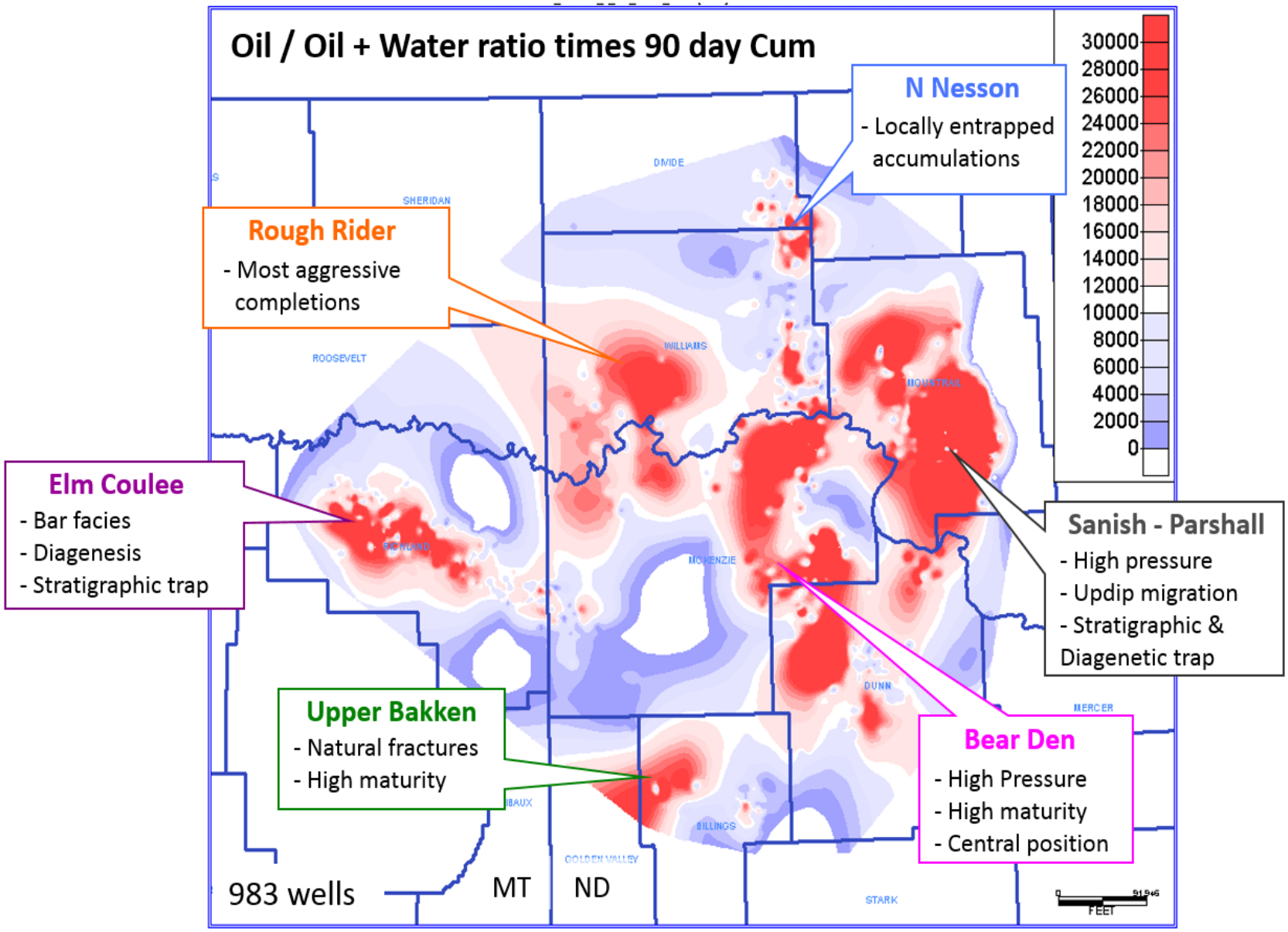

1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-6000
-6000
-7000
-8000
-8000
20 miles
Bakken
1st 90 days
Oil/(Oil+Wtr)



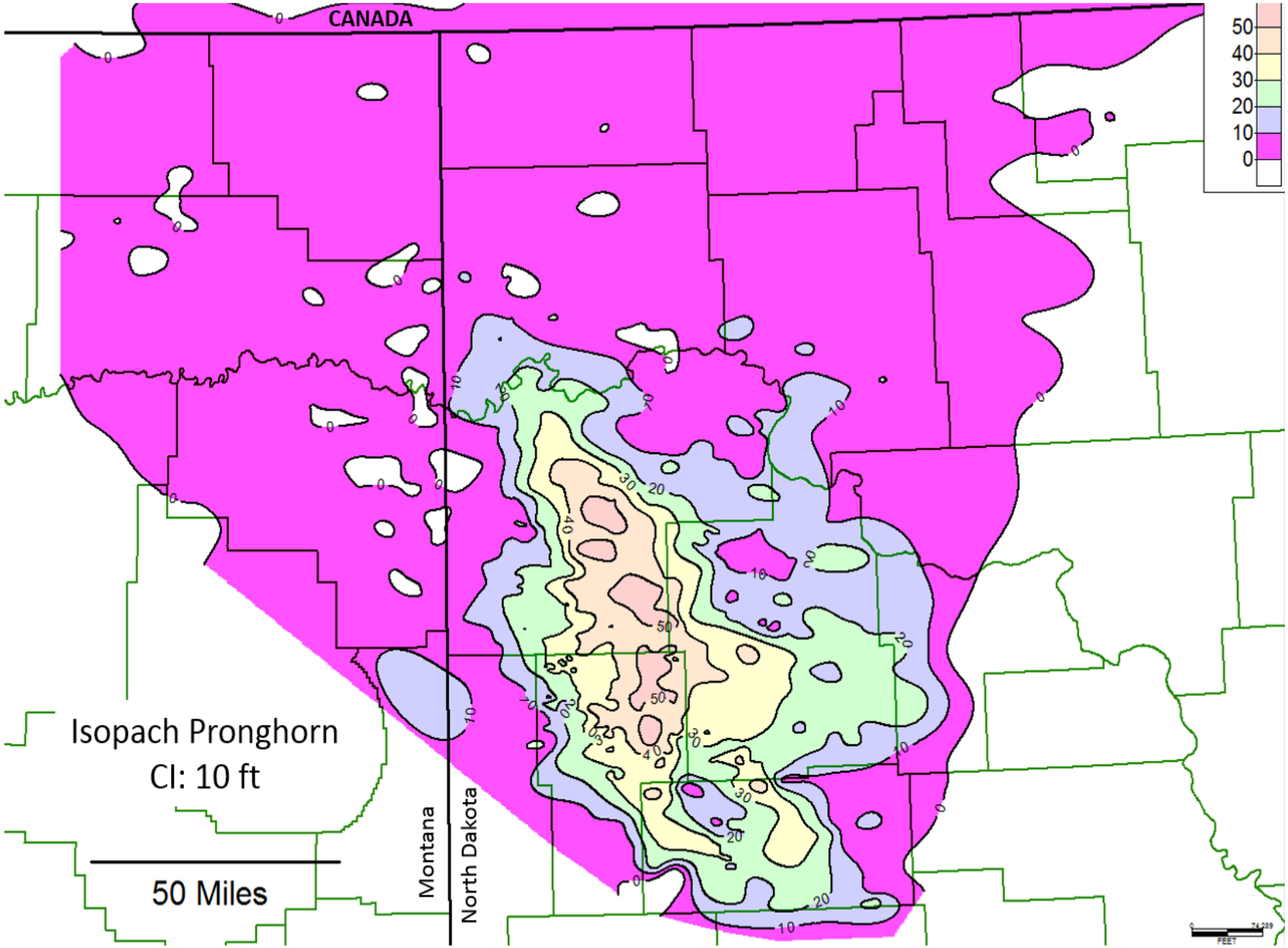
From Theloy, 2013

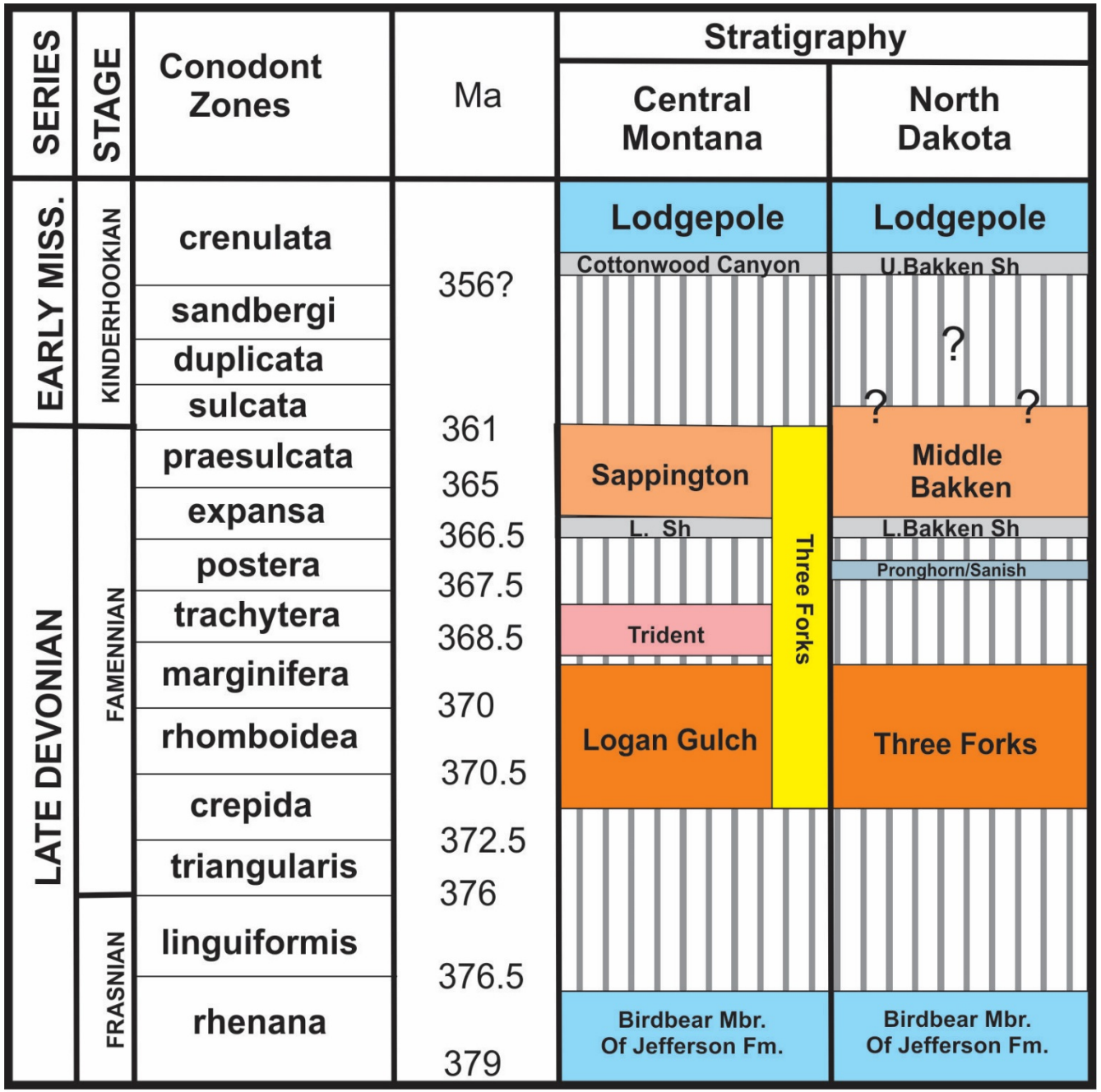


From Theloy, 2013

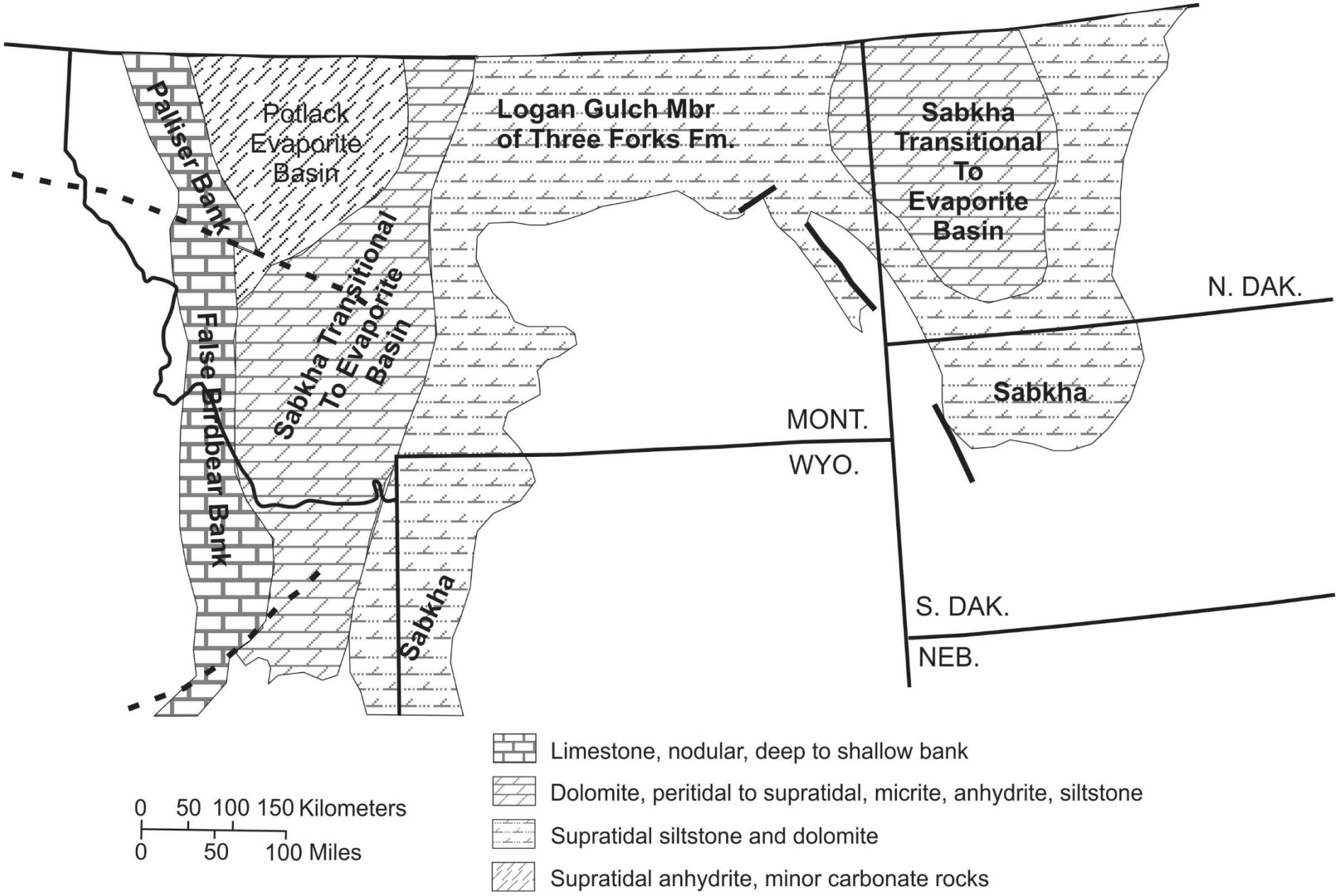


From Theloy, 2013

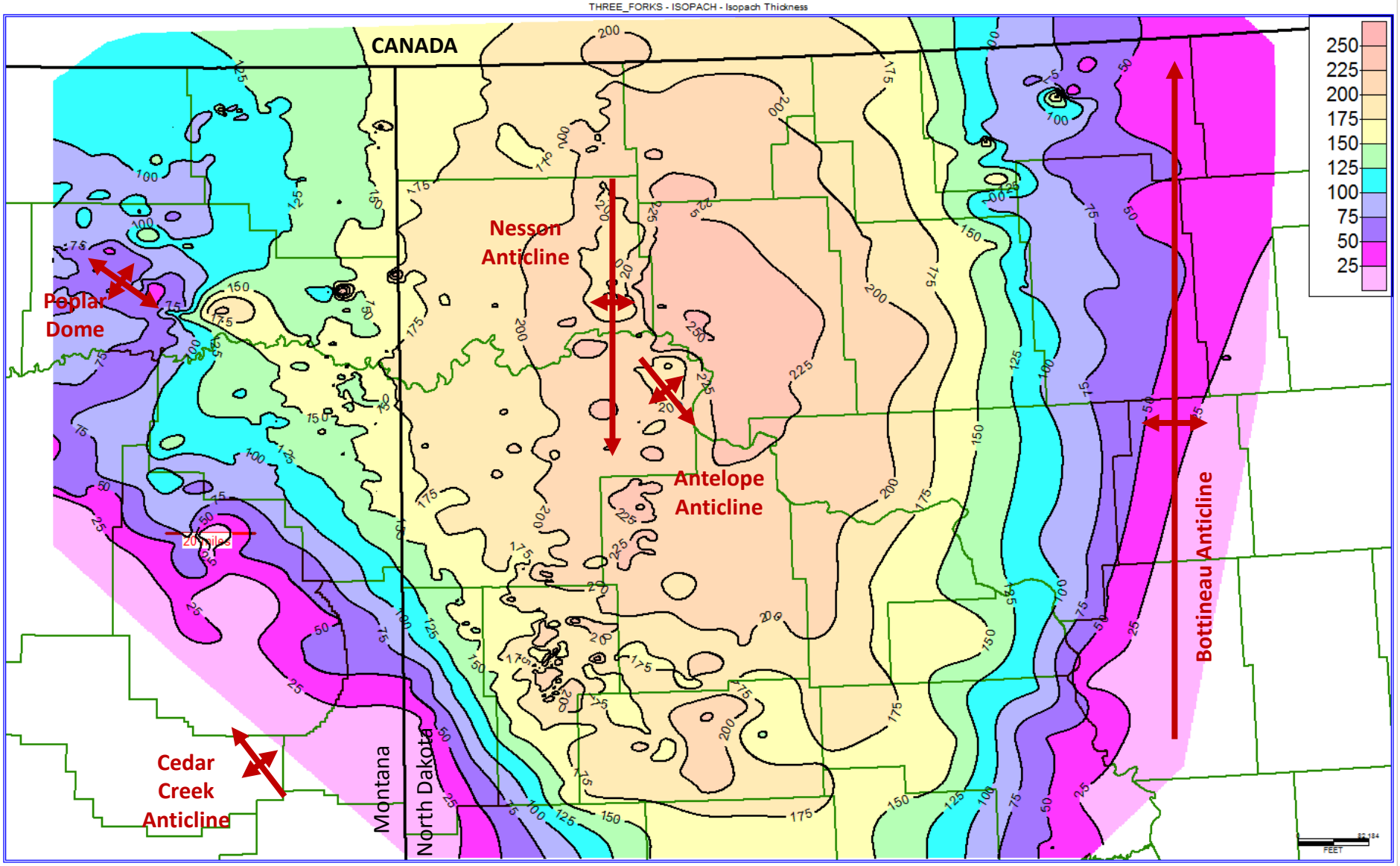

CANADA
Montana
North Dakota
Isopach Pronghorn
CI: 10 ft
50 Miles
50
40
30
20
10
0



modified from Sandberg et al., 1988; Hartel et al., 2012

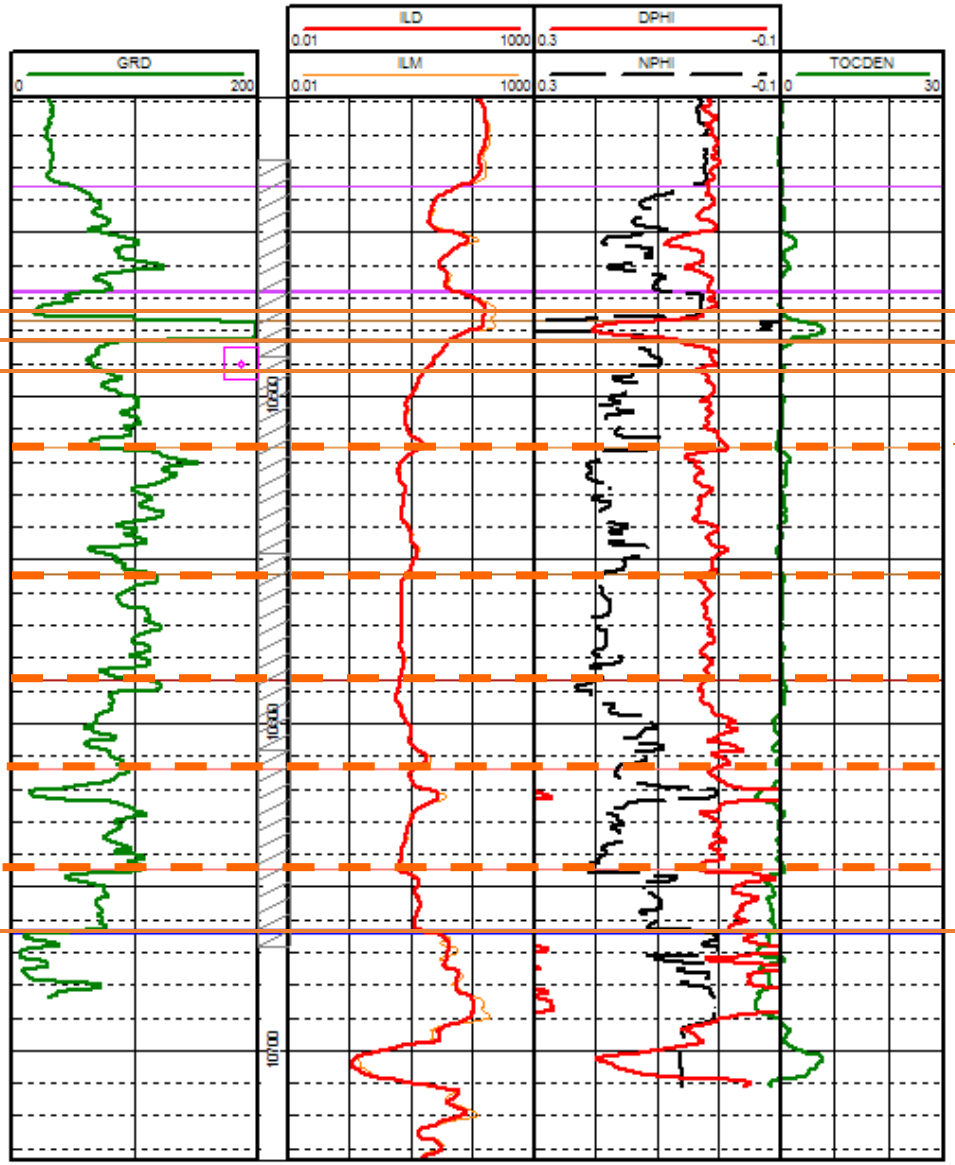


Modified from Sandberg et al., 1988


THREE_FORKS - ISOPACH - Isopach Thickness
CANADA
Nesson Anticline
Poplar Dome
Antelope Anticline
Bottineau Anticline
Cedar Creek Anticline
Montana
North Dakota
250
225
200
175
150
125
100
75
50
25
20 miles
FEET

MAXUS EXPL CO
SHORT-FEE
31-3

T142N R102W S3



Subtidal

Intertidal (dolosiltone)

Intertidal (dolosiltstone)

Supratidal/Intertidal

Supratidal/Sabkha
Chicken-wire anhydrites

False Bakken

Scallion

Upper Bakken Shale

Pronghorn

Lodgepole

BAKKEN

Upper

Middle

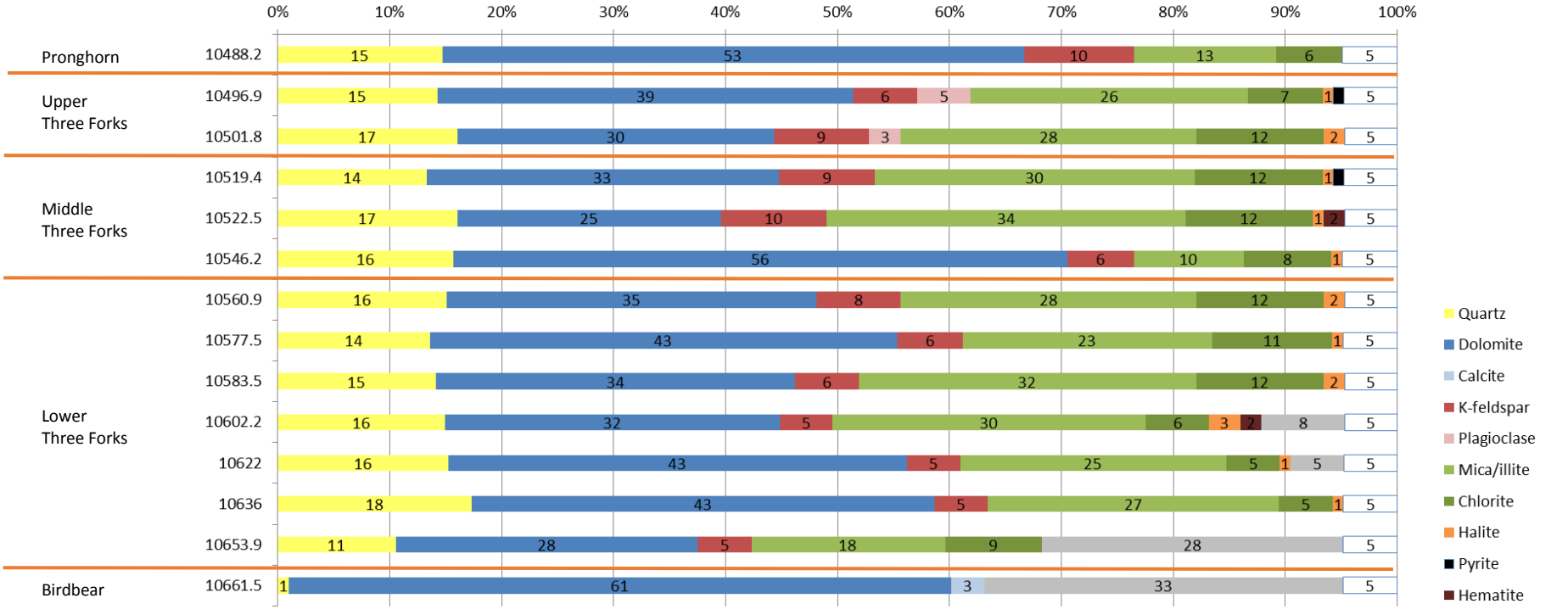
Lower

Three Forks

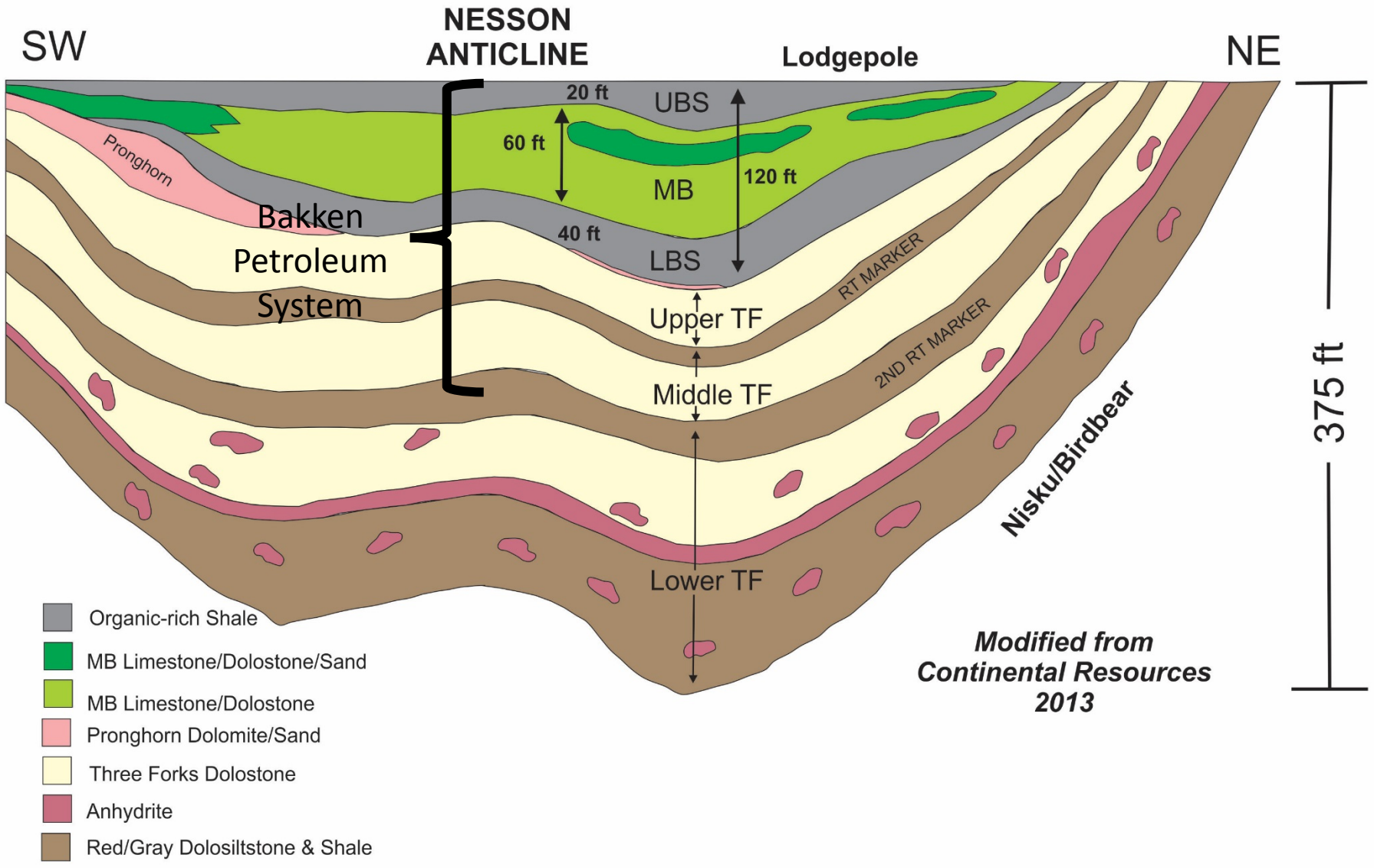
Nisku/Birdbear

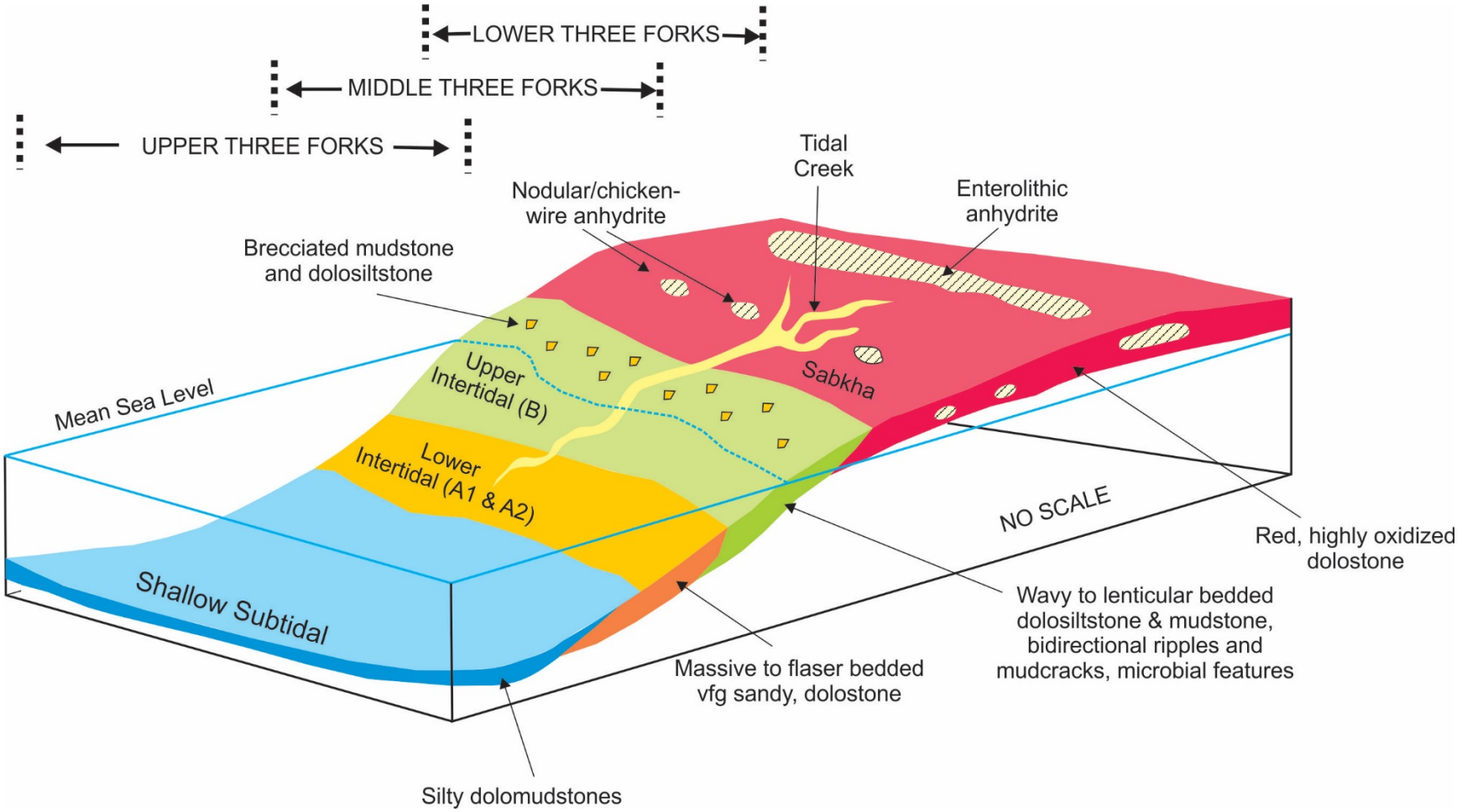
Modified from
Gantyno, 2010

Short Fee XRD

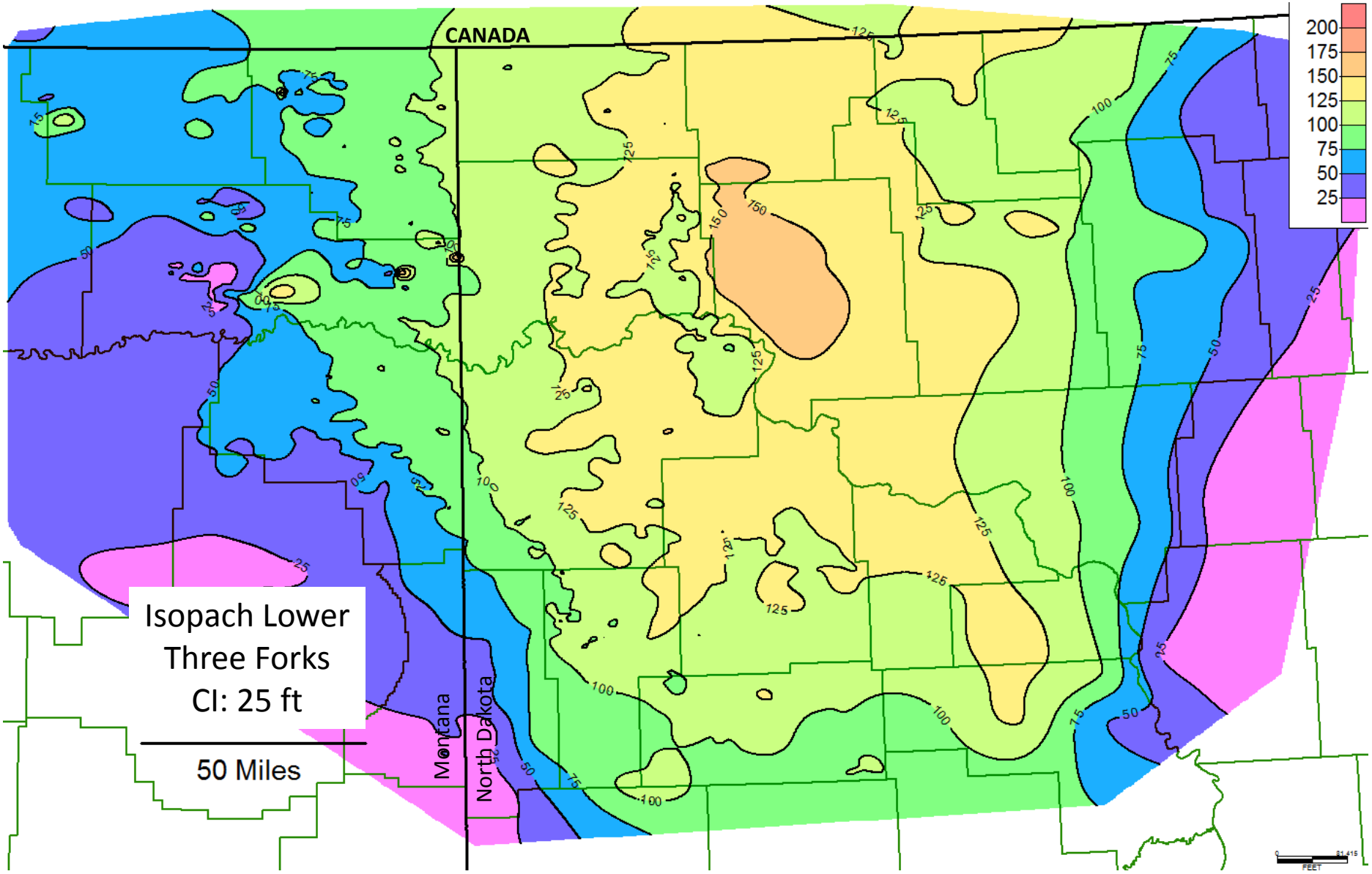


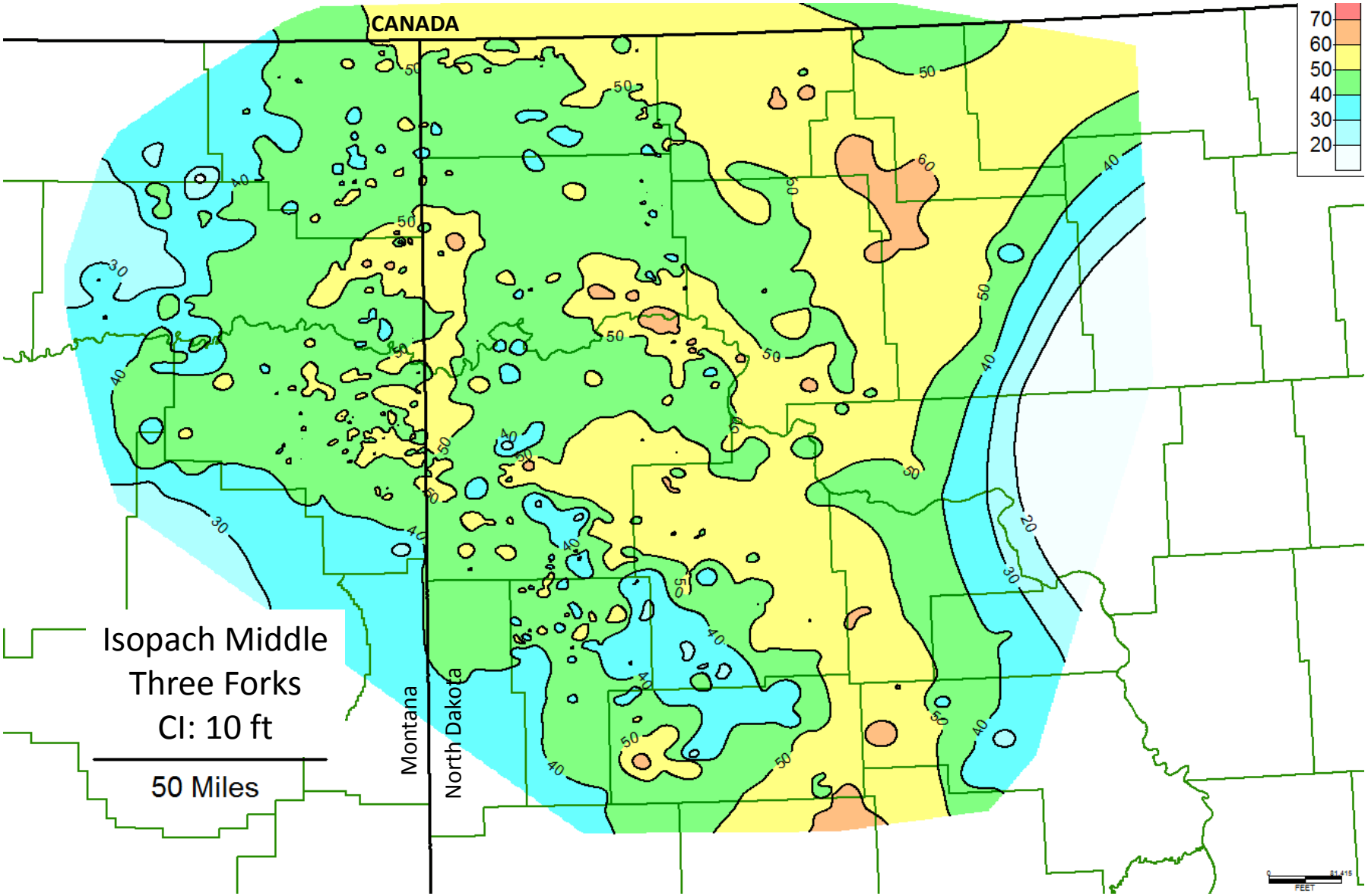
	10661.5	10653.9	10636	10622	10602.2	10583.5	10577.5	10560.9	10546.2	10522.5	10519.4	10501.8	10496.9	10488.2
Quartz	1	11	18	16	16	15	14	16	16	17	14	17	15	15
Dolomite	61	28	43	43	32	34	43	35	56	25	33	30	39	53
Calcite	3													
K-feldspar		5	5	5	5	6	6	8	6	10	9	9	6	10
Plagioclase												3	5	
Mica/illite		18	27	25	30	32	23	28	10	34	30	28	26	13
Chlorite		9	5	5	6	12	11	12	8	12	12	12	7	6
Halite			1	1	3	2	1	2	1	1	1	2	1	
Pyrite											1		1	
Hematite					2					2				
Anhydrite	33	28		5	8									
"Unidentified"	5	5	5	5	5	5	5	5	5	5	5	5	5	5

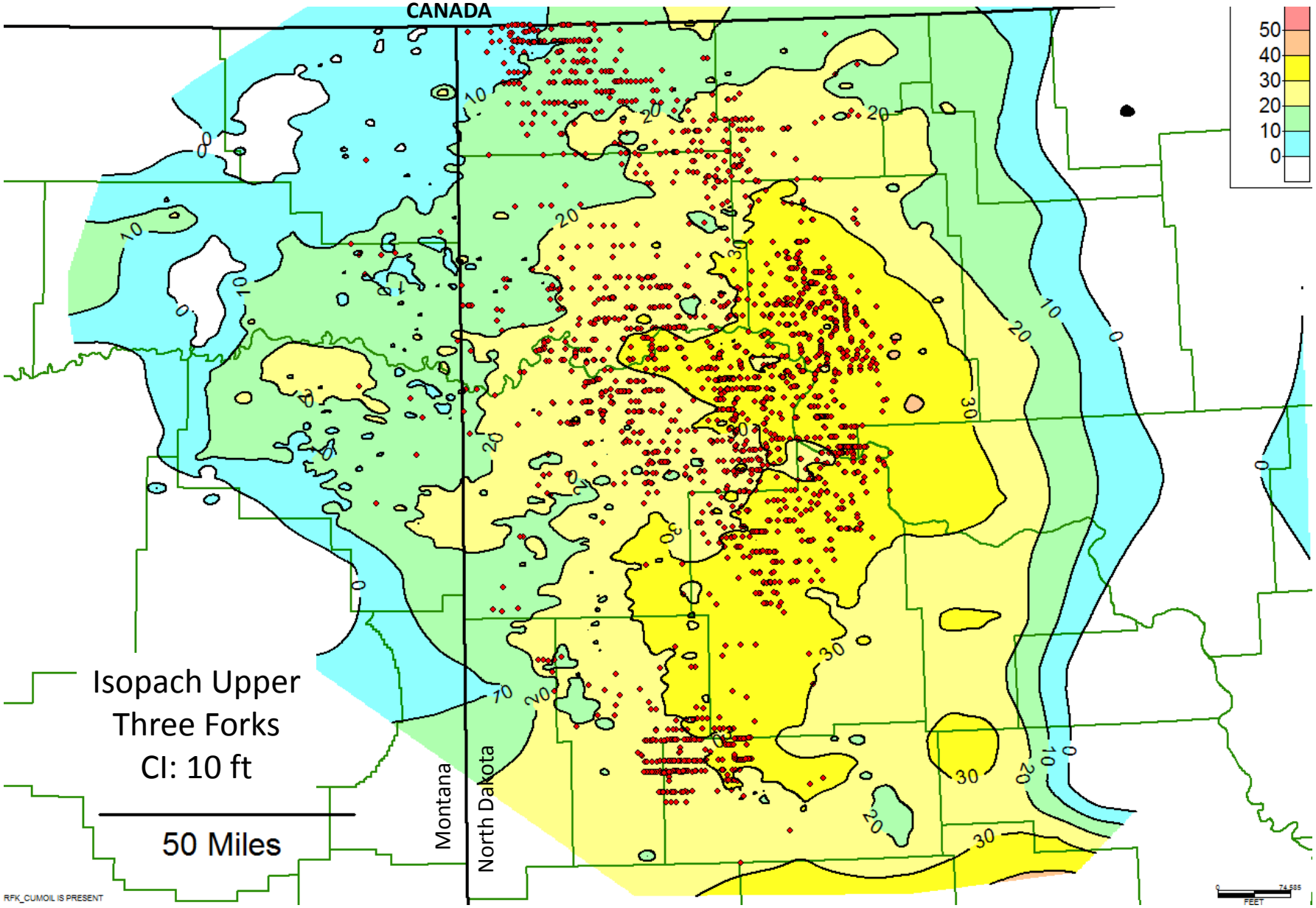

SW
NESSON ANTICLINE
Lodgepole
NE
20 ft
UBS
60 ft
120 ft
MB
40 ft
LBS
Pronghorn
Bakken Petroleum System
Upper TF
RT MARKER
2ND RT MARKER
Middle TF
Nisku/Birdbear
Lower TF
375 ft
Organic-rich Shale
MB Limestone/Dolostone/Sand
MB Limestone/Dolostone
Pronghorn Dolomite/Sand
Three Forks Dolostone
Anhydrite
Red/Gray Dolosiltstone & Shale
Modified from Continental Resources 2013

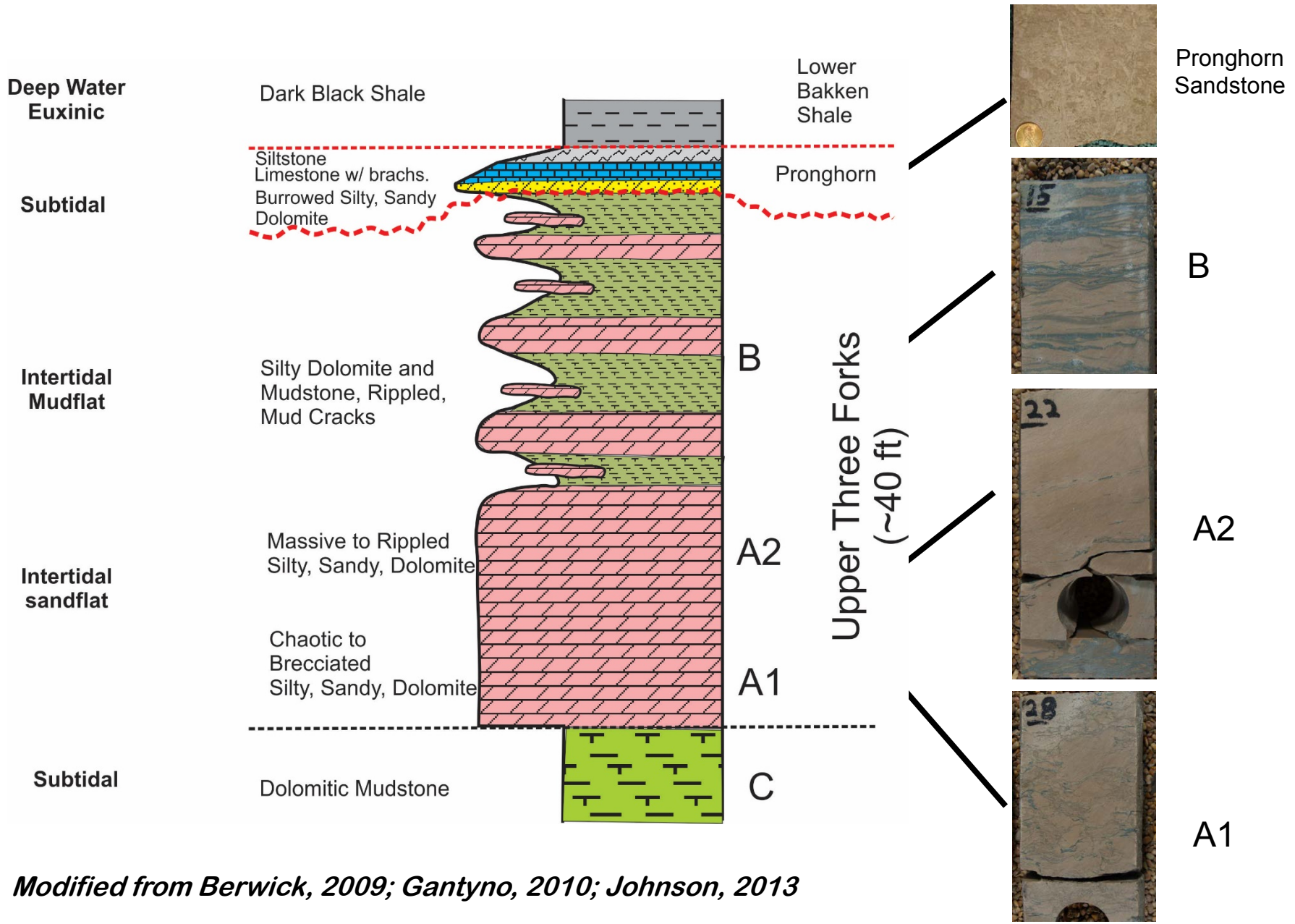


Modified from Dumoncaux, 1984; Berwick; 2009; Gantyno, 2010; Franklin and Sonnenberg, 2012

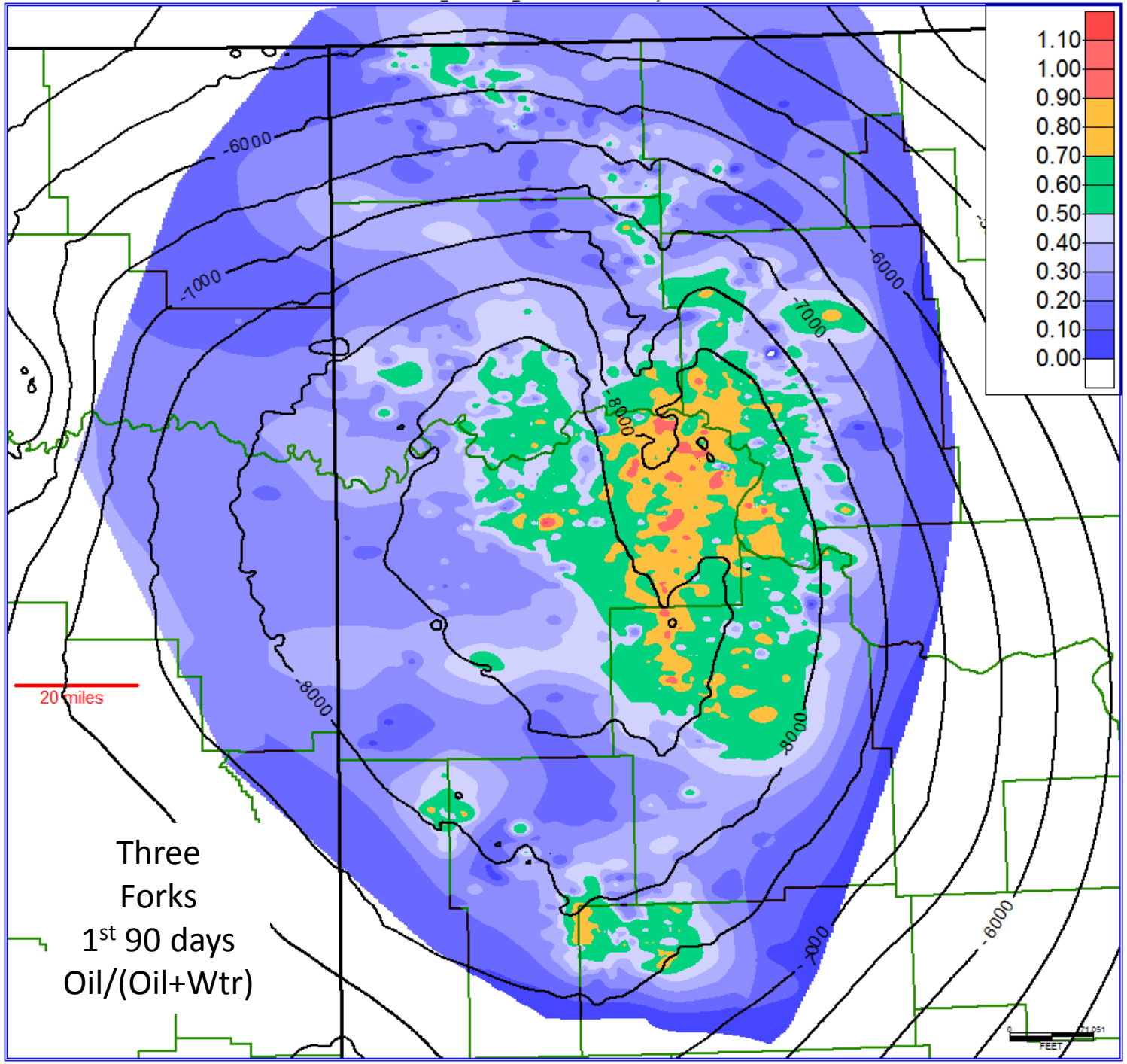

CANADA
Montana
North Dakota
Isopach Lower
Three Forks
CI: 25 ft
50 Miles
200
175
150
125
100
75
50
25

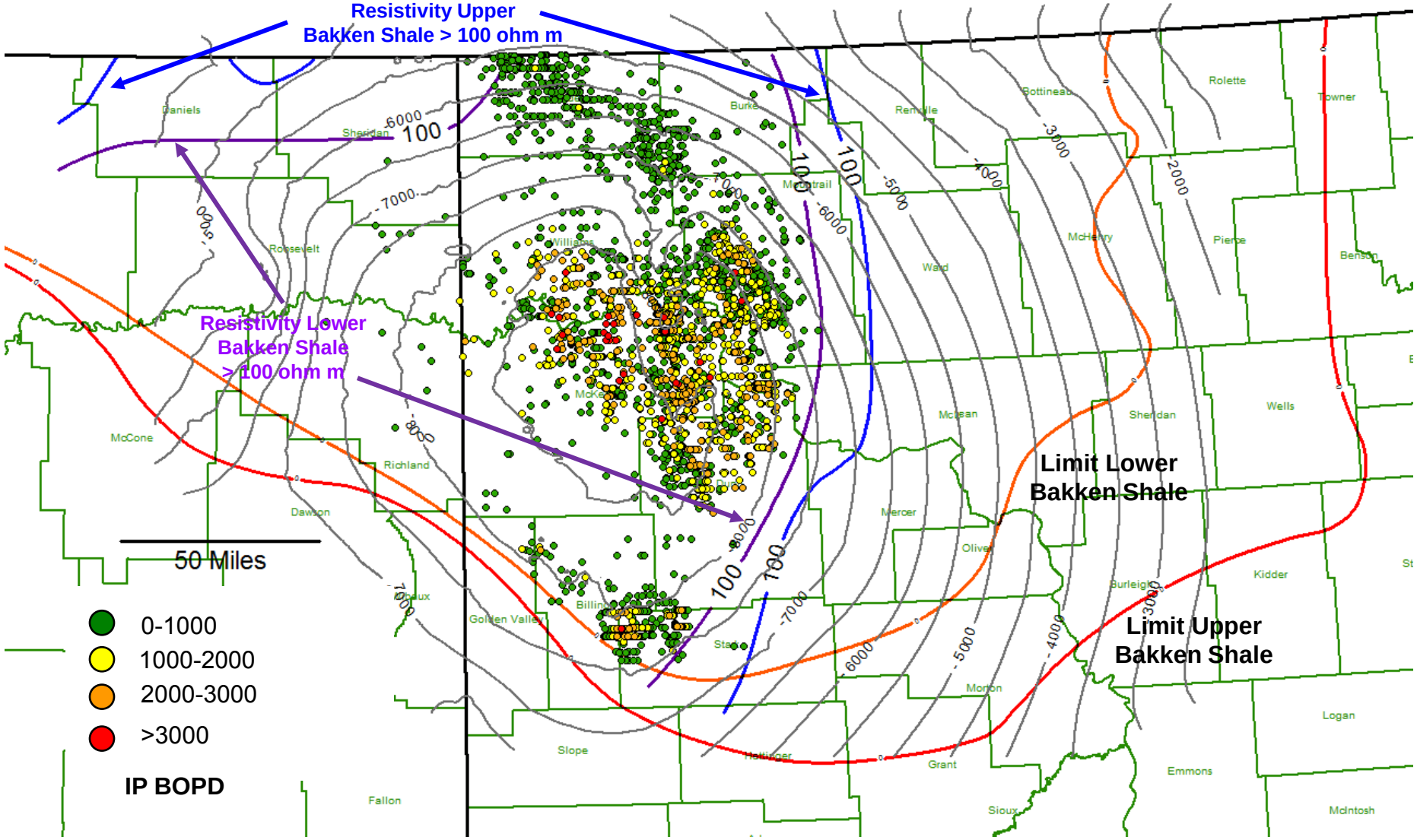

CANADA
Montana
North Dakota
Isopach Middle
Three Forks
CI: 10 ft
50 Miles
70
60
50
40
30
20


CANADA
Montana
North Dakota
Isopach Upper
Three Forks
CI: 10 ft
50 Miles
50
40
30
20
10
0
RFK_CUMOIL IS PRESENT



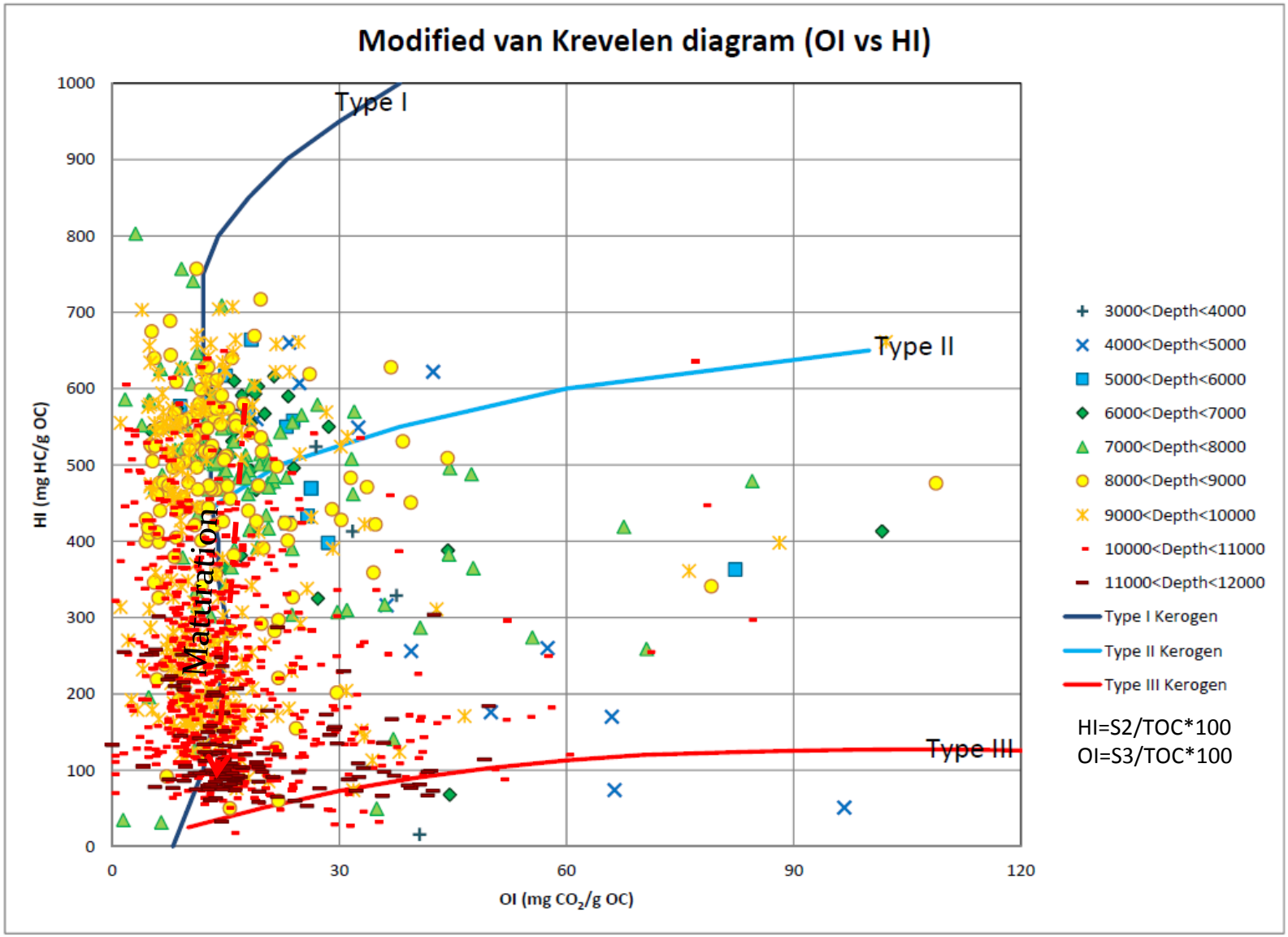
Modified from Berwick, 2009; Gantyno, 2010; Johnson, 2013


1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-6000
-7000
-8000
-9000
-10000
20 miles
Three
Forks
1st 90 days
Oil/(Oil+Wtr)

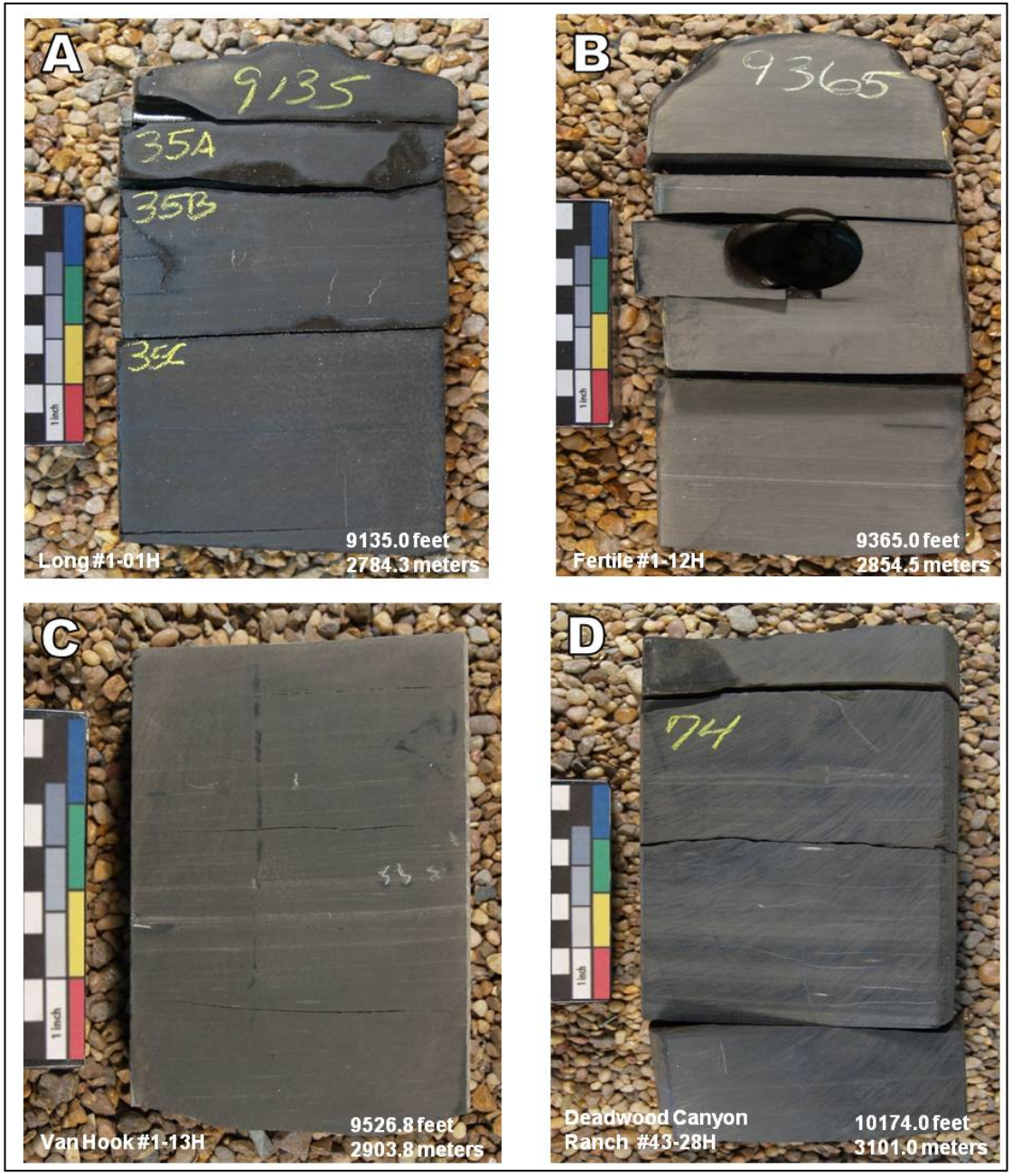


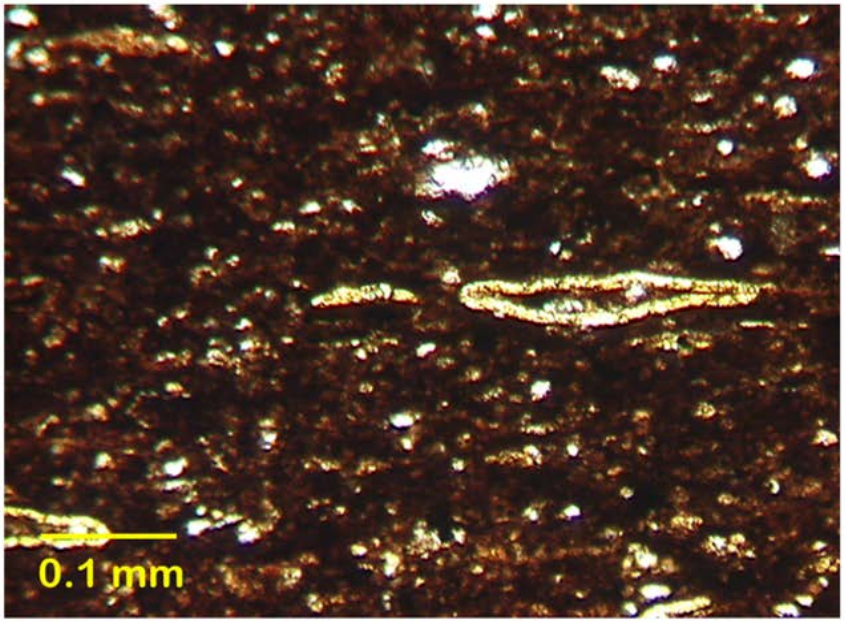
Structure Bakken, Bakken Shale Resistivity and Three Forks IP Map

Results – Kerogen type (majority Type I/II)



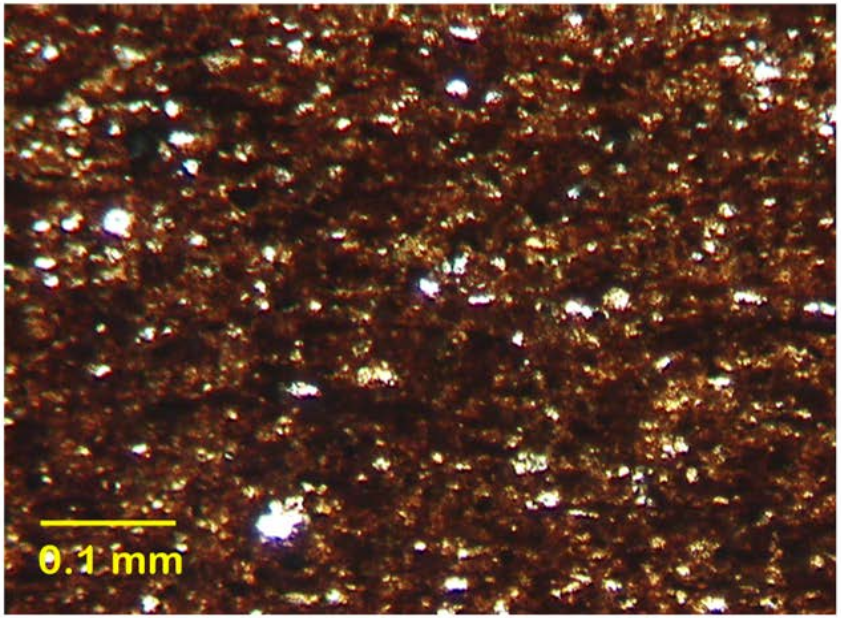
Jin, 2013


A
9135
35A
35B
35C
9135.0 feet
2784.3 meters
Long #1-01H
B
9365
9365.0 feet
2854.5 meters
Fertile #1-12H
C
9526.8 feet
2903.8 meters
Van Hook #1-13H
D
9174
Deadwood Canyon
Ranch #43-28H
10174.0 feet
3101.0 meters



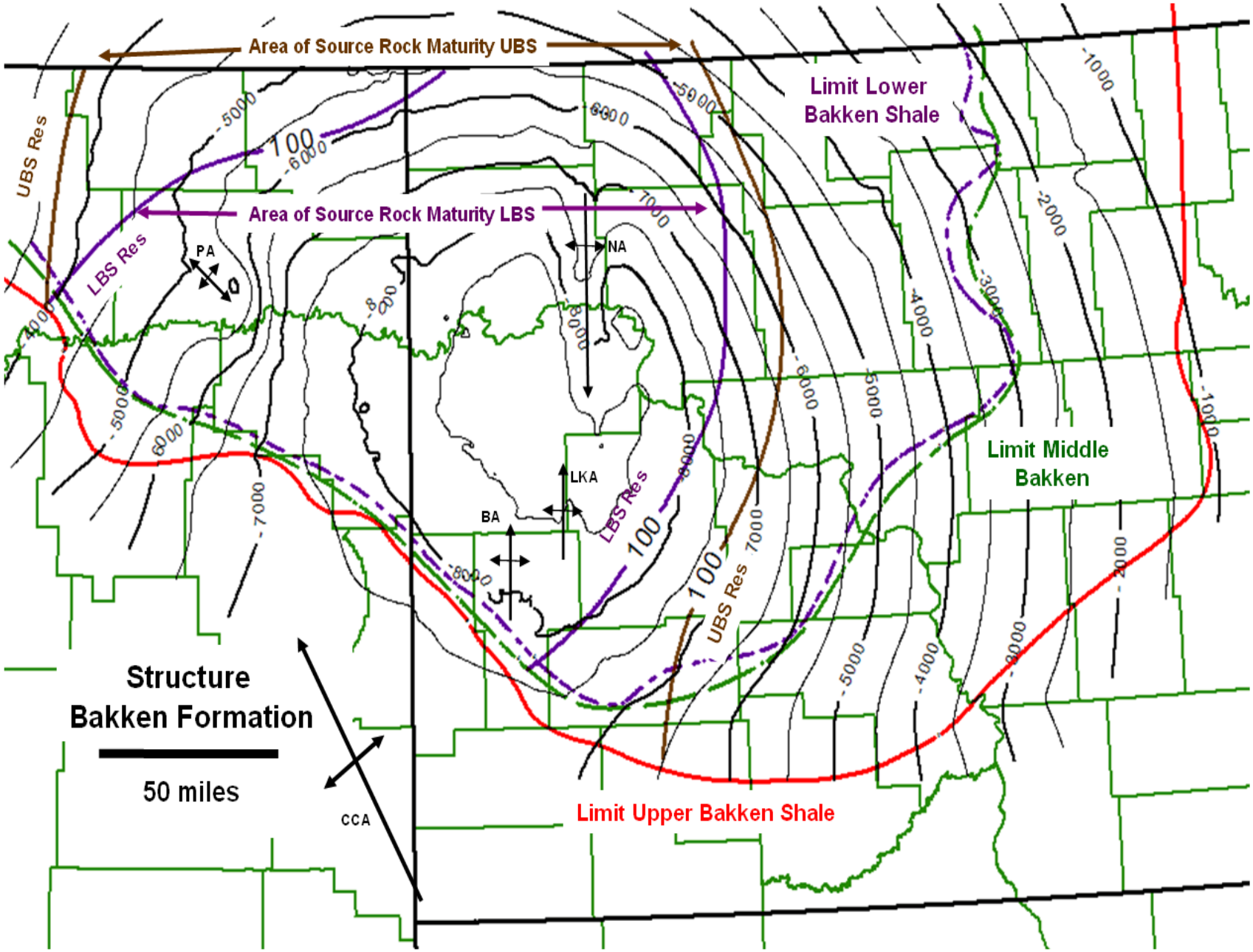
Braaflat 9940
Sec. 11-T153N-R91W
Lower Bakken Shale

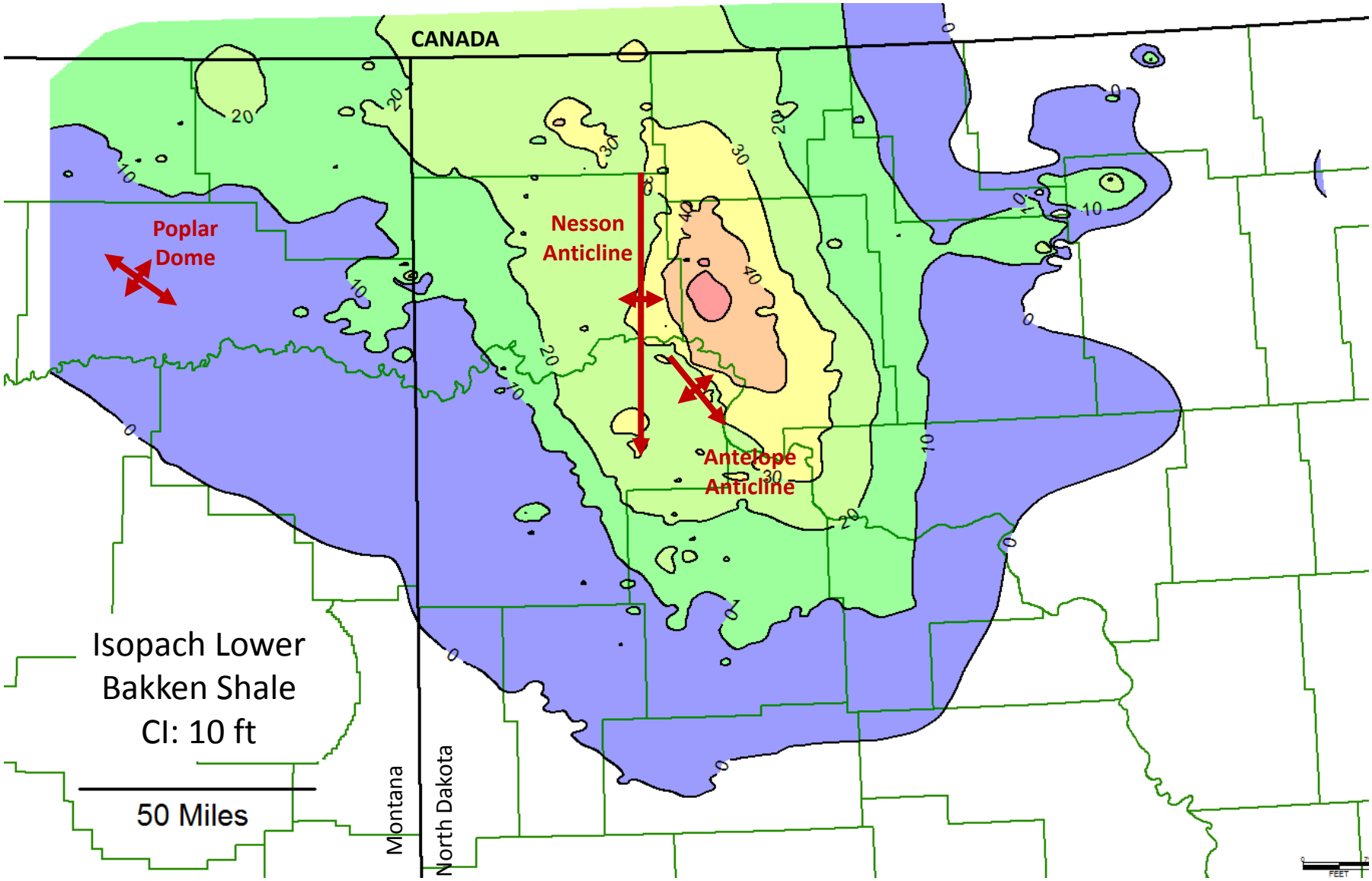
TOC 15.6
Tmax 435
HI 669
PI 0.06

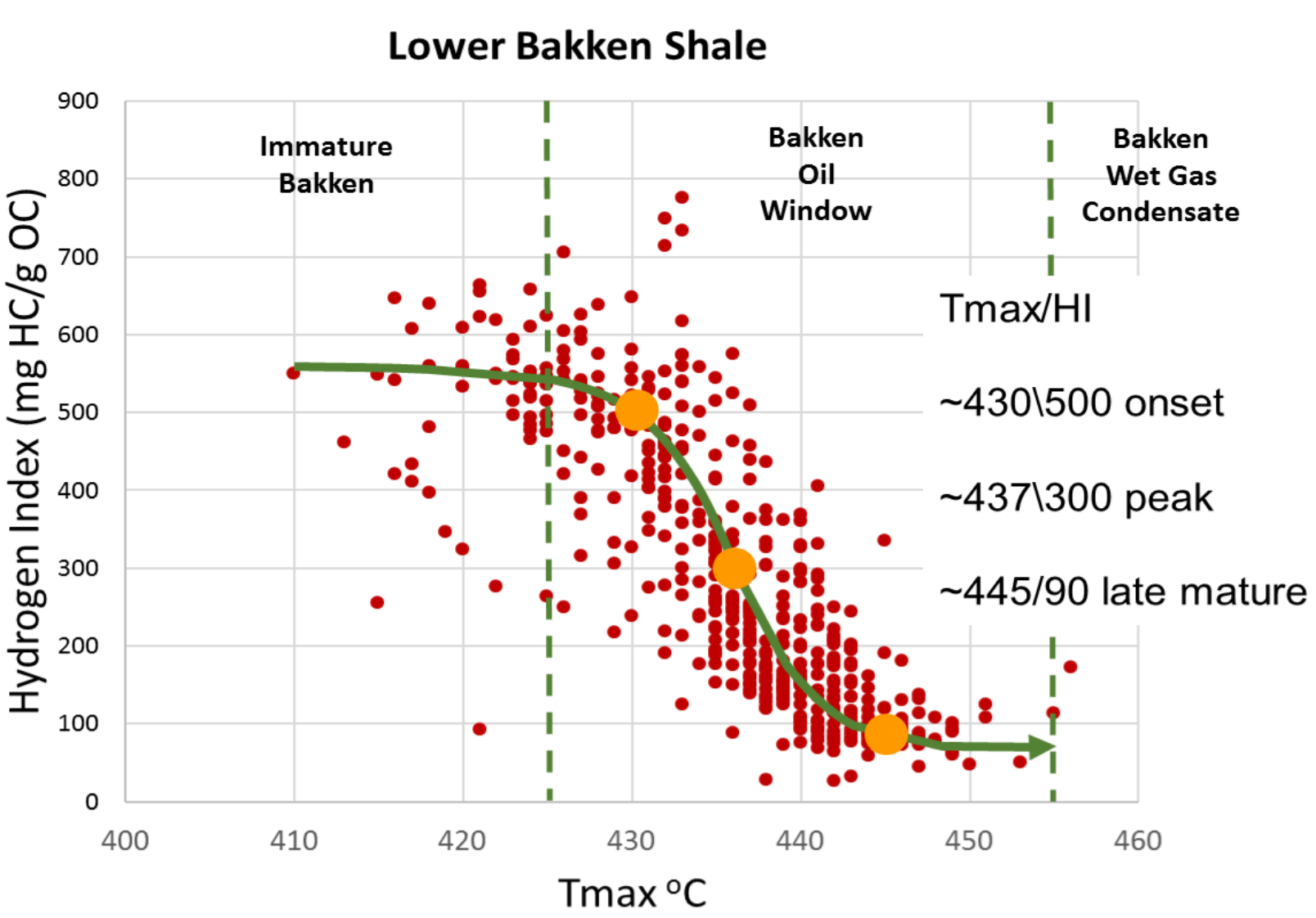


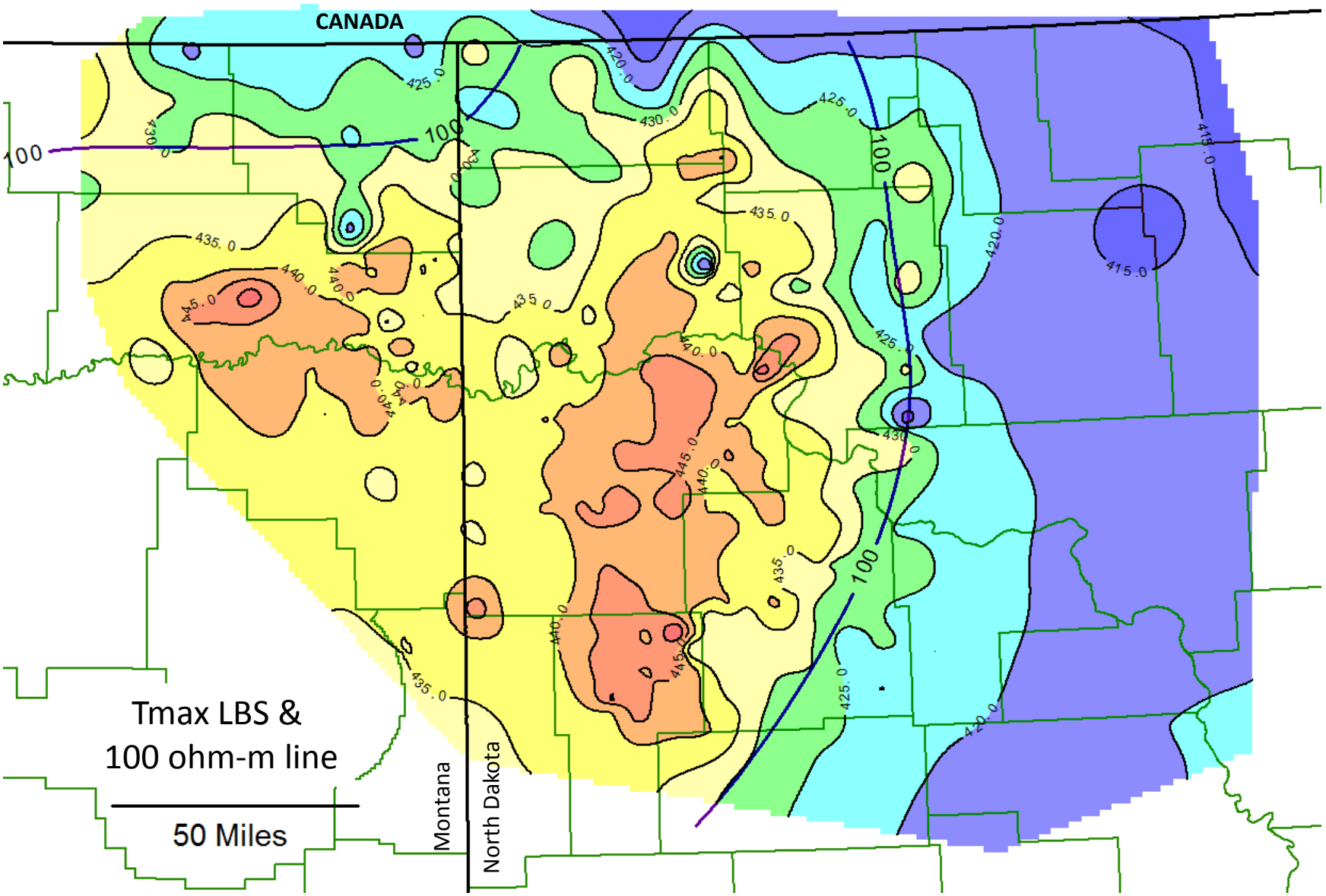
Braaflat 9864 ft
Sec. 11-T153N-R91W
Upper Bakken Shale

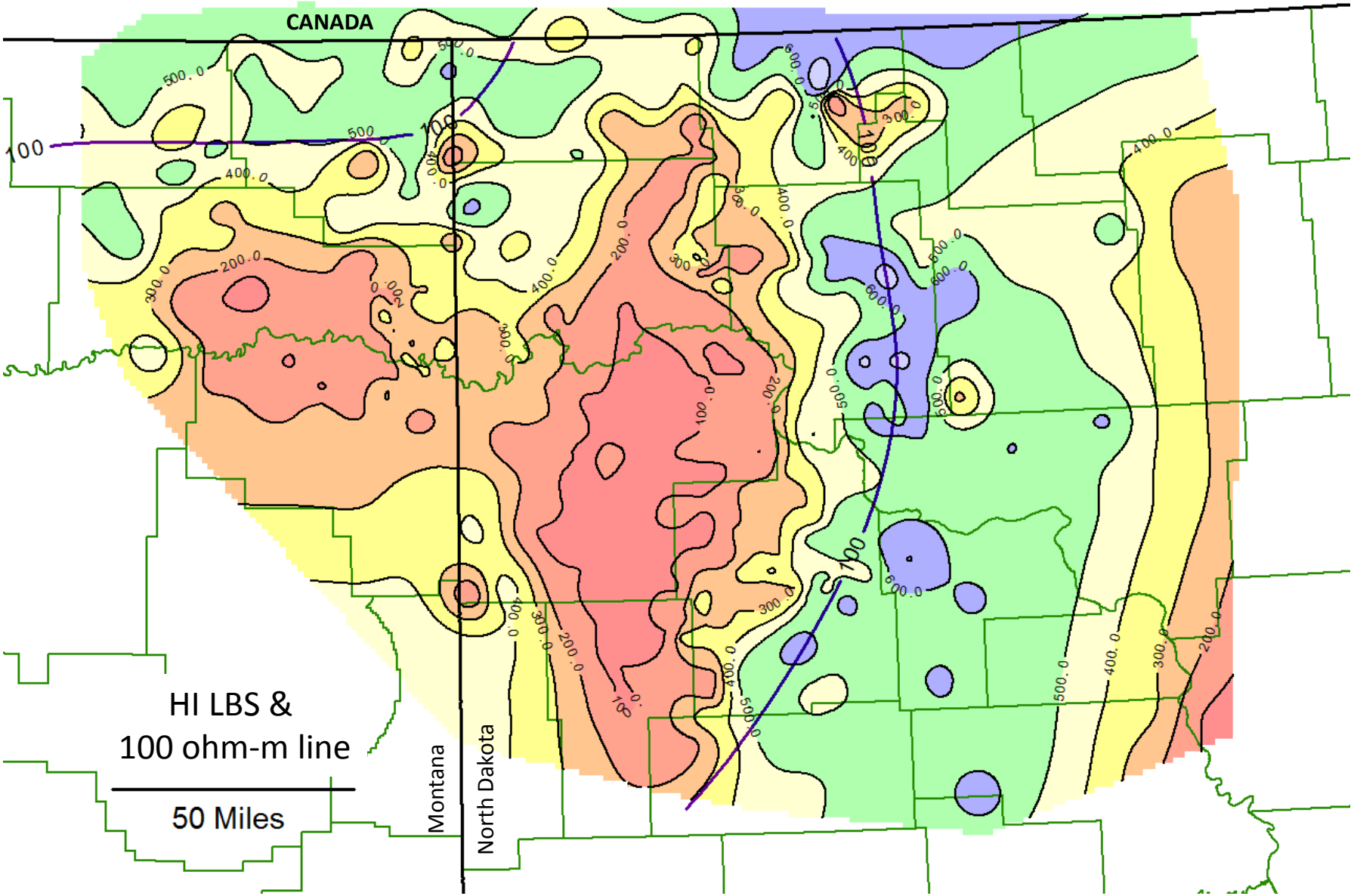
TOC 14.5
Tmax 435
HI 656
PI 0.05


Area of Source Rock Maturity UBS
Area of Source Rock Maturity LBS
Limit Lower Bakken Shale
Limit Middle Bakken
Limit Upper Bakken Shale
UBS Res
LBS Res
PA
NA
LKA
BA
CCA
Structure
Bakken Formation
50 miles

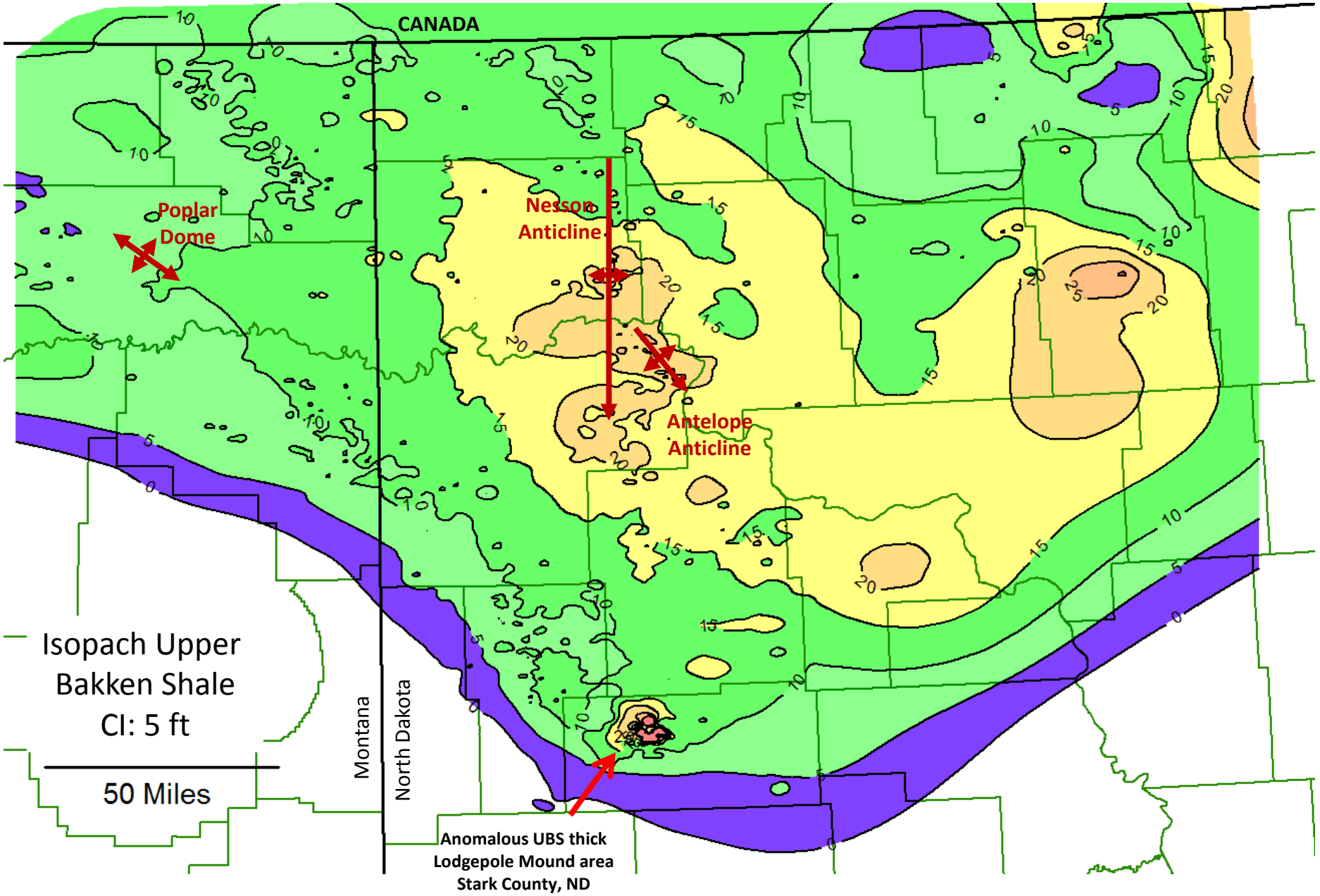

CANADA
Poplar Dome
Nesson Anticline
Antelope Anticline
Isopach Lower Bakken Shale
CI: 10 ft
50 Miles
Montana
North Dakota

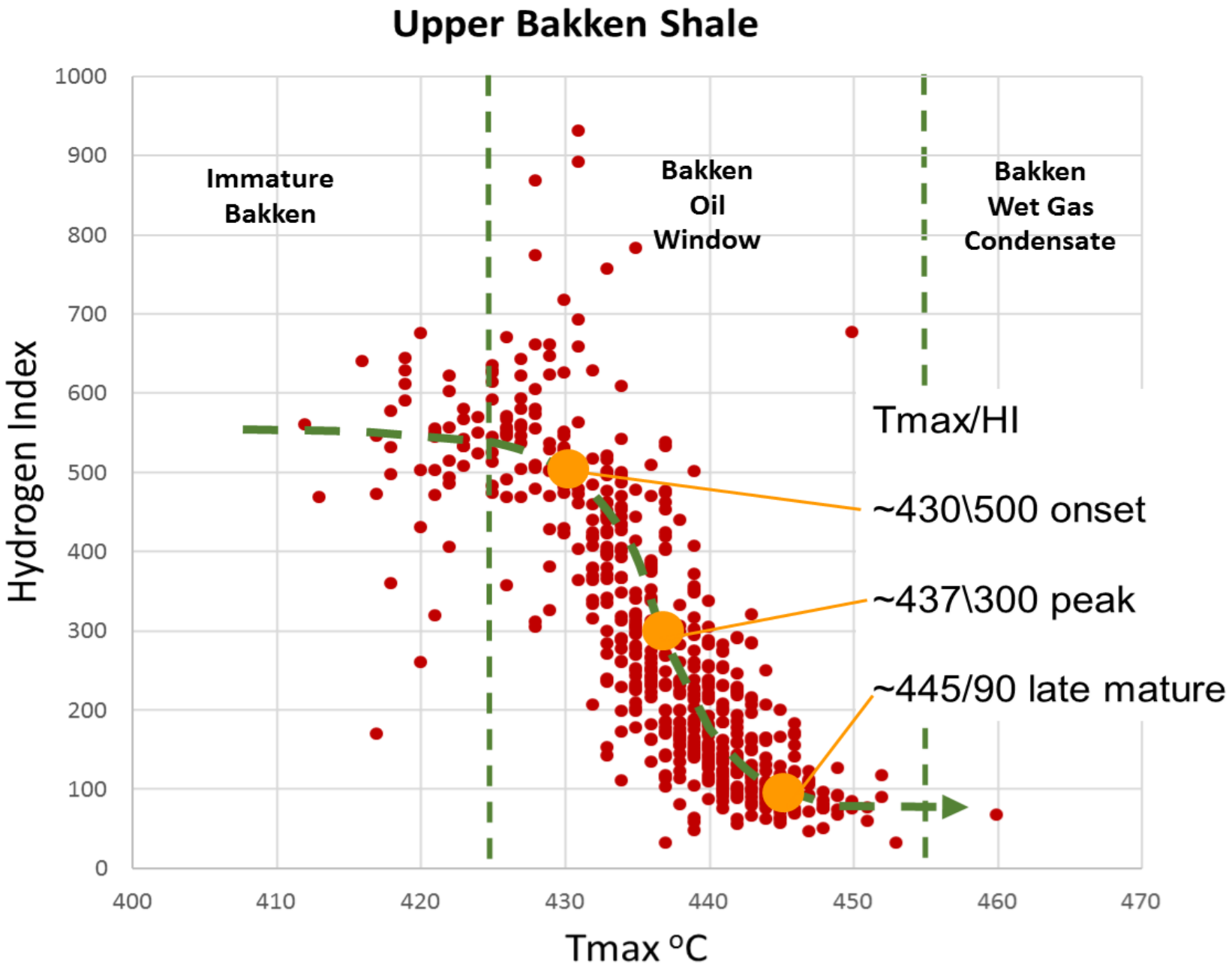

Lower Bakken Shale
Immature Bakken
Bakken Oil Window
Bakken Wet Gas Condensate
Tmax/HI
~430\500 onset
~437\300 peak
~445/90 late mature
Hydrogen Index (mg HC/g OC)
900
800
700
600
500
400
300
200
100
0
400
410
420
430
440
450
460
Tmax °C

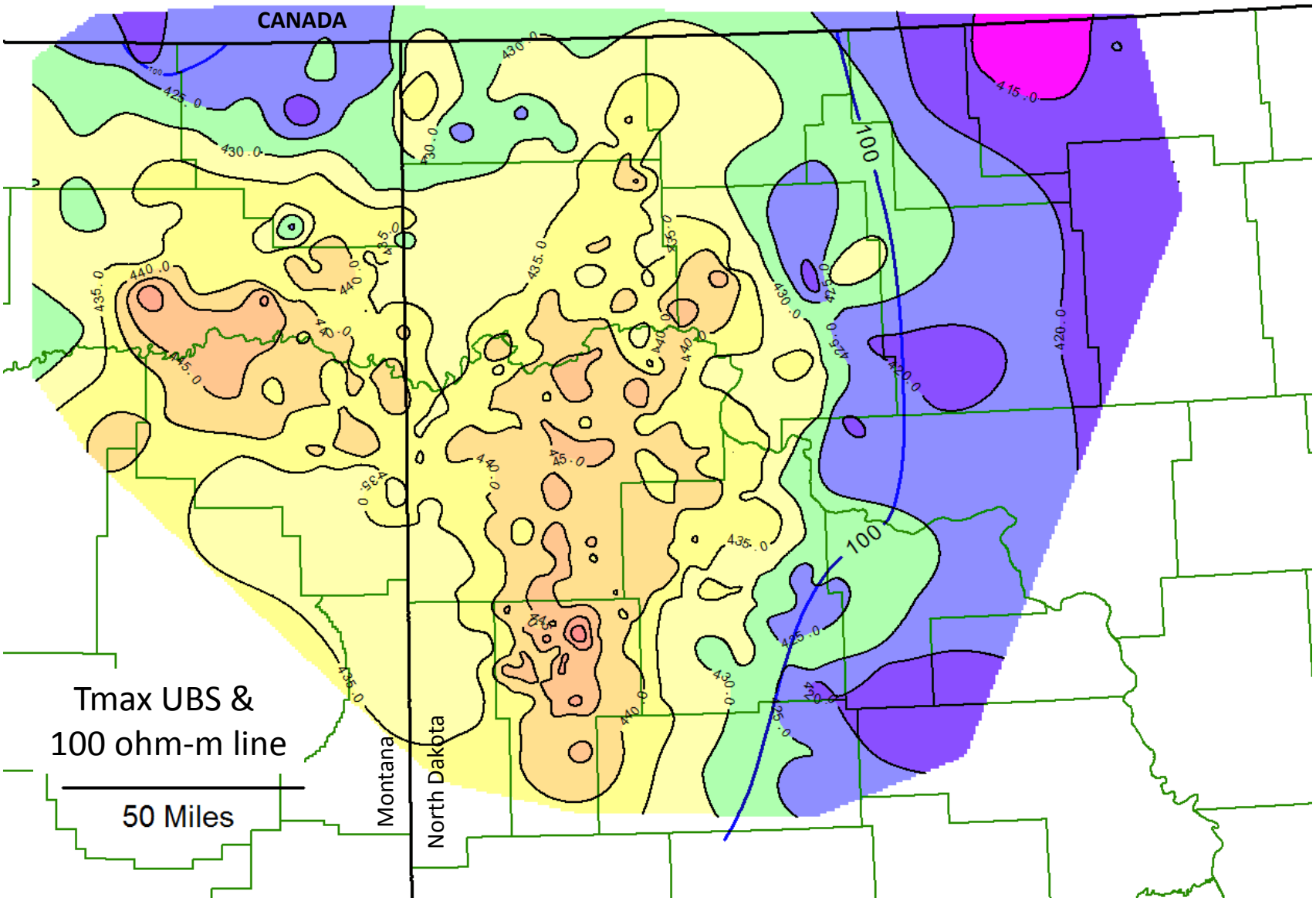

CANADA
100
100
100
100
420.0
425.0
430.0
435.0
440.0
445.0
415.0
Tmax LBS &
100 ohm-m line
50 Miles
Montana
North Dakota



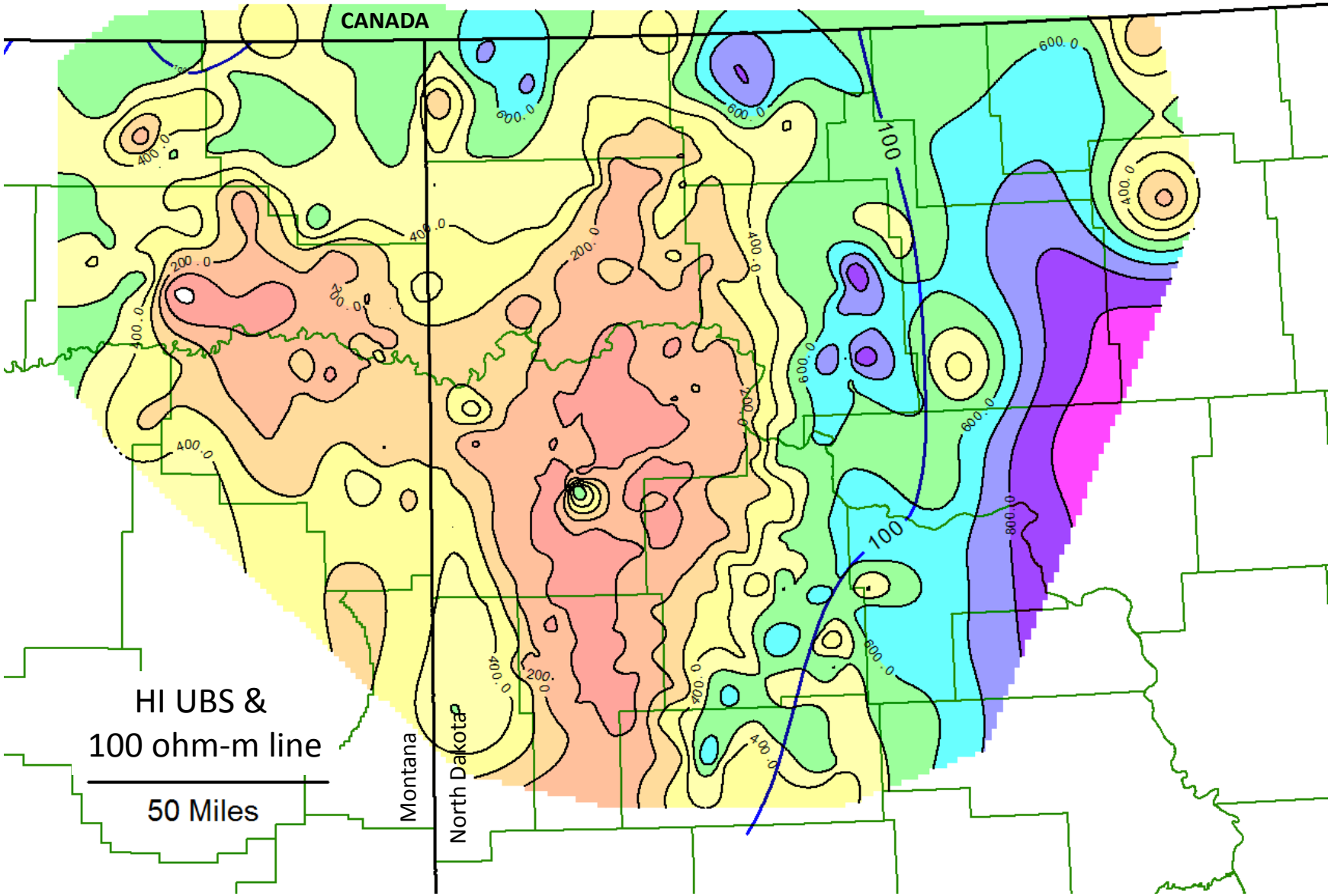
HI - LBS


CANADA
Poplar Dome
Nesson Anticline
Antelope Anticline
Isopach Upper Bakken Shale
CI: 5 ft
50 Miles
Montana
North Dakota
Anomalous UBS thick Lodgepole Mound area Stark County, ND

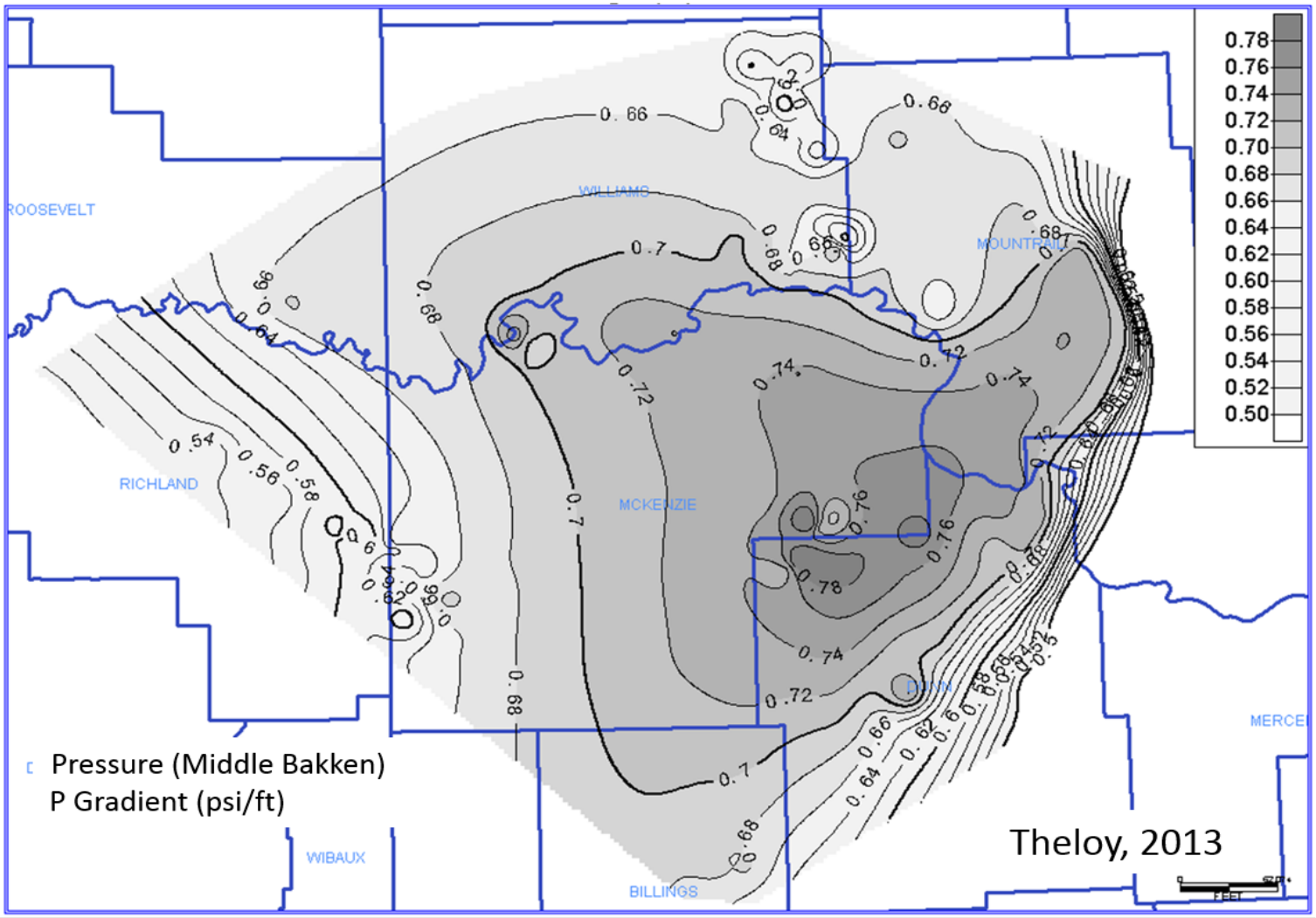

Upper Bakken Shale
Immature Bakken
Bakken Oil Window
Bakken Wet Gas Condensate
Tmax/HI
~430\500 onset
~437\300 peak
~445/90 late mature
Hydrogen Index
Tmax °C
1000
900
800
700
600
500
400
300
200
100
0
400
410
420
430
440
450
460
470



Tmax – UBS & 100 ohm-m line



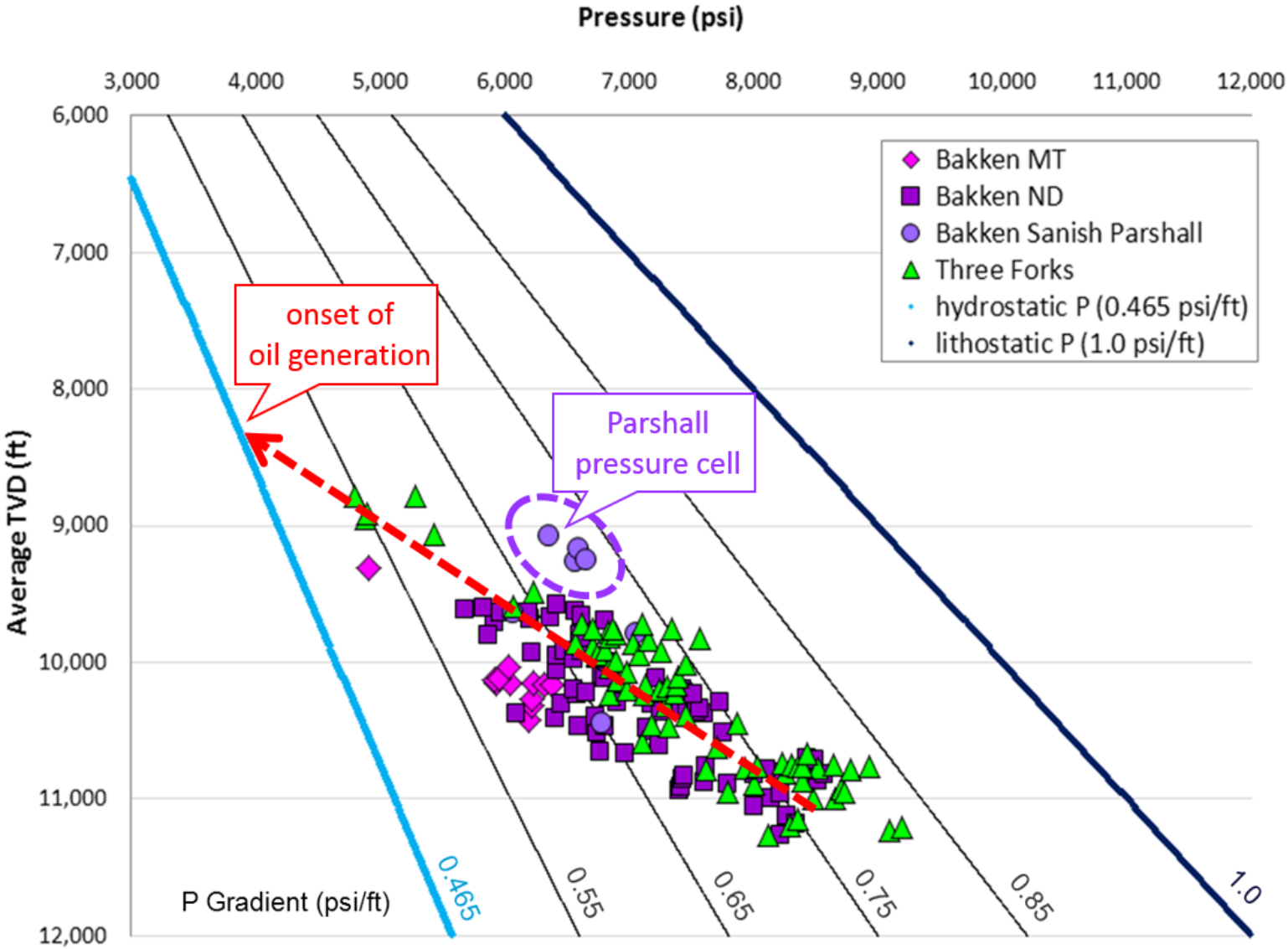
HI - UBS



92 BHP and DFIT data points + 6 hydrostatic points at eastern margin + 6 Sanish-Parshall points

No DST data

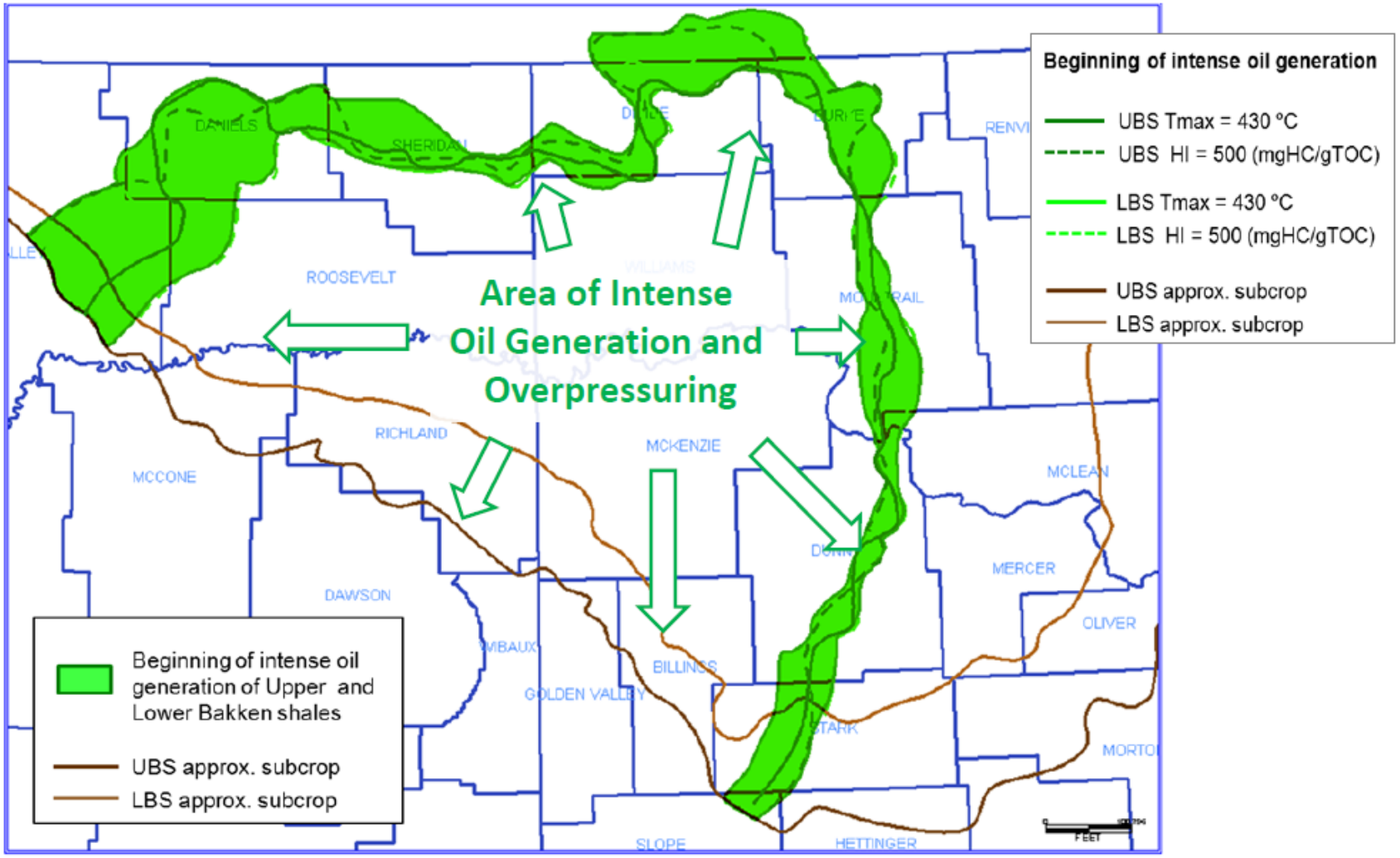
From Theloy, 2013



Indicative plot for **inverted continuous system**, leaking pressure at top

From Theloy, 2013

Maturity Boundary



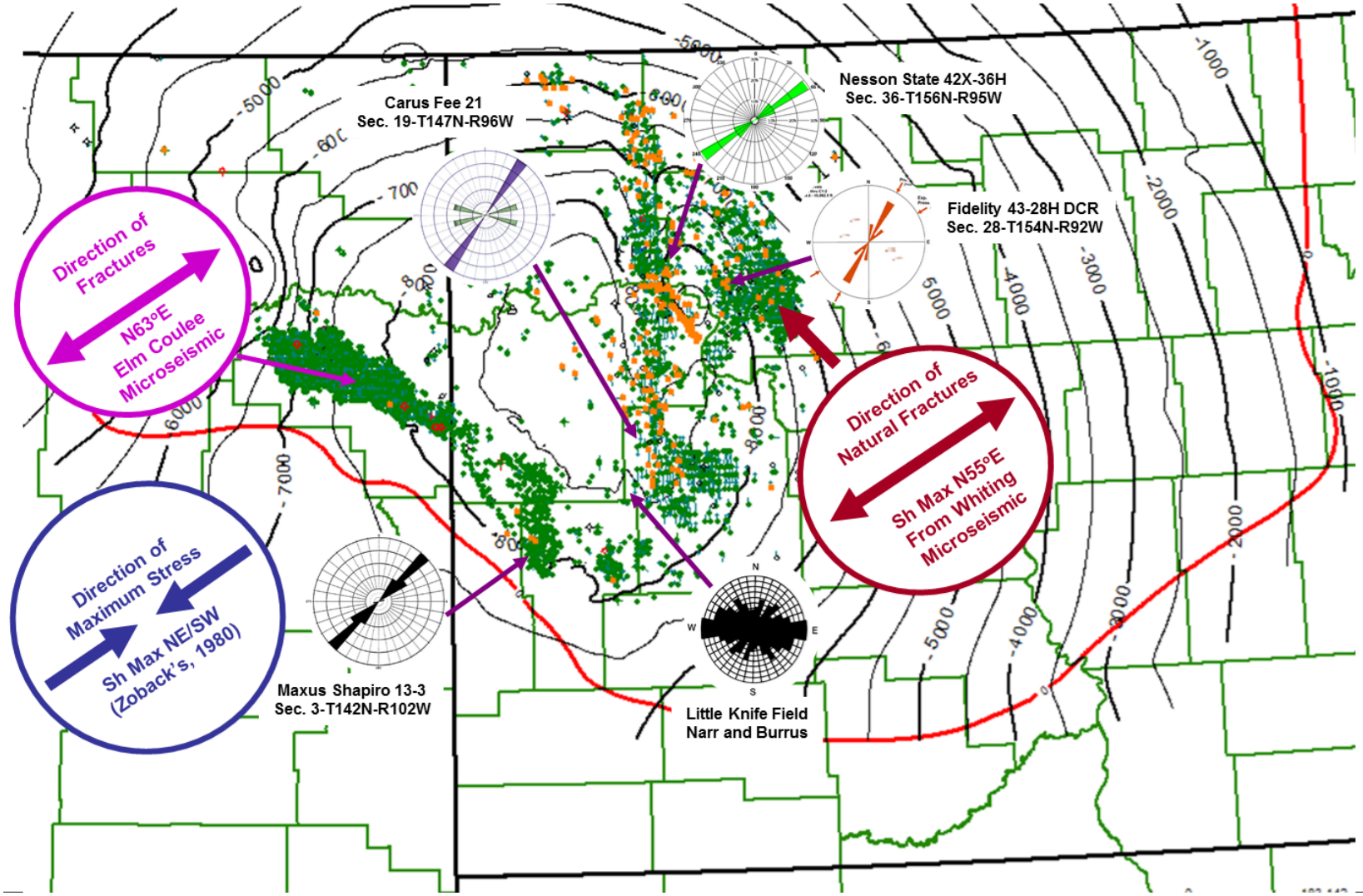
Beginning of intense oil generation based on Tmax and HI constraints of both Upper and Lower Bakken shales

Theloy, 2013

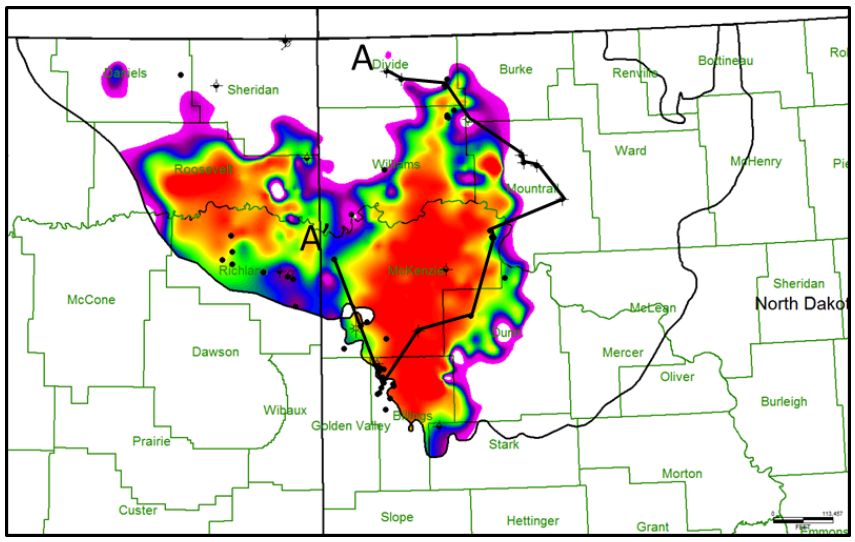
Faults & Fractures

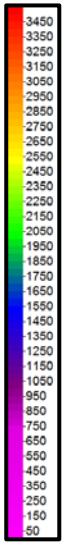
- Tectonic
  - Faults
  - Force Folds
  - Recurrent movement on basement faults
  - Evaporite dissolution
  - Differential compaction
- Regional Stress Field (Sh_{max})
- Diagenetic
  - Hydrocarbon generation
  - Overpressure
  - Compaction/Dewatering (PFS)

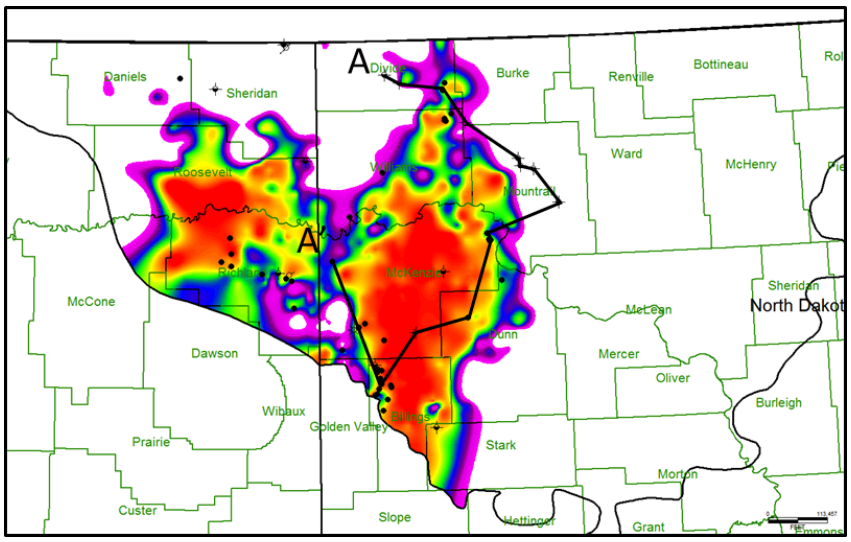
Regional Fractures



Petroleum-Expulsion Fracture Map



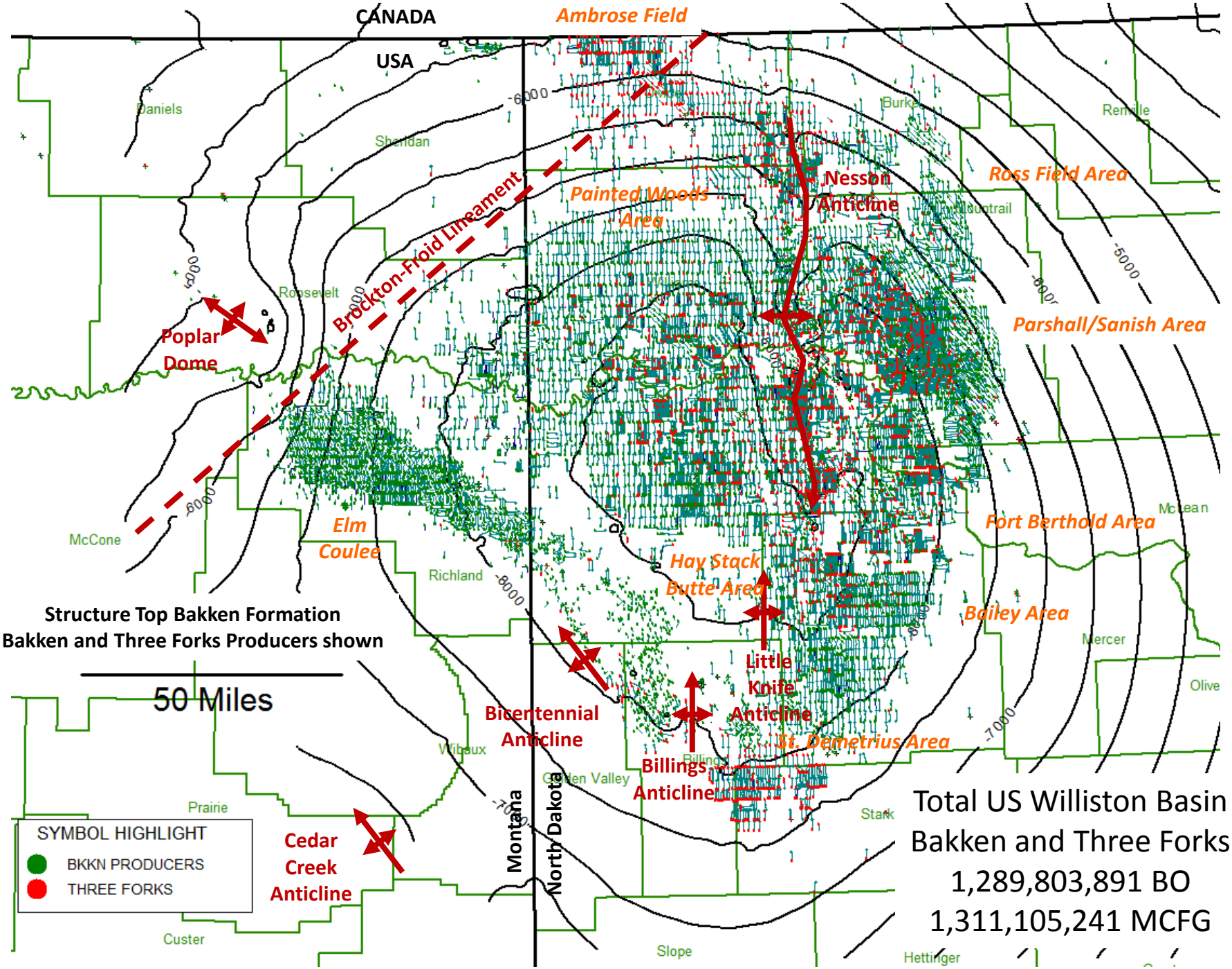




Lower Bakken Shale

Upper Bakken Shale

Al Duhailan, 2014


CANADA
USA
Ambrose Field
Brockton-Froid Lineament
Painted Woods Area
Nesson Anticline
Ross Field Area
Parshall/Sanish Area
Poplar Dome
Elm Coulee
Hay Stack Butte Area
Fort Berthold Area
Bailey Area
Little Knife Anticline
St. Demetrius Area
Bicentennial Anticline
Billings Anticline
Cedar Creek Anticline
Structure Top Bakken Formation
Bakken and Three Forks Producers shown
50 Miles
SYMBOL HIGHLIGHT
BKKN PRODUCERS
THREE FORKS
Total US Williston Basin
Bakken and Three Forks
1,289,803,891 BO
1,311,105,241 MCFG
Montana
North Dakota
Daniels
Sheridan
Roosevelt
McCone
Richland
Wibaux
Prairie
Custer
Billings
Golden Valley
Slope
Hettinger
Stark
Mercer
Olive
McLean
Renville
Burke
Mountrail
-6000
-5000
-7000
-8000

Conclusions

- A **"giant" continuous accumulation** is present in the Bakken and Three Forks of the Williston Basin

- Sophisticated completion technology and **geological factors have a large impact on productivity**

- **Sweetspots** influenced by **hydrocarbon generation, pore overpressure, inferred oil saturations and productivity, net pay, facies, natural fractures, etc.**

- **Optimal completion design depends on area and field maturity**
  - 40-stage completions may not be economic in low-productivity areas
  - Simpler (cheaper) completions may be preferable for infill wells at late development stage

- **Multistage hydraulic fracturing and horizontal drilling** are game changers for tight oil systems

Colorado School of Mines Bakken Consortium