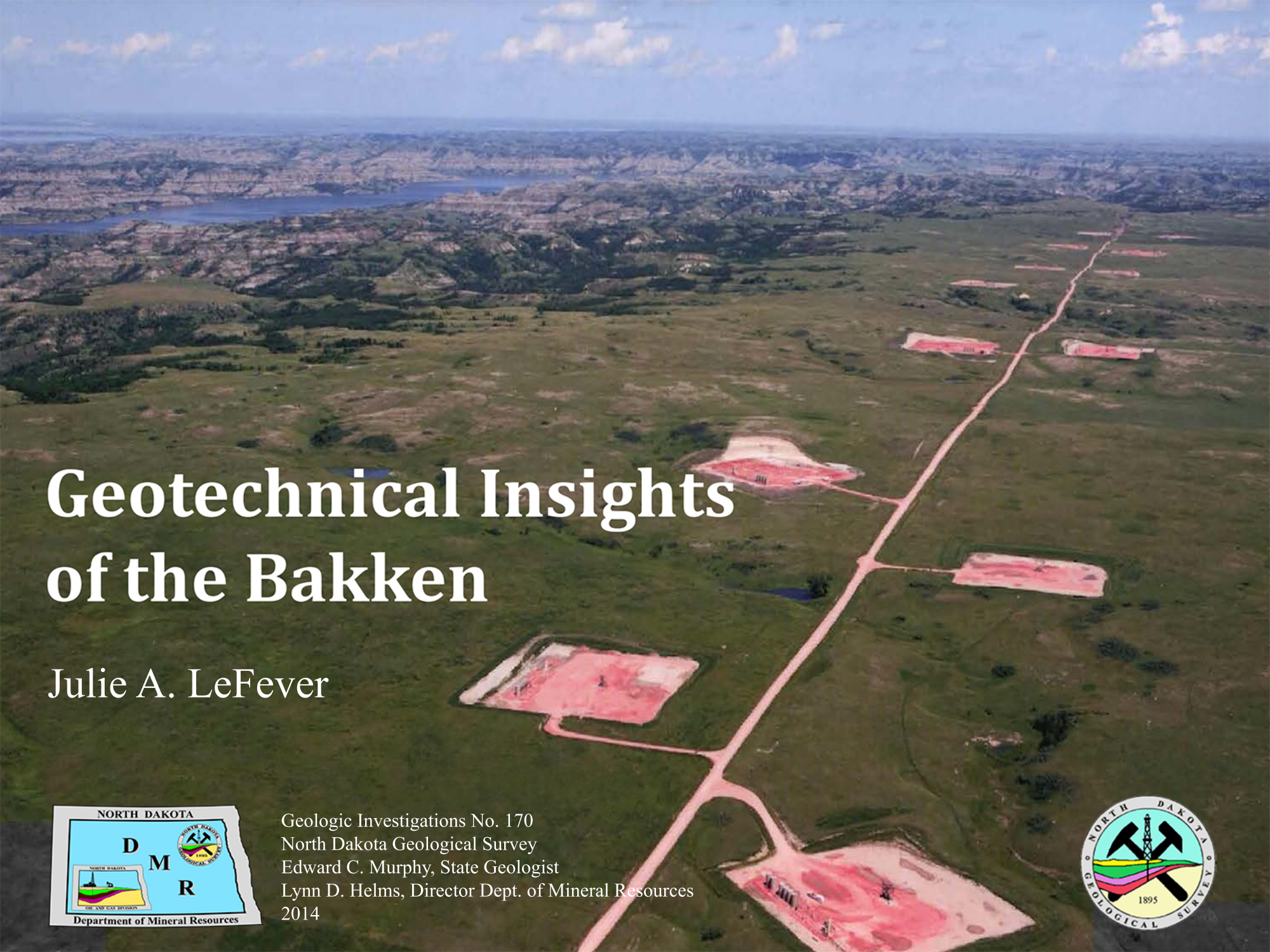


Geotechnical Insights of the Bakken

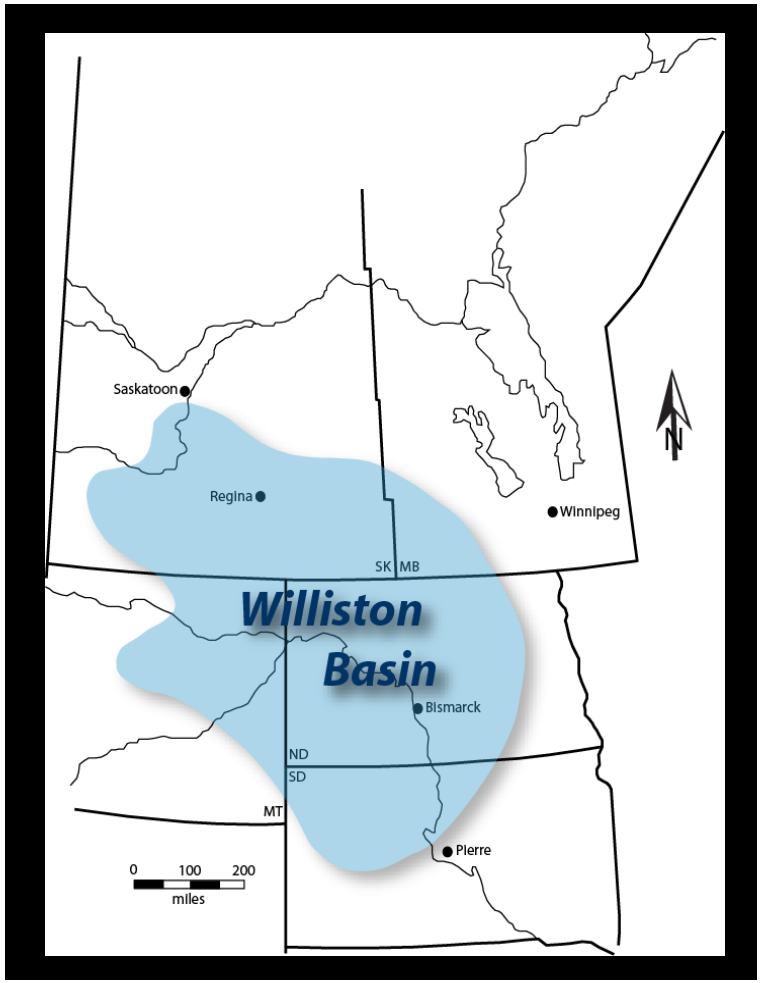
Julie A. LeFever

Geologic Investigations No. 170
North Dakota Geological Survey
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2014

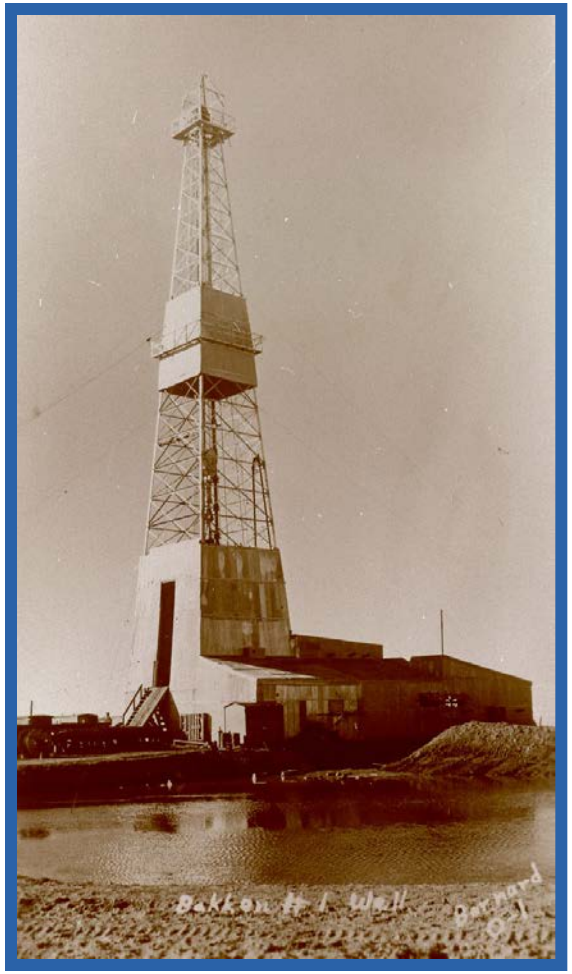
Why the Bakken?

1. Pre-1987 Conventional Drilling
2. 1987-1999 Horizontal Drilling
3. 2001 Discovery of Elm Coulee Field, Richland Co., MT
    1. 2013 – 130,220,389 Bbls Oil, 113,551,136 MCF Gas, 773 wells
4. 2004 Discovery of Parshall Field, Mountrail Co., ND
    1. 2013 – 67,417,851 Bbls Oil, 31,012,481 MCF Gas, 246 wells
5. 2008 USGS Assessment (ND + MT); State of North Dakota Assessment
    1. 3.65 BBbls Oil, 1.85 TCF (USGS); 2.1 BBls Oil (NDIC – ND only)
6. Unconventional Resource Play
7. 2013 USGS Assessment

Overview

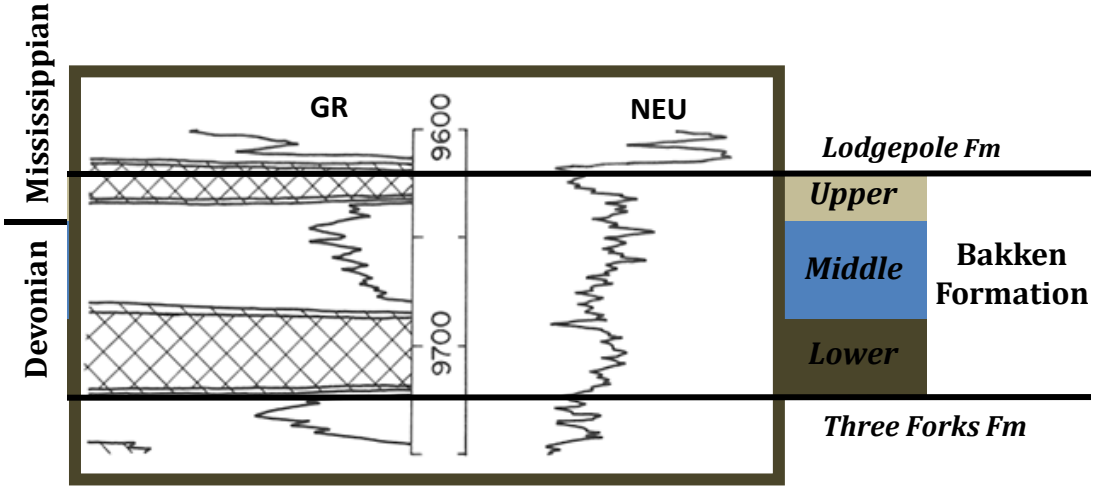


- Examine the Bakken
  - Basic Information
  - Source Potential
- Observations
- Questions
- Tectonic Framework
- Predictability
- Conclusions



(Photos from the William E. "Bill" Shemorry Photograph Collection, property of the Williston State College Foundation; Photo 1, Harry Bakken, mother Mary Bakken, and (standing) Henry Bakken were photographed by the late Bill Shemorry for a story appearing in the Williams County Farmers Press on July 12, 1951, the day before drilling commenced on the H.O. Bakken No. 1; Photo 2, the H.O. Bakken No. 1 as photographed by Bill Shemorry in 1951.)

SWNW Sec. 12, T.157N., R.95W.
Amerada Petroleum Corp.
#1 H.O. Bakken



9620-9630

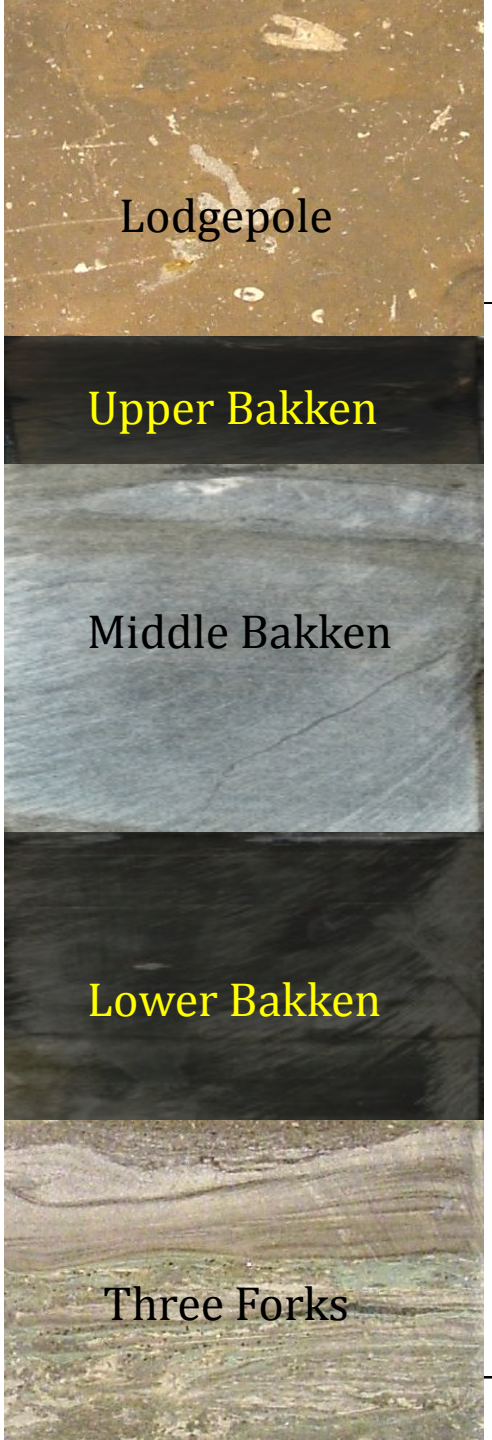
9670-9680

9710-9720

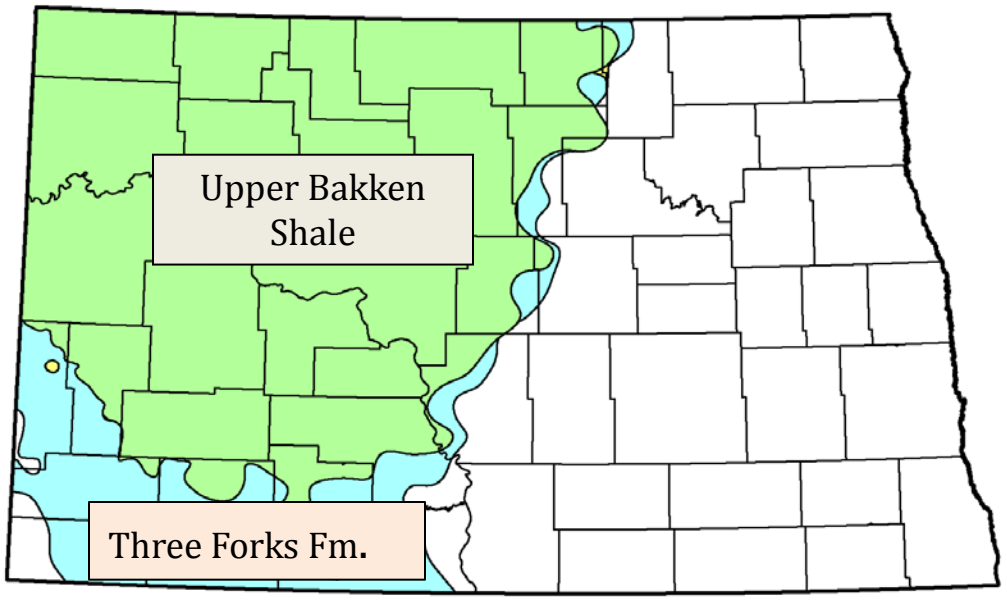
Stratigraphy

Bakken Formation

- **Nomenclature**
  - Defined in 1953
  - Amerada Petroleum - #1 H.O. Bakken
  - Restricted to the Subsurface
  - 105 ft thick
  - upper and lower shale
  - middle limestone member



Distribution of Bakken and Three Forks Rocks in North Dakota



Average Total Organic Carbon:
11.5 weight %
30-40 % by volume

Upper Shale

Lithofacies 5

Lithofacies 4

Lithofacies 3

Lithofacies 2

Lithofacies 1

Lower Shale

Shell Oil Co.
#32-4 Young Bear

Conoco, Inc.
#17 Watterud “A”

Upper Shale

Lithofacies 5

Lithofacies 4

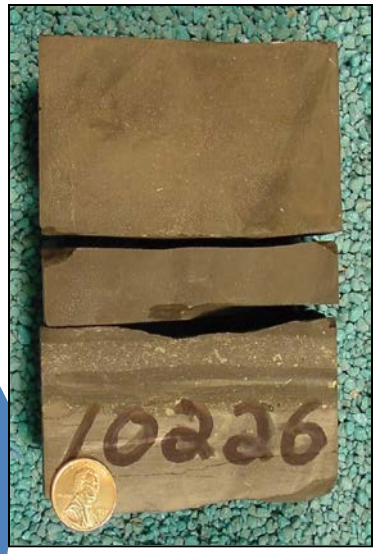
Lithofacies 3

Lithofacies 2

Lithofacies 1

Lower Shale

Shell Oil Co.
#32-4 Young Bear



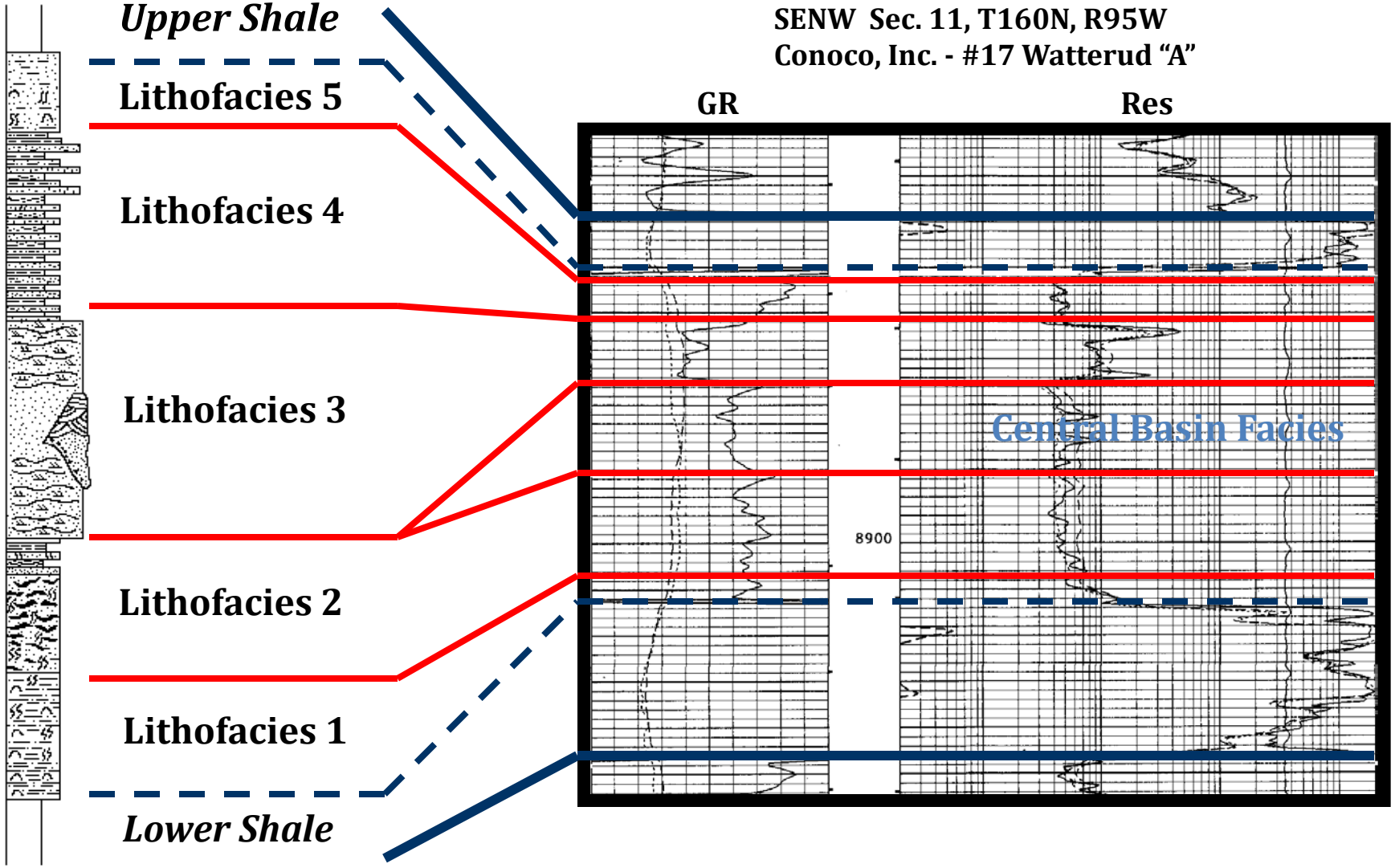
Meridian Oil, Inc.
#44-27 MOI

Middle Bakken Member

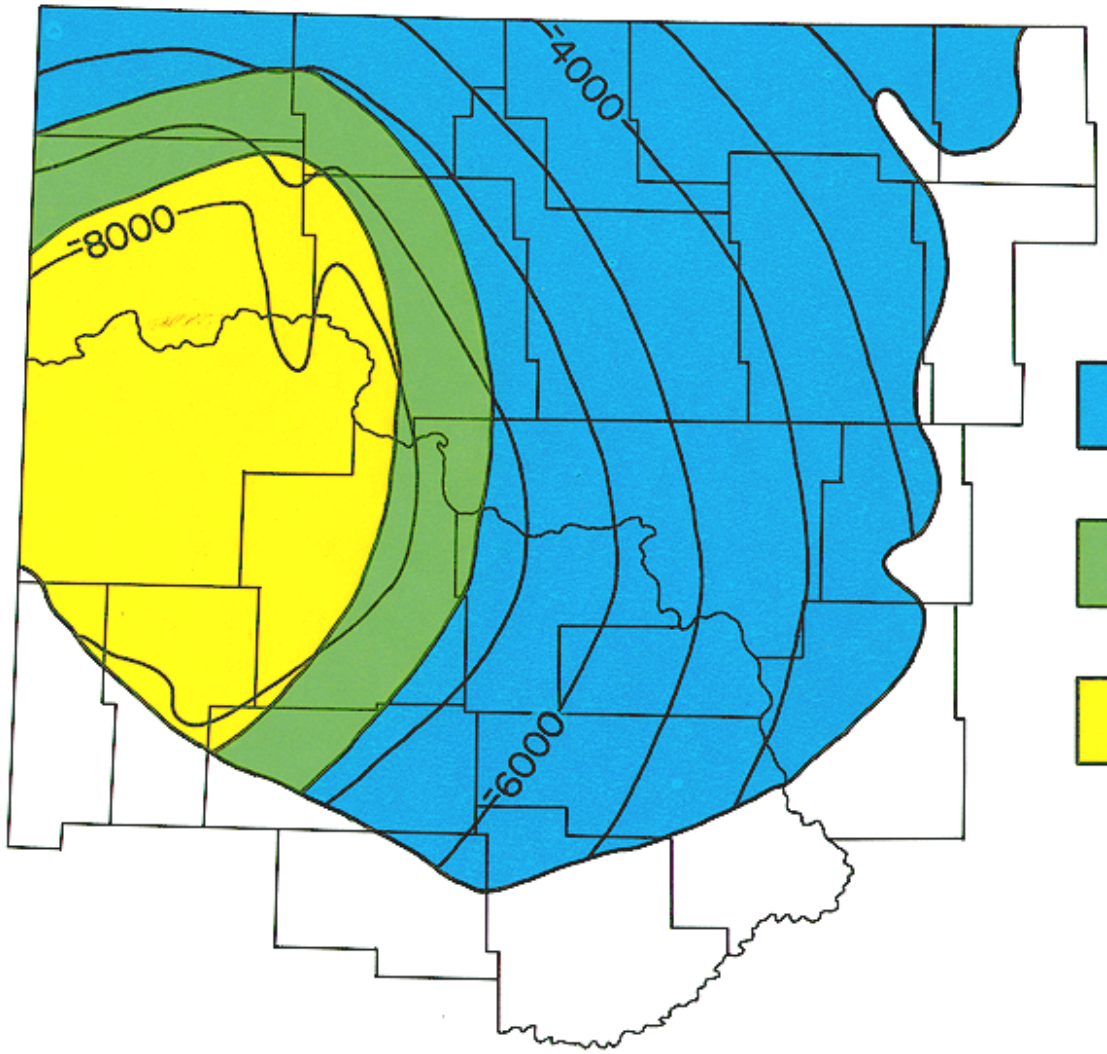
- Mixed Carbonate-Clastic Sequence
- Uniform Distribution of Sediments and Facies
- Nesson Anticline Barrier –
  - Eastern side – clastic rich
  - Western side – sediment starved
- Low porosity-Low permeability

#33-053-01599 – 10835 ft

Lithofacies of the Middle Member



(From LeFever and others, 1991)



Immature

Onset of Generation

Intense Generation

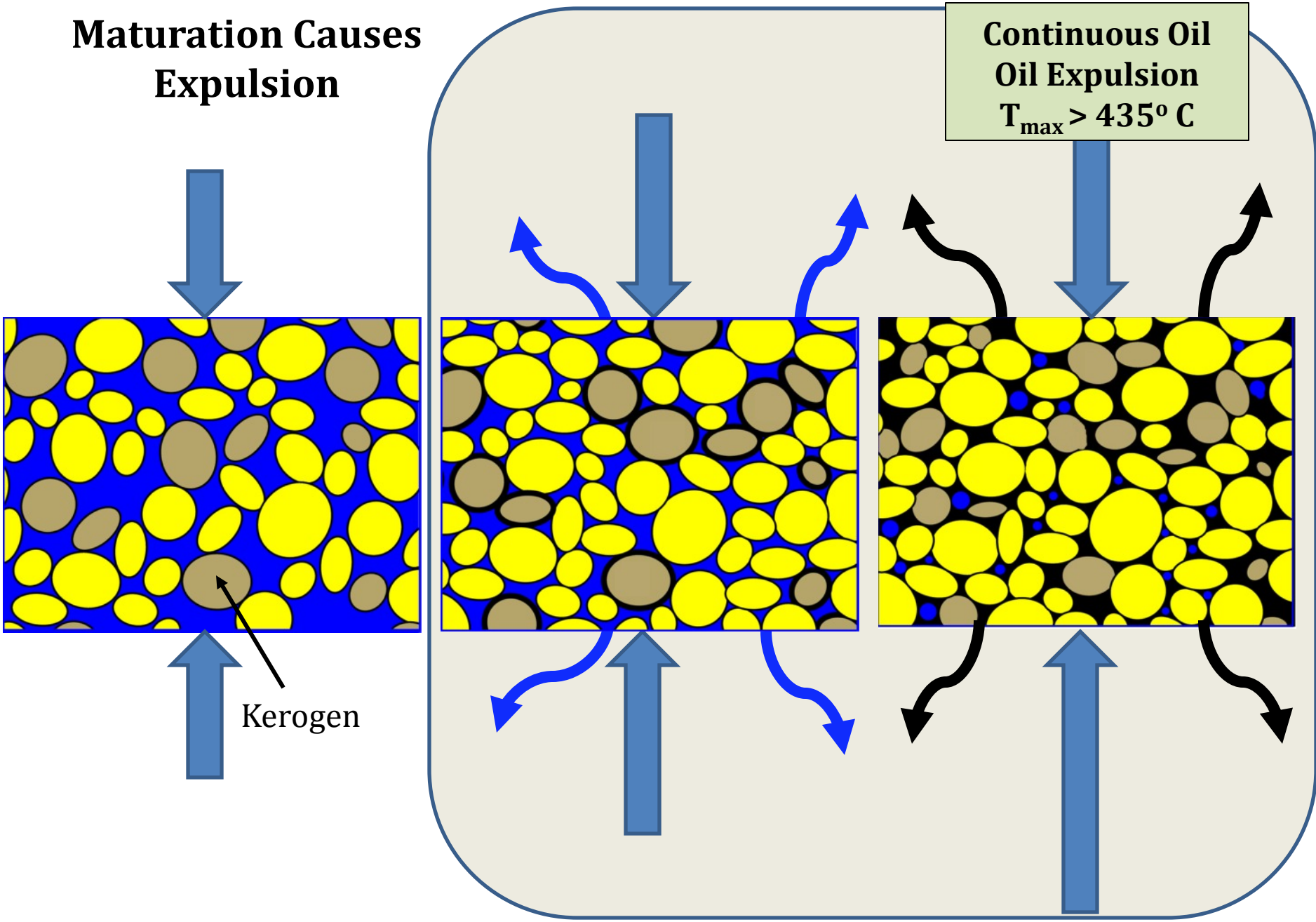
Webster, 1982

Source Rock Maturity Zones

Source Rock Potential

- Total Organic Content – 0 to 40%
  - Decrease towards depositional edge
- Kerogen
  - 70-90% amorphous; 0-20% herbaceous; 30% coaly; 5% woody
- Formed in subaquatic oxygen-restricted environmentHydrocarbon Generation
  - Depth of 9000 ft
  - 100^{o} C
- Hydrocarbon Generation
  - Up to 413 billion barrels (ND & MT)
  - Bulk volume change in the rock
  - Formation of micro and macro fractures
  - Common in zones with higher organic content
- Highly overpressured – 5500 to 7600 psi
  - Migration
  - Bakken Source System
- Producers
  - High Gravity Oil – 35 to 46^{o} API
  - No water

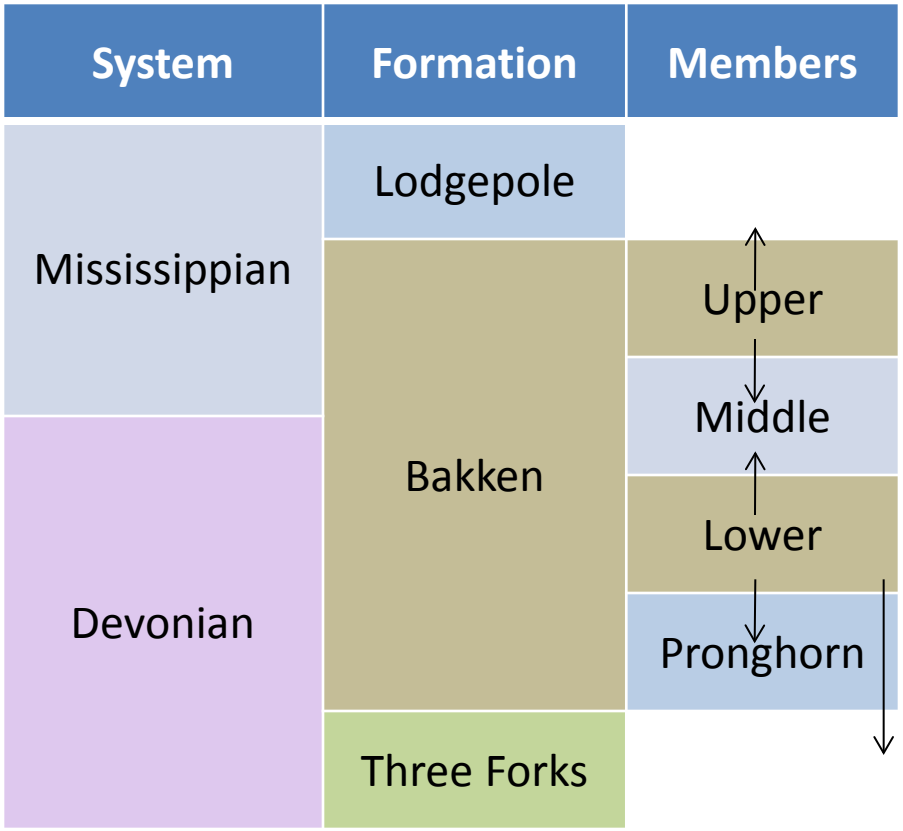
Maturation Causes Expulsion



Nordeng after Meissner, 1978

Expulsion of Petroleum from Source Beds into Poorly Permeable Bounding Beds

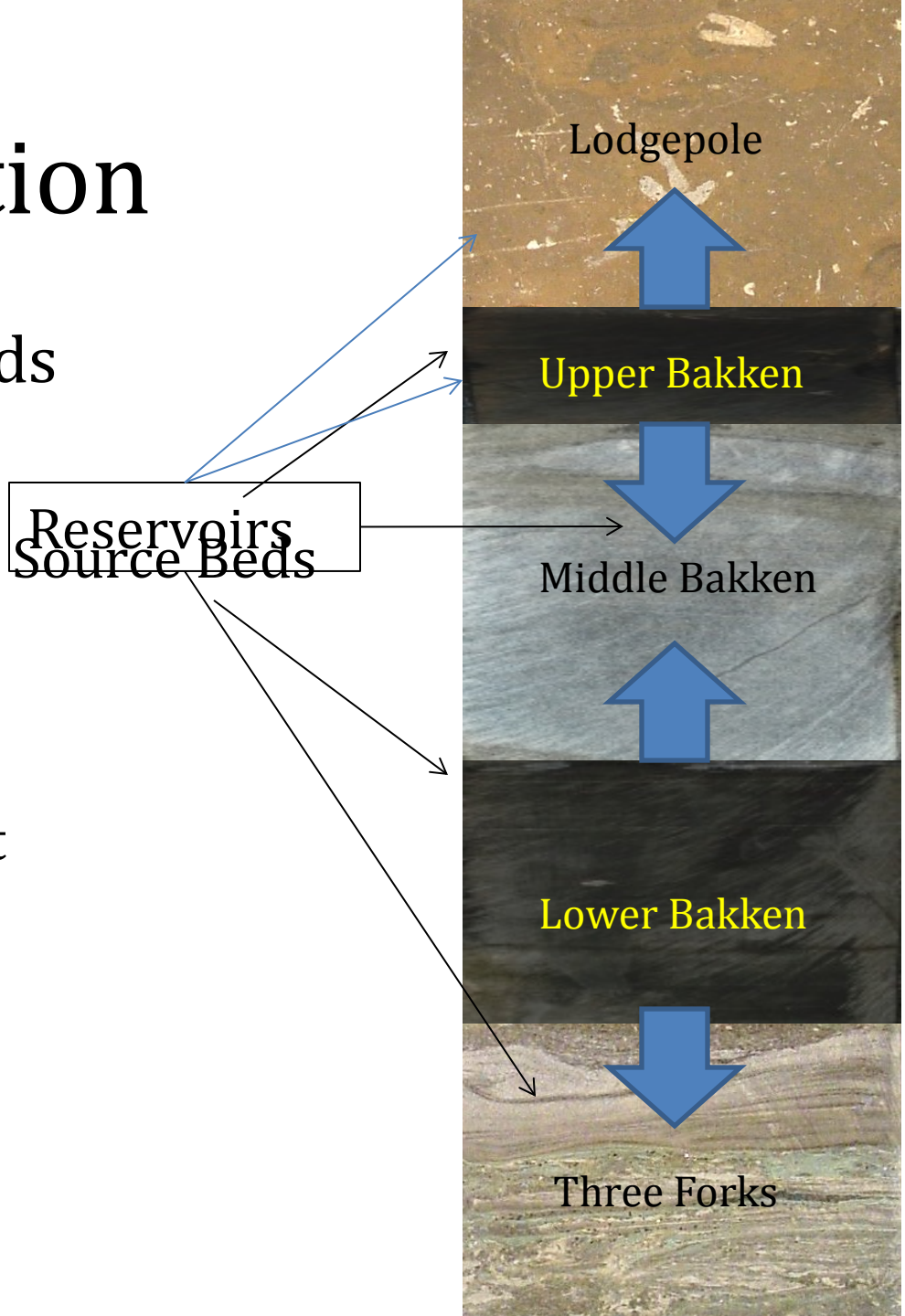
- Source
  - Upper and Lower Shales
- Reservoirs
  - Bakken Shales
  - Clastic-carbonate Middle Member of the Bakken Fm.
  - Dolo-mudstones of the Pronghorn Member
  - Three Forks Fm.
  - Lodgepole (?) Lower 50’



Modified from Nordeng, 2012

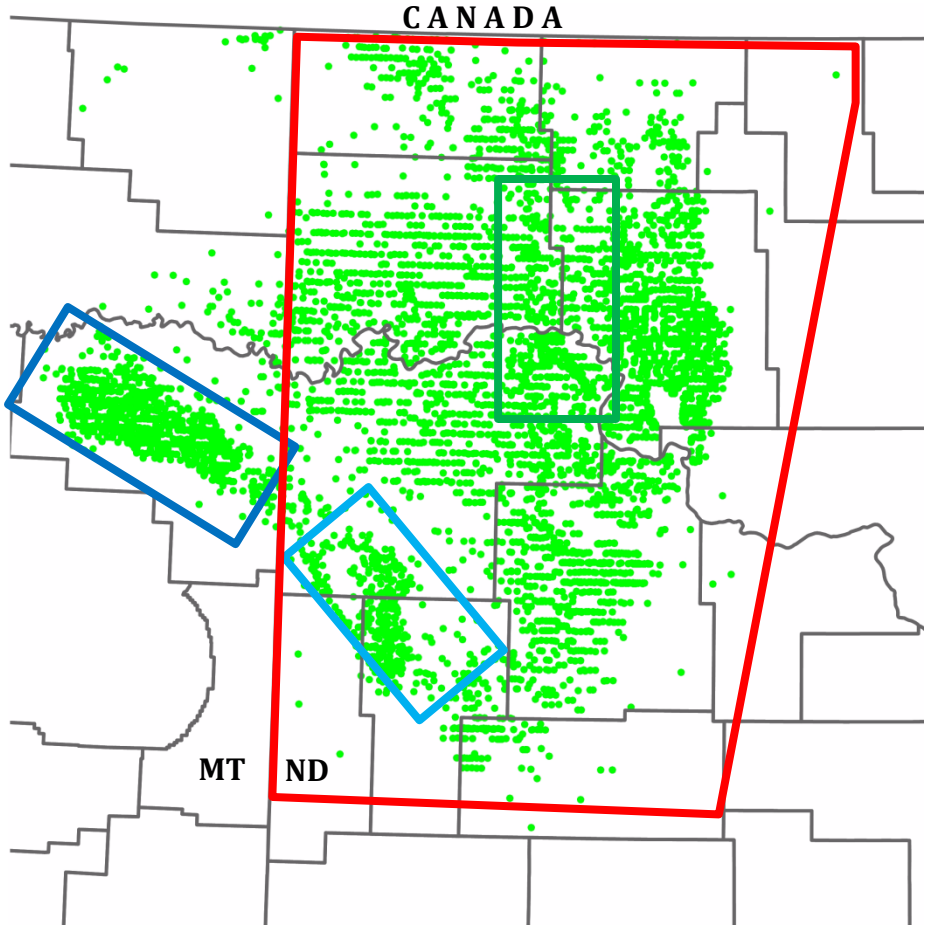
Accumulation

- Low permeability beds above and below.
  - Prevents Migration
  - Produces High Pressures
  - Impossible to get out economically without some help.



(Modified from Nordeng)

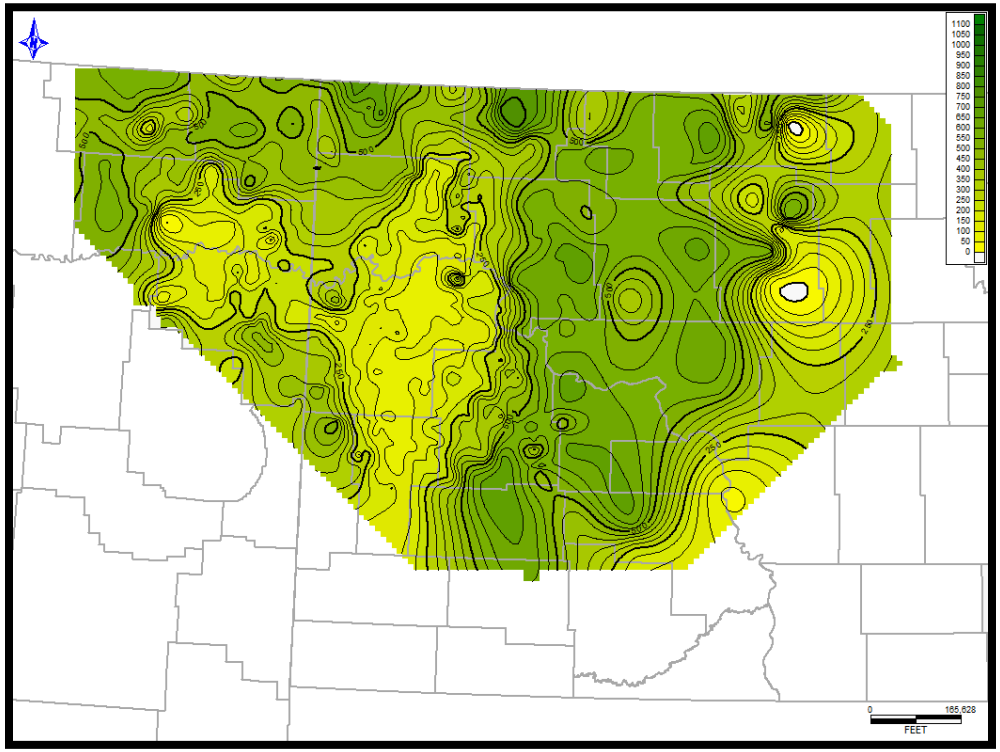
Available Cores



- 1953 to 1987 – 94 Bakken Cores
  - 70 cores – Restricted to the Nesson Anticline
  - 24 cores – Vertical wells along the Bakken Fairway
- 1987 to 2000 – 36 Bakken Cores
- 2006 to Present – 100+ Bakken Cores
  - Basinwide
  - Longer (150+ ft)

Rock Eval Data
Upper Bakken Shale

Hydrogen Index

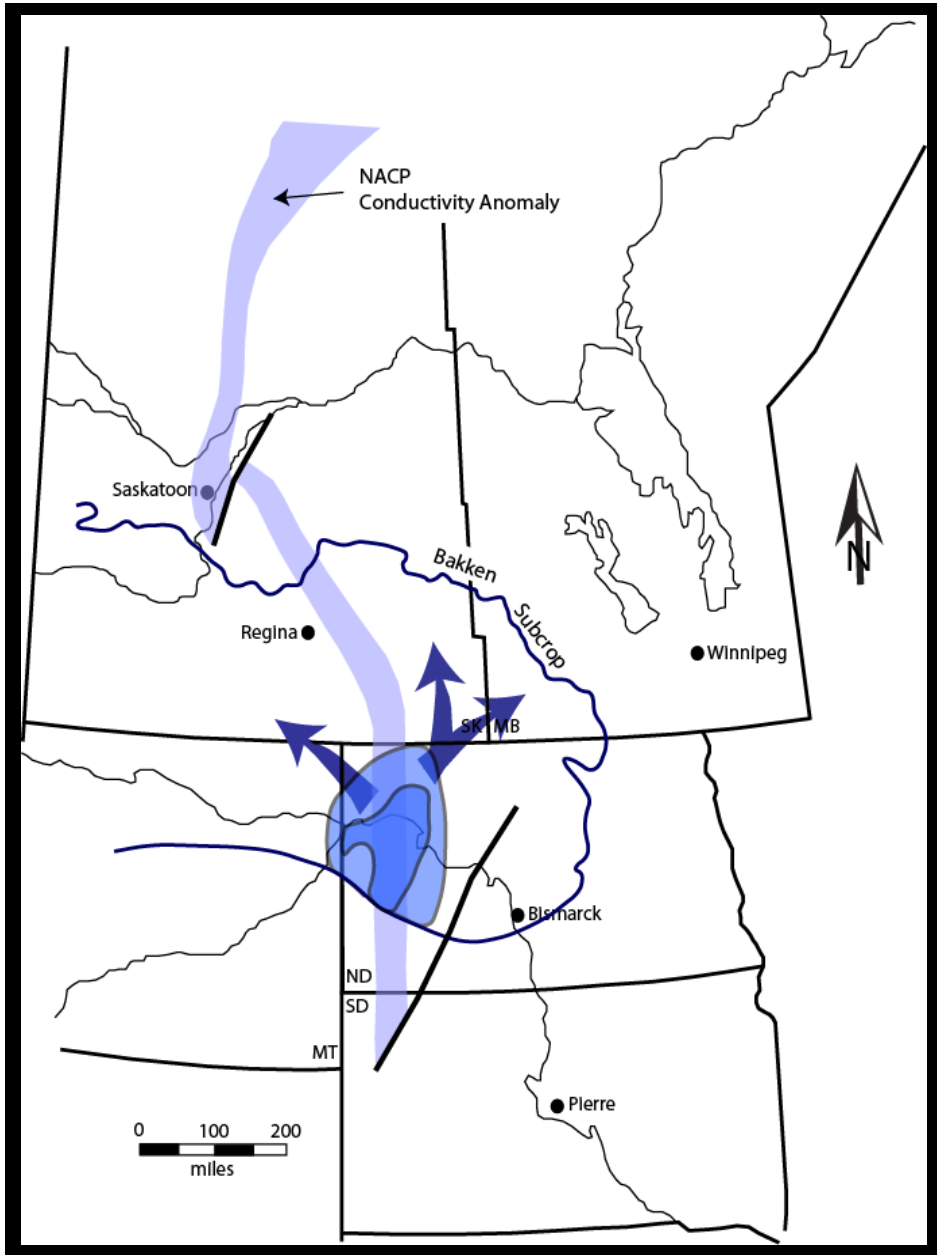


Overall Characteristics

- **Total Organic Content – 0 to 40% Kerogen**
  - **Type II Organic Matter - 70-90% amorphous; 0-20% herbaceous; 30% coaly; 5% woody**
- **Sub-aquatic oxygen-restricted environment**
- **Hydrocarbon Generation -Depth of 9000 ft; 100° C**
- **Localized areas of high heat – relative maturity**

- **Lower Shale is similar**

So What About Parshall Field??

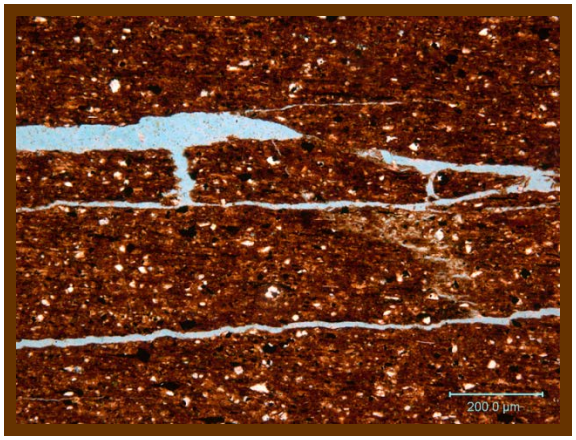


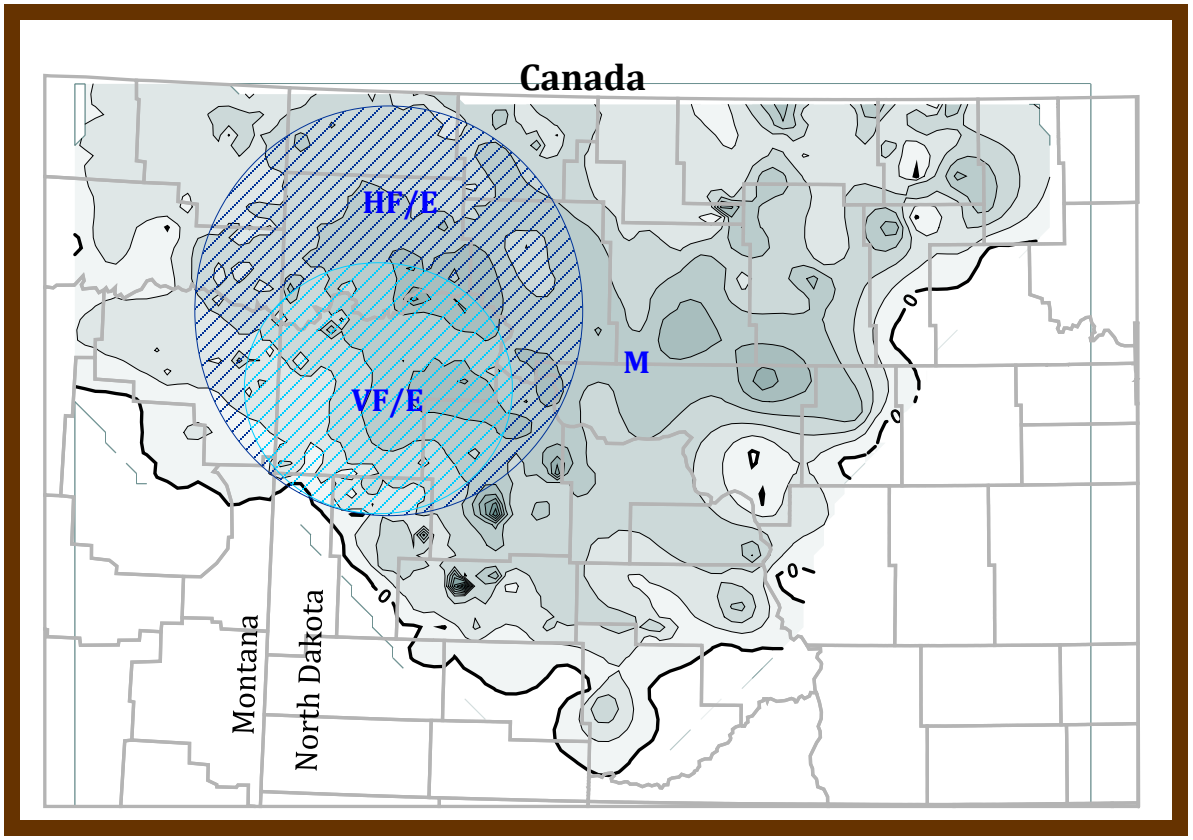
Bakken Generation and Migration

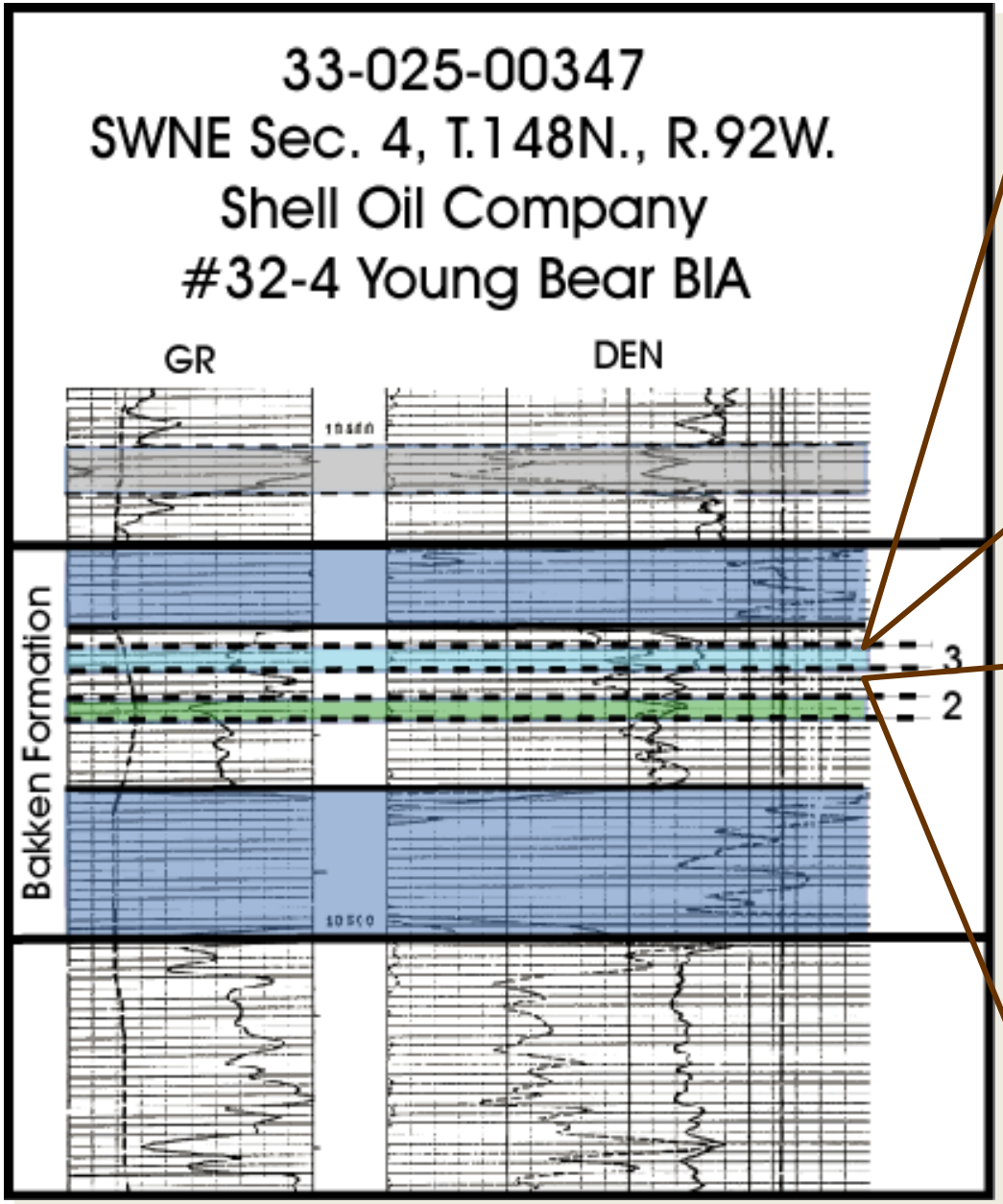
Upper Bakken Shale

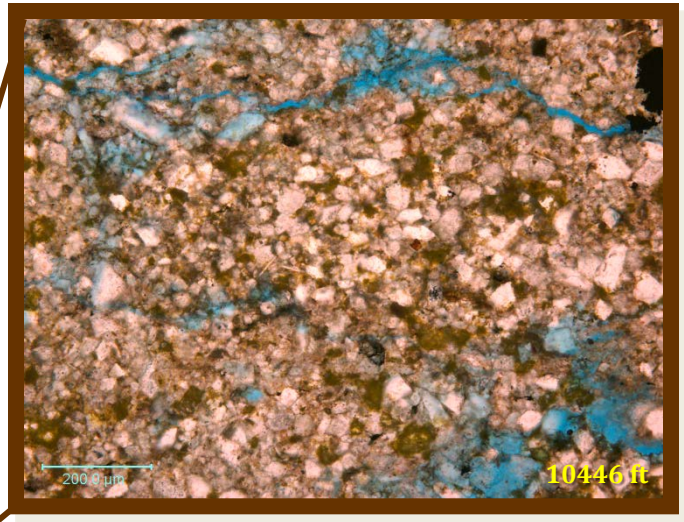
Texaco, Inc - #1-5 Thompson

Shell Oil Co. - #32-4 Young Bear

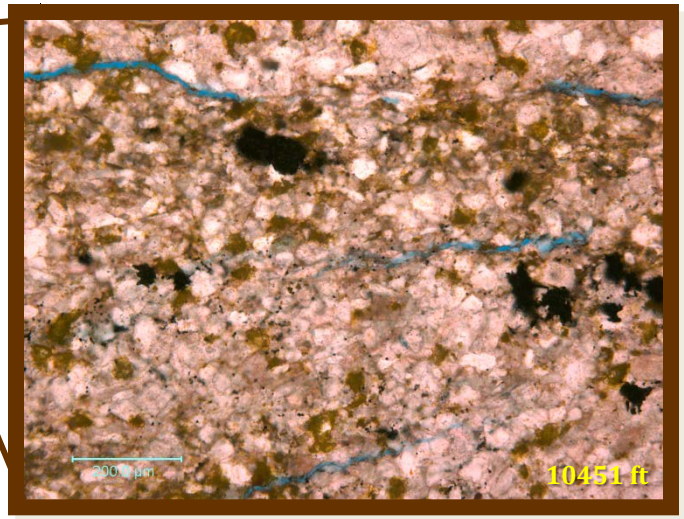






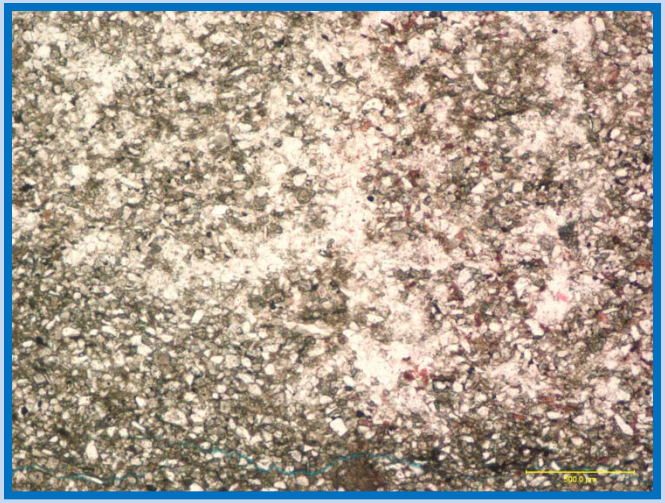


Lithofacies 3

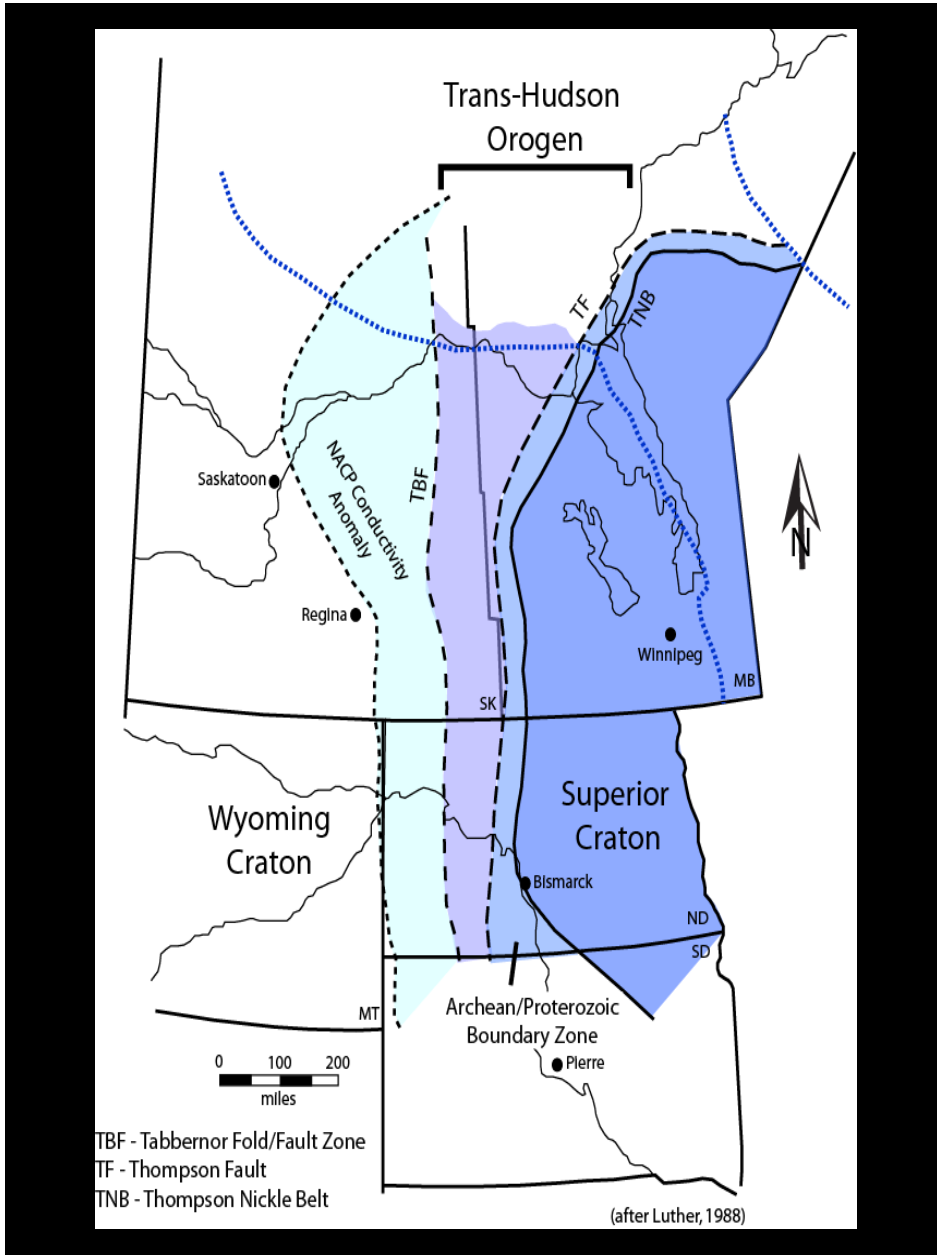


Central Basin Facies

Diagenesis



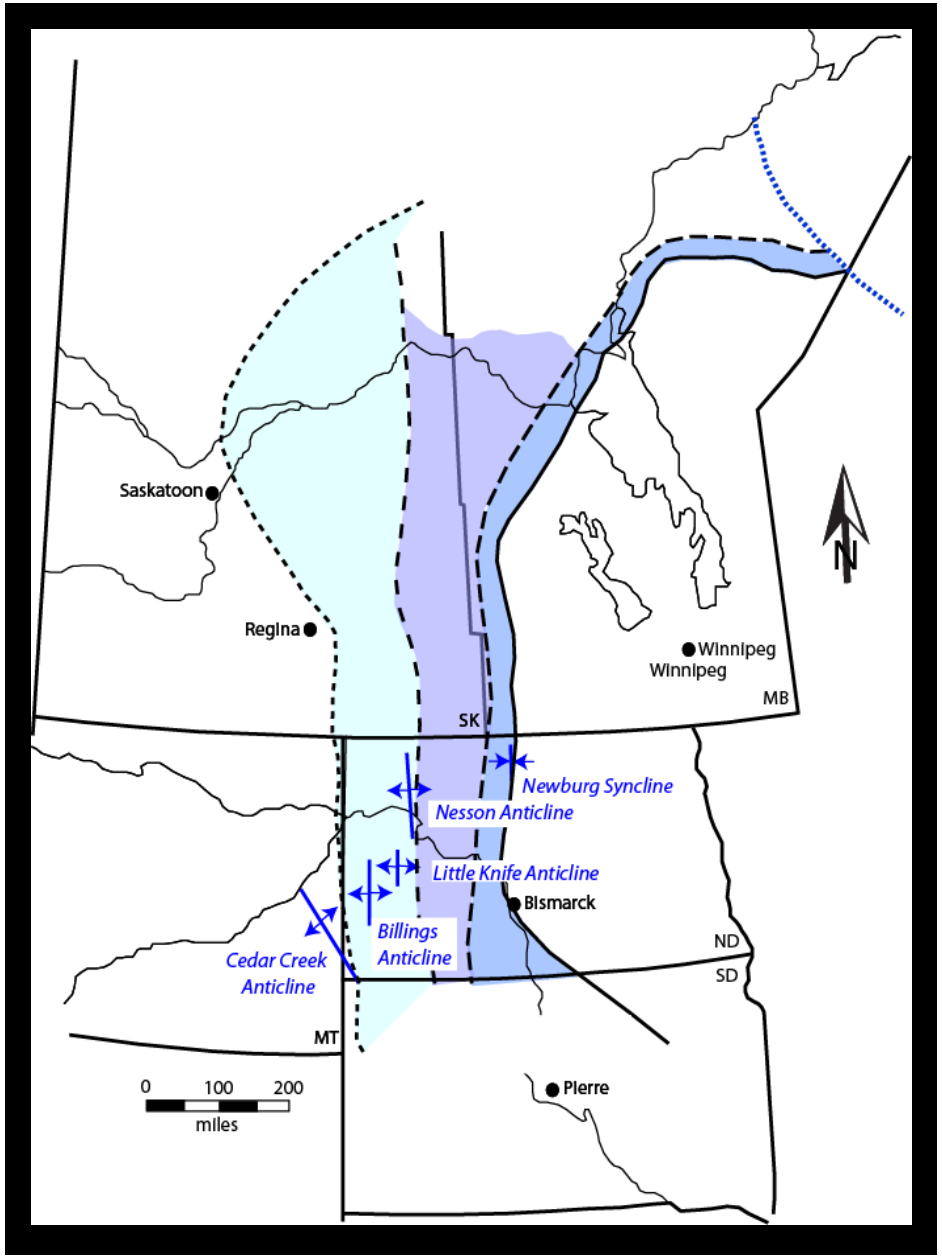
- Multiple phase of dolomitization
- Multiple cements
  - Calcite
  - Pyrite
  - Dolomite
  - Silica
- Dissolution
- Some reservoir enhancing and some reservoir destroying



Williston Basin Precambrian Basement Tectonics

3 Main Regions

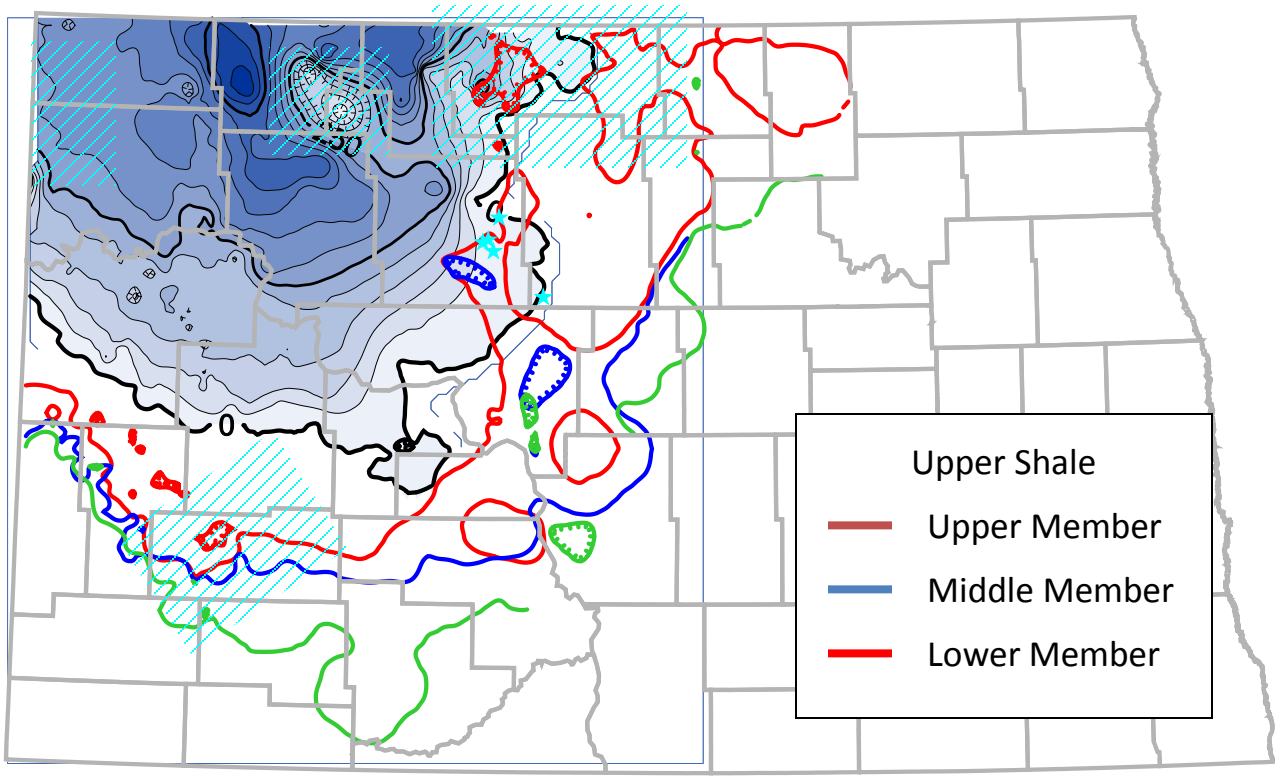
Superior Craton
Trans-Hudson Orogenic Belt
Wyoming Craton



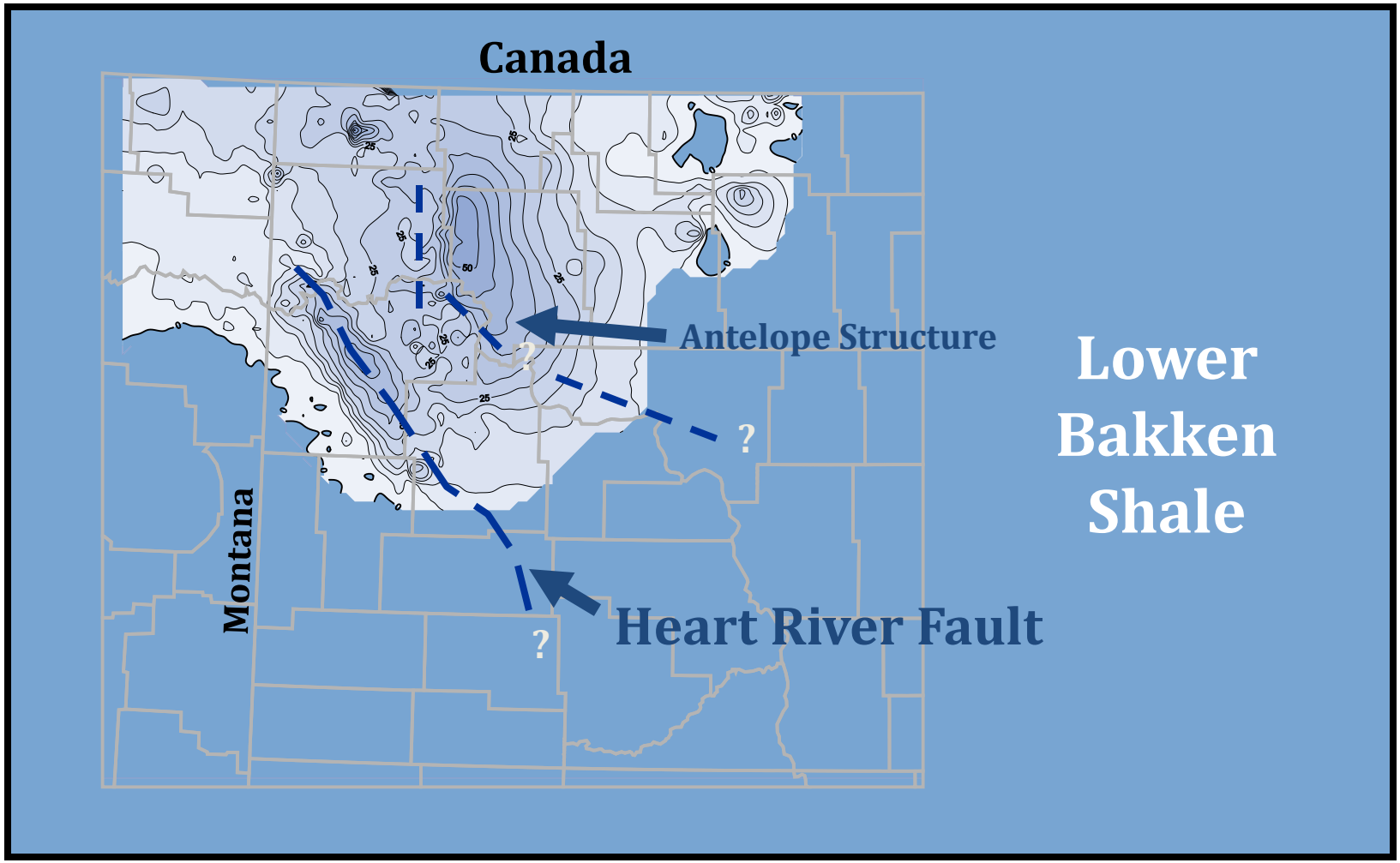
Existing Structures and Basement Terranes

Folds and Associated Faults

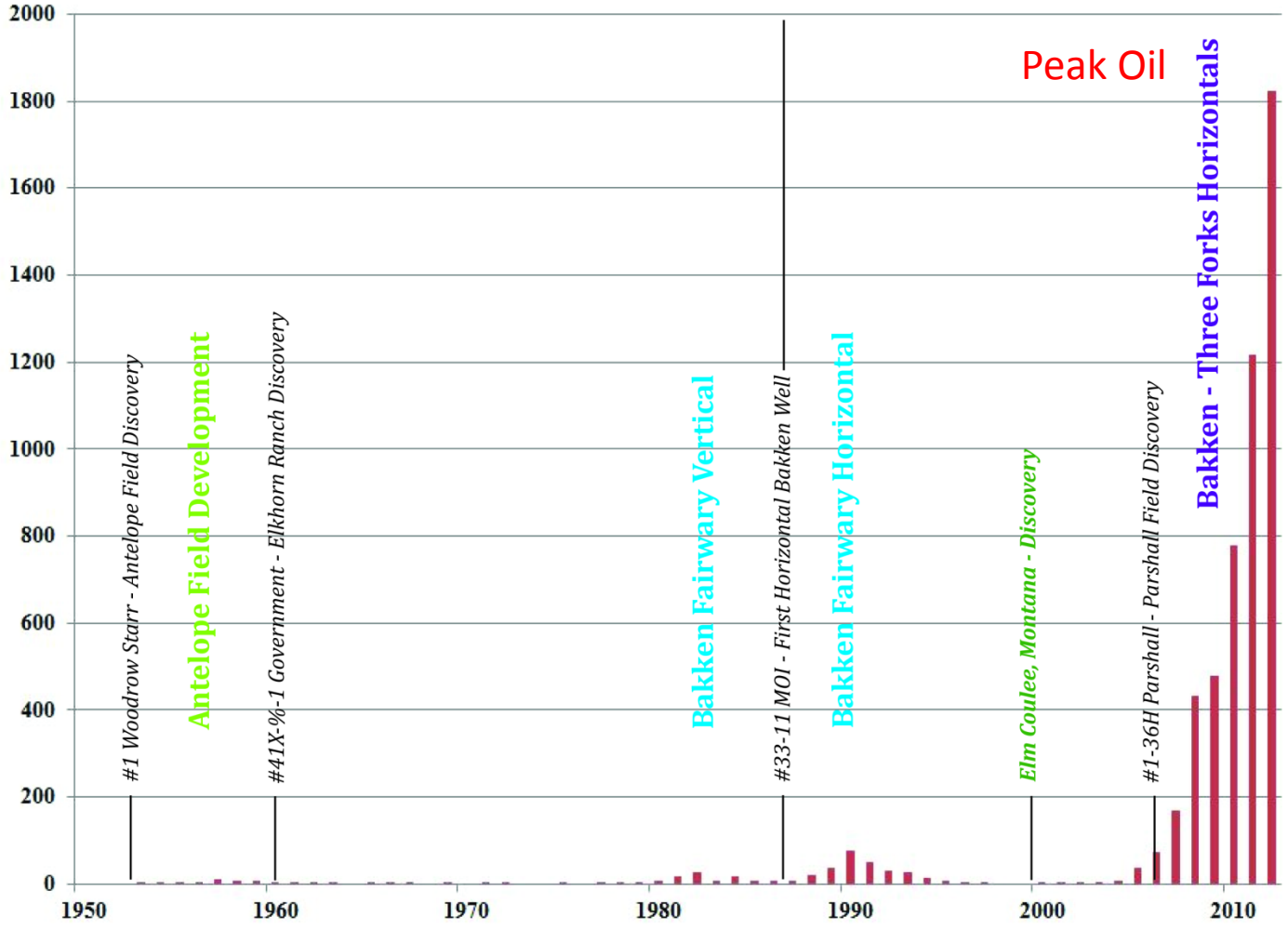
Salt Tectonics



Regional Fractures

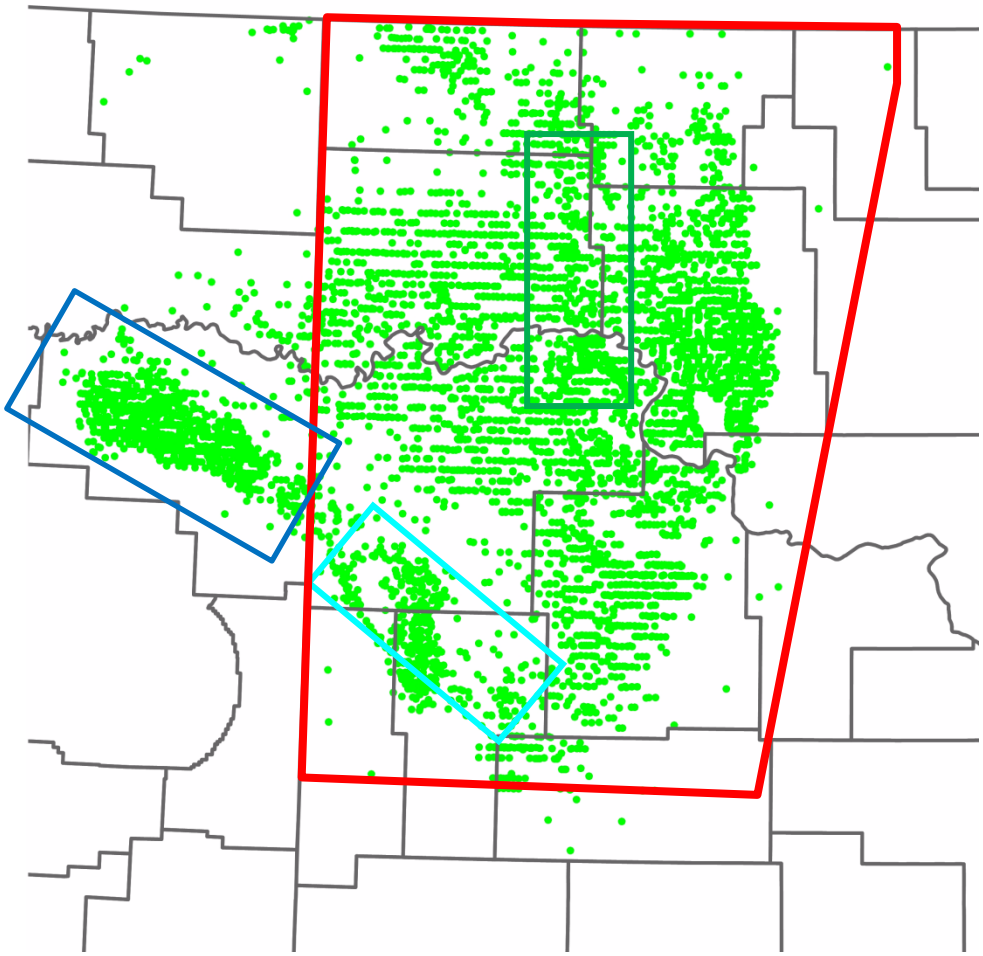


Time Line of Bakken Development



(modified Nordeng, 2011)

Bakken Activity



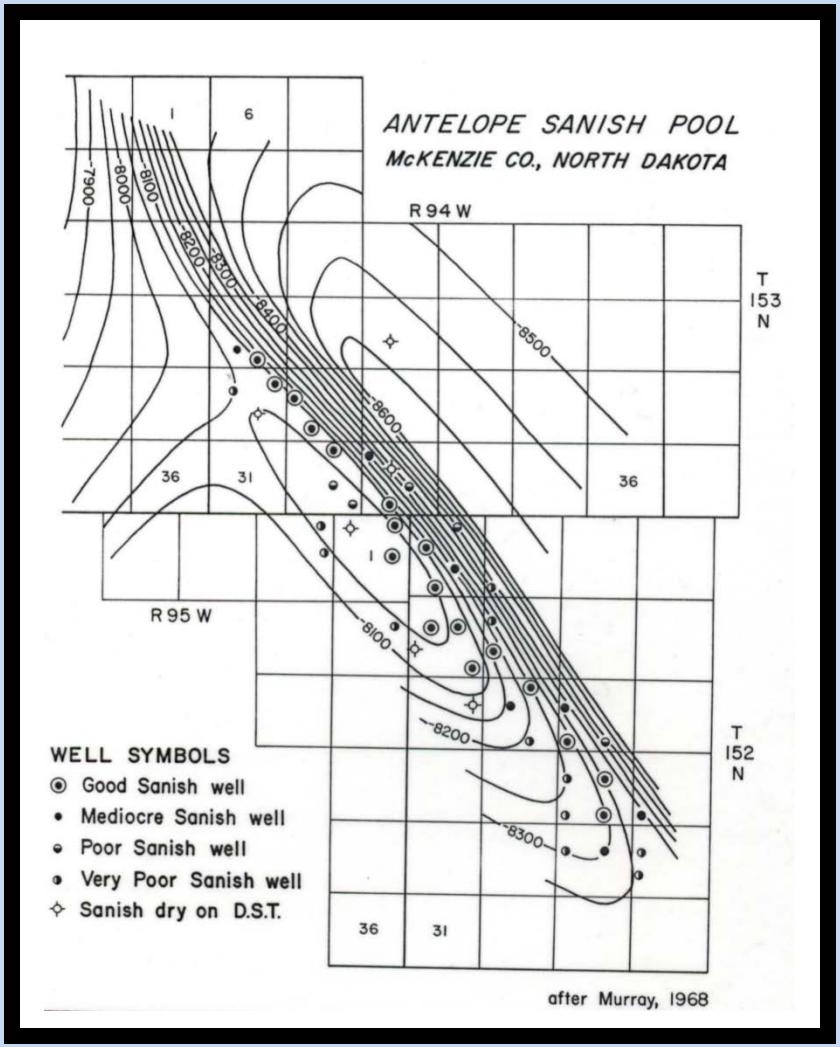
Conventional Bakken
(pre-1987)

Horizontal Drilling -
Upper Bakken Shale
(1987-1995)

Elm Coulee
(2000-present)

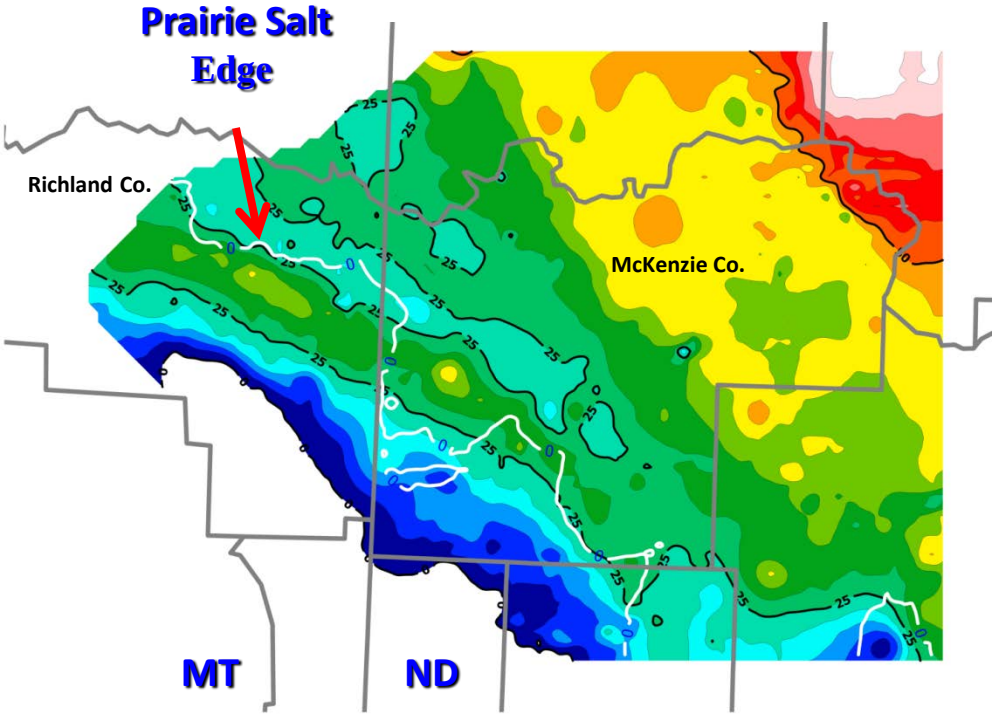
Horizontal Drilling –
Bakken Middle Member
(2001-present)

Antelope Field



- Antelope Field (1953 to present)
  - 59 wells; current 12 wells
    - 20.2 million bbl oil
    - 285 MCF Gas
  - Three distinctive production zones
    - Bakken
    - "Sanish Sand"
    - Upper Three Forks
  - Significant structural component
    - Best wells not on the crest of the structure

Elm Coulee

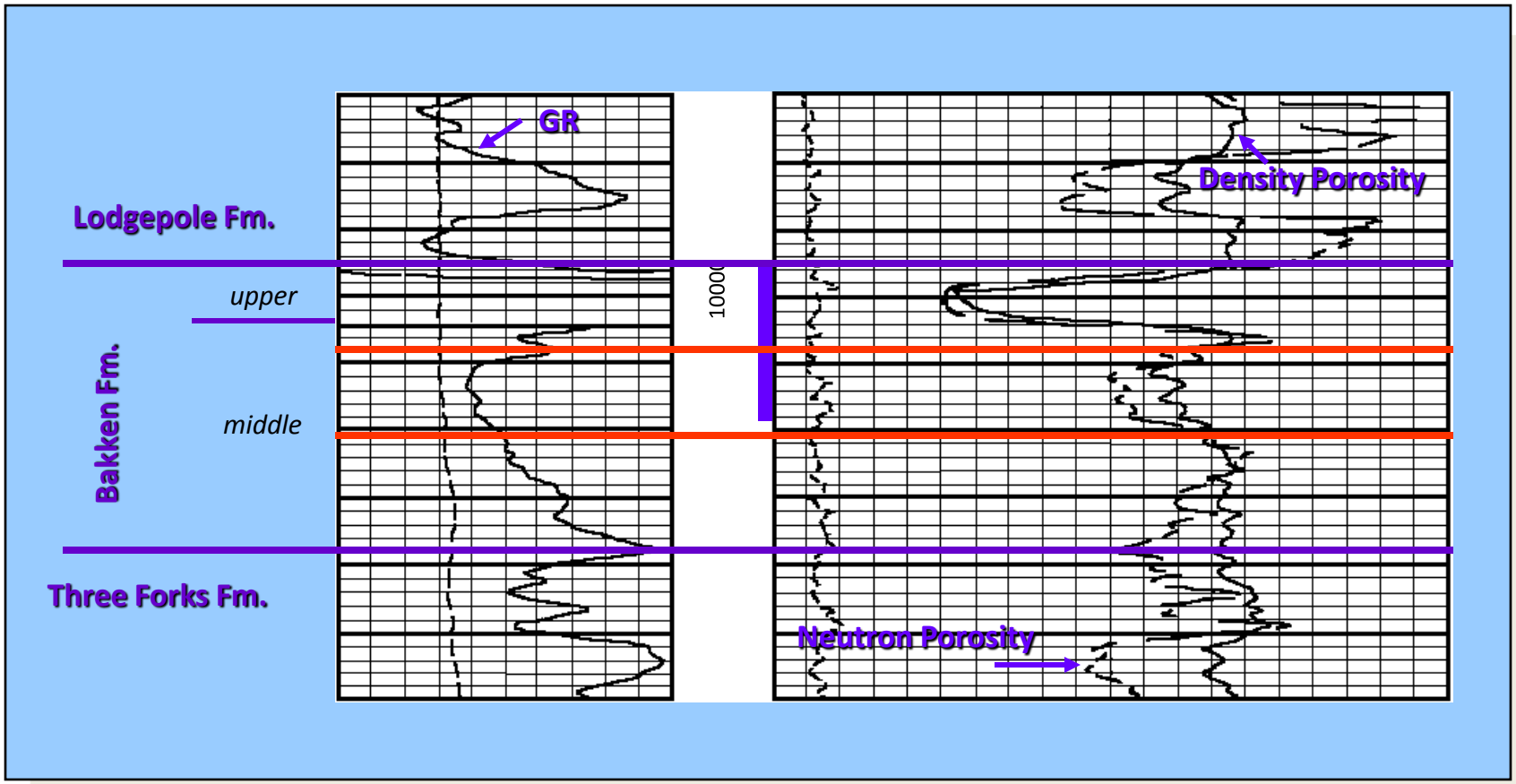


Middle Member Isopach

- Established with Kelly/Prospector – 2-33 Albin FLB
- NW – SE trending dolomitized carbonate shoal
- 600 horizontal wells – 450 square mile field
  - 130,220,389 Bbls Oil
  - 113,551,136 MCF Gas
- 3-9% Porosity; K - .04 md
- Pressure of .53 psi
- Stimulations – Sand, Gel, and Water

Balcron Oil - #44-24 Vaira

SESE Sec. 24, T.24N., R.54E.

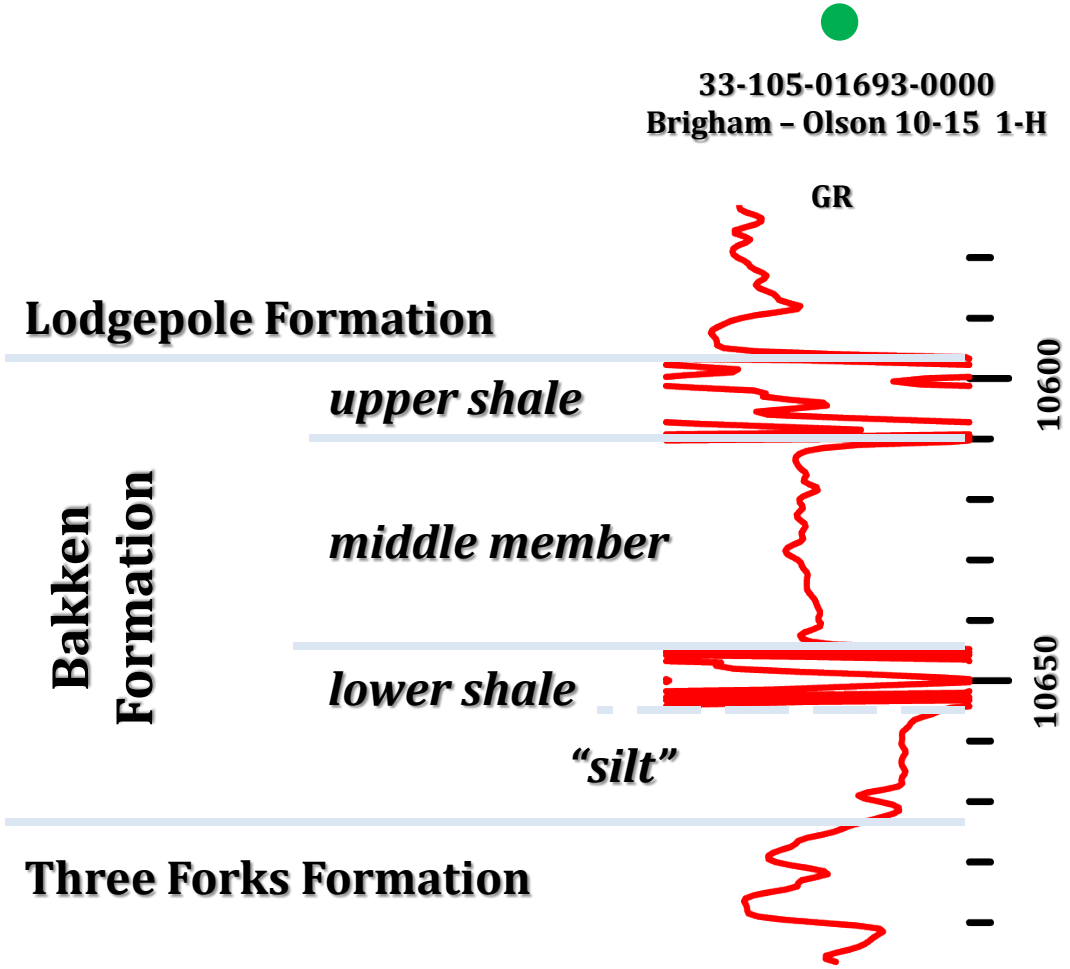


North Dakota 2004-06 (Before Parshall)

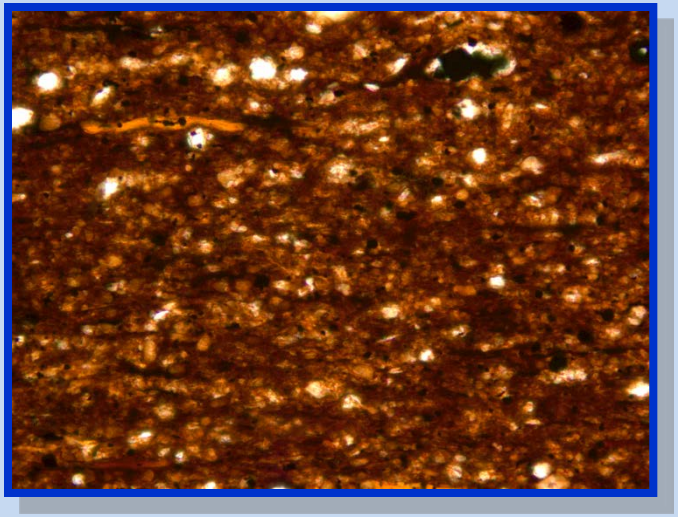
Bakken Middle Member Wells

- 52 Horizontal Wells
  - 3 Dry Holes
  - 49 Producers
    - 9 wells > 300 BOPD
    - 17 wells – 100 – 200 BOPD
    - 23 wells < 100 BOPD
  - Problems
    - Drilling and stimulating wells
      - Overpressured
      - Lithological Different
      - Higher BHTs

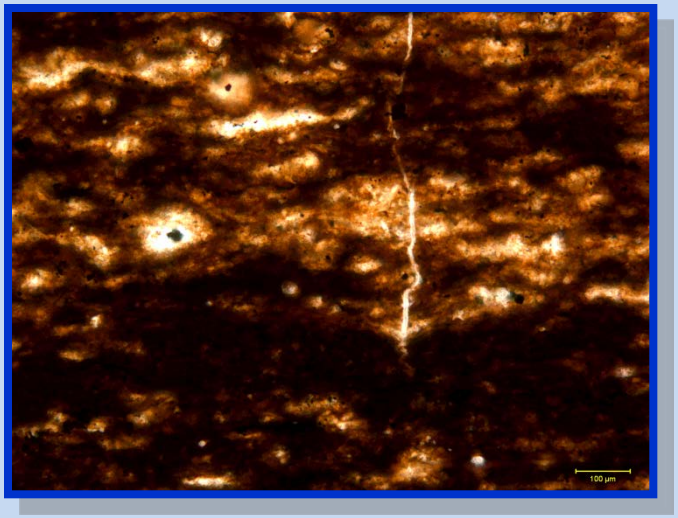
North Dakota – Lower Bakken Silt



Parshall Field



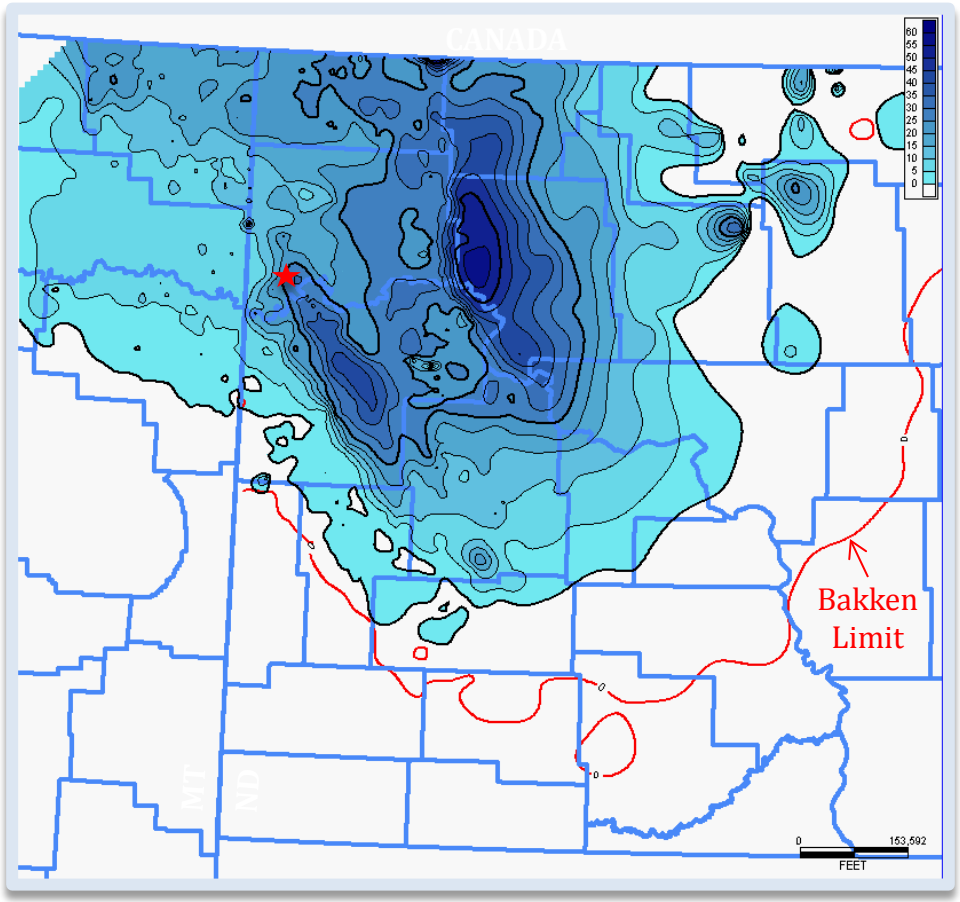
- Upper and Lower Shale
  - Marginally mature??
- Explain the high production rates
- Presence of horizontal “hydraulic” fracturing thru section & expulsion fractures

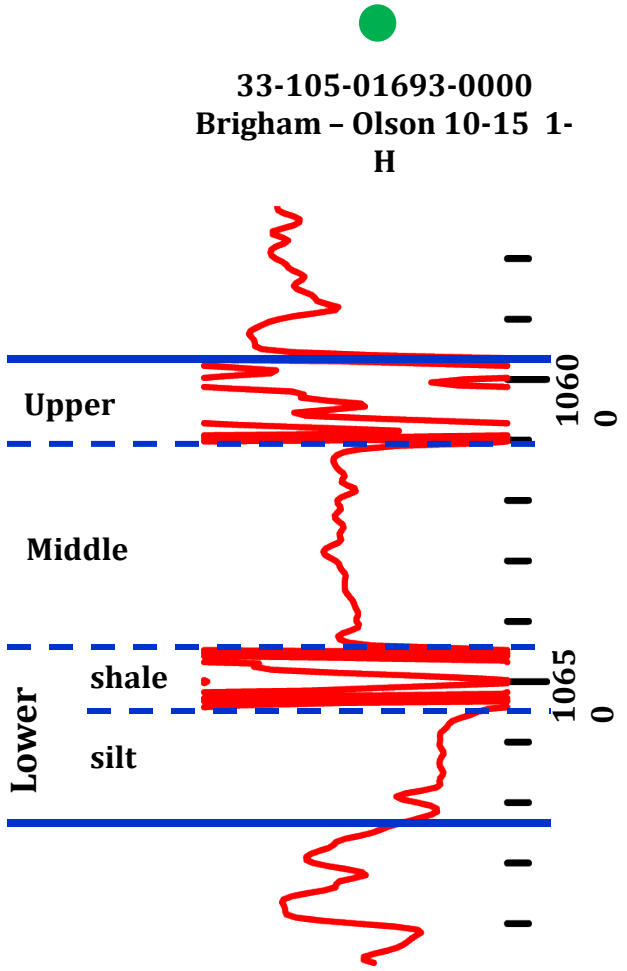


Middle Member – Parshall Field

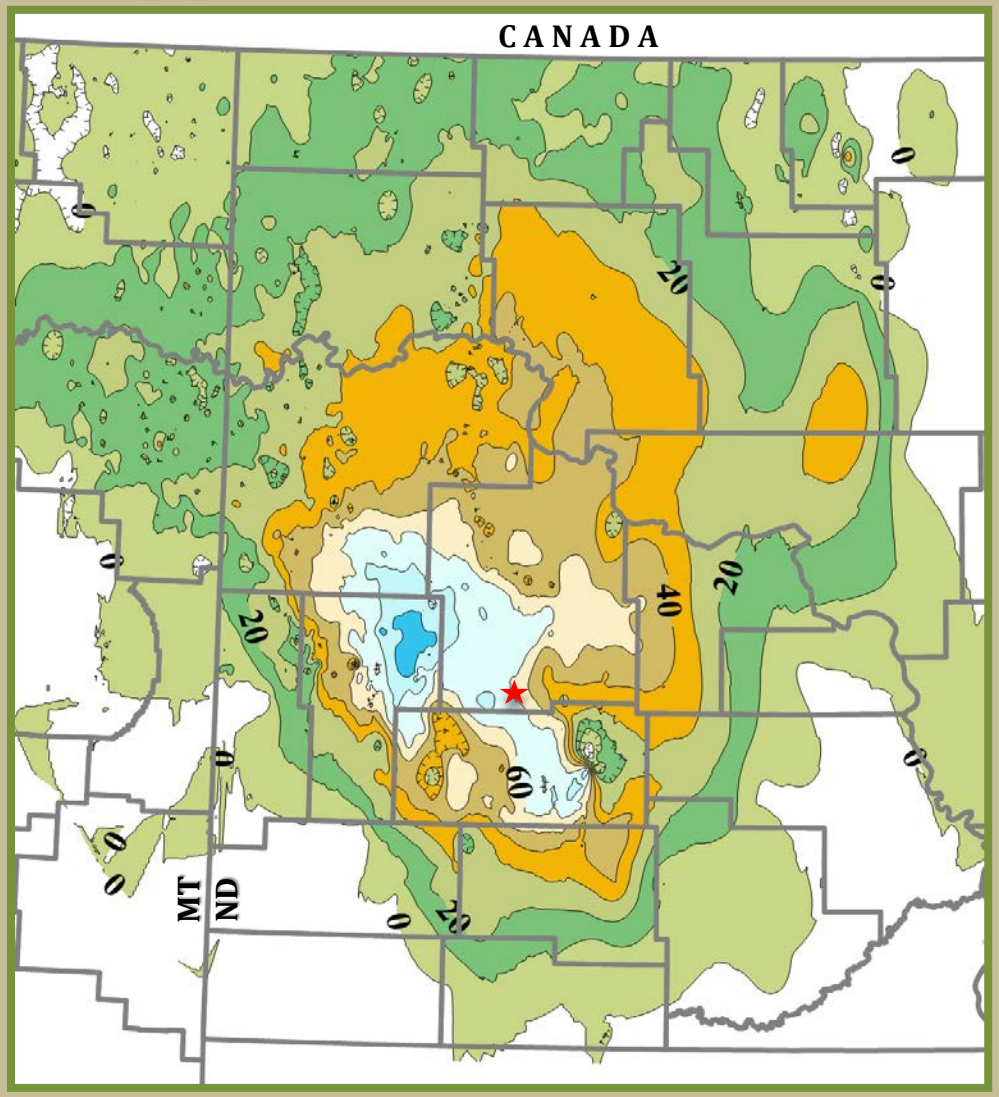
- Rock Eval Data
  - presence of 3 types of organic matter
    Type I, Type II (Bakken), Type (III)
- Possible sequence of events
  - Type III – gas prone organics
    - Matures earlier (?)
  - Overpressures the reservoir resulting in
    middle member "hydraulic-like" microfractures
  - Raises the P & T of the shales
  - Smectite to Illite – onset generation in kerogen-rich layers
  - Mixed oil
  - Shales provide accommodation space

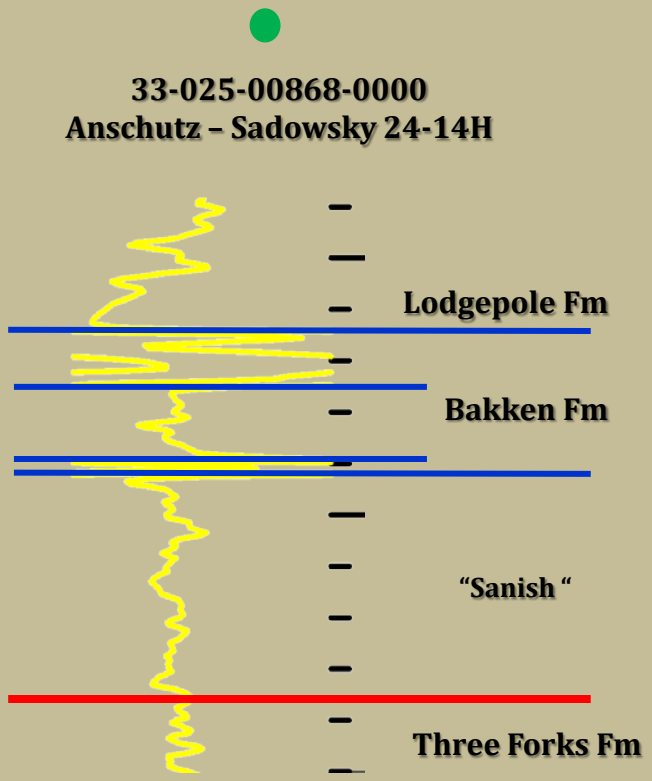
Isopach of the Lower Bakken Shale



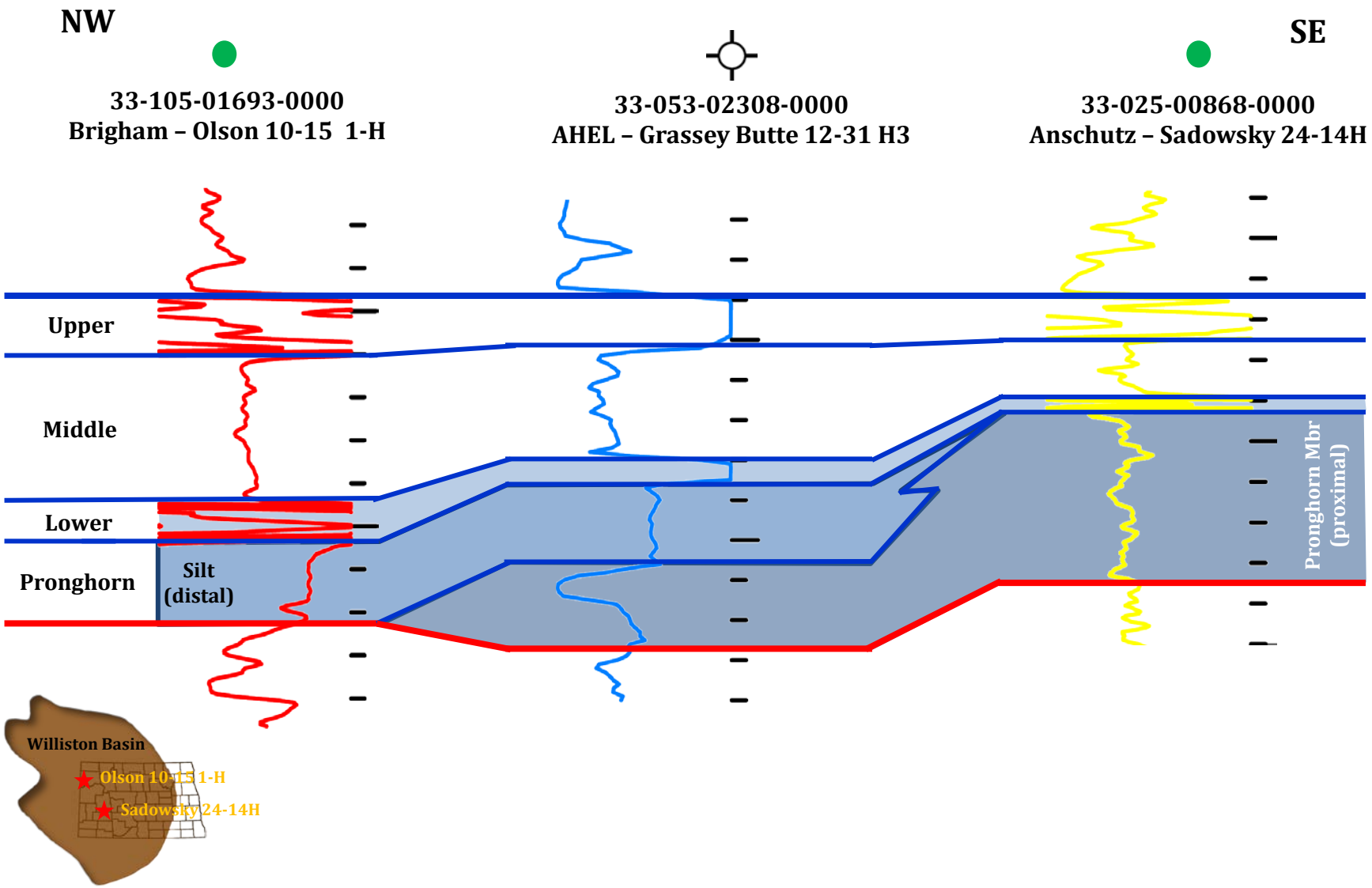


Isopach of the Upper Member of the Three Forks Formation

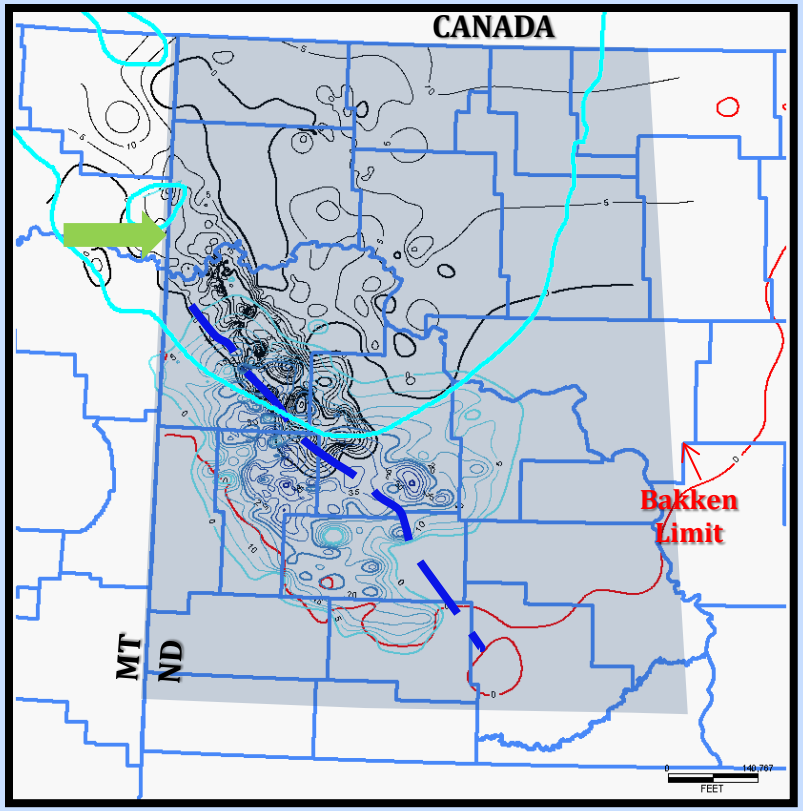




ND Cross-Section



Isopach of the Lower Bakken Silt



Possible Interpretations For Depositional Pattern

Faulting

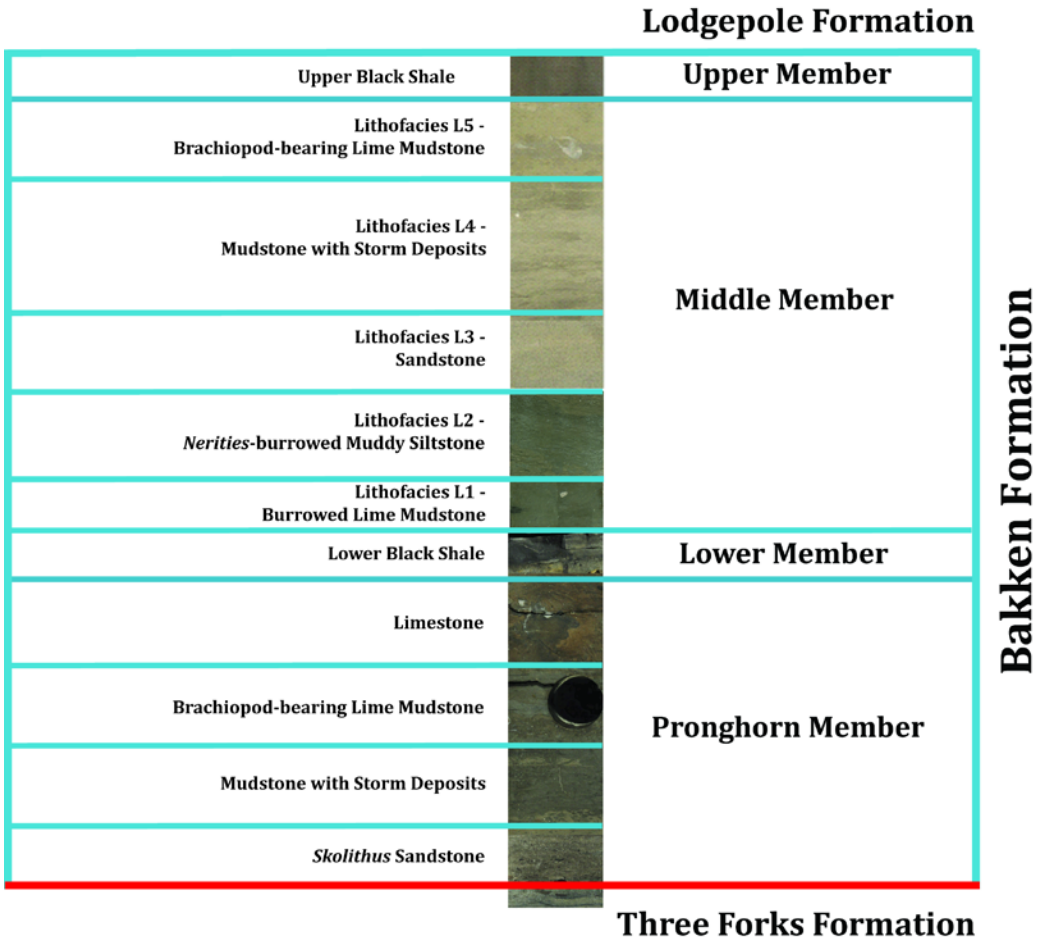
- **Heart River**
- **Central Montana Trough**
- **Trans-Hudson Orogenic Belt**
  - **N-S Basement Faults**

Dissolution of Salt

- **Devonian Prairie Salt**
  - **Hummingbird Trough**

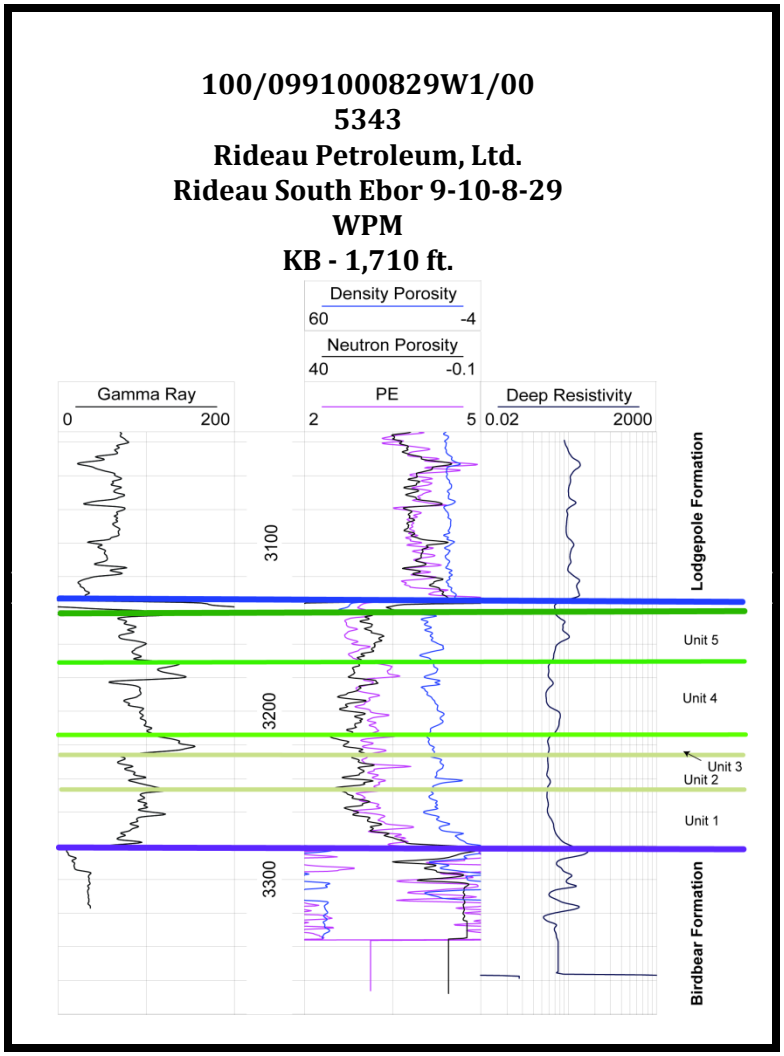
Combination of Both

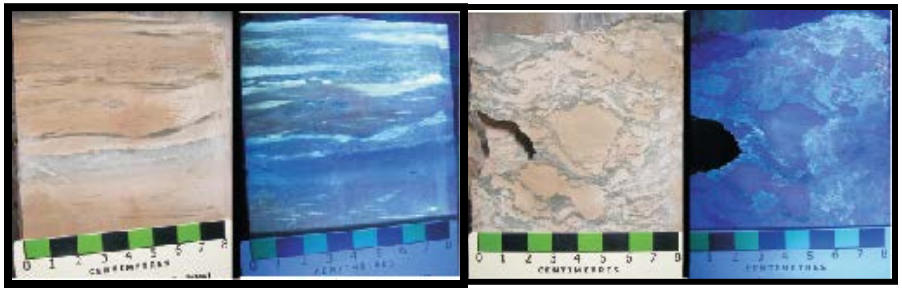
Changes to Current Stratigraphy



- **The members have been formalized (Upper, Middle and Lower Members of the Bakken Formation)**
- **The name "Pronghorn Member" has been assigned to strata referred to as the "Sanish" The Pronghorn Member is now included in the Bakken as the lowest member**
- **The use of the term "Sanish" has been abandoned**

Sinclair Field
Manitoba





Production

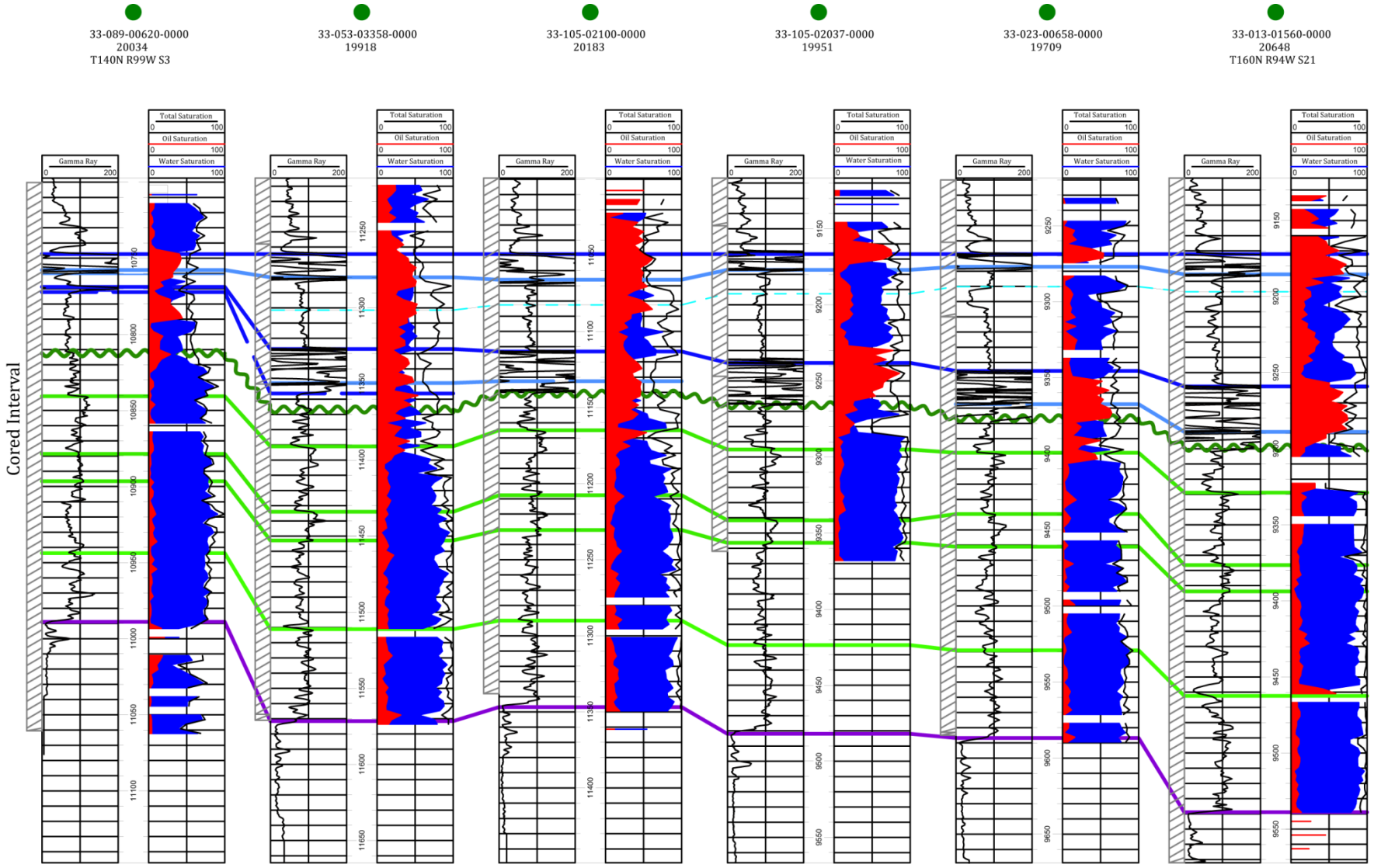
- **Middle Bakken**
- **Three Forks**
  - **2 separate intervals**

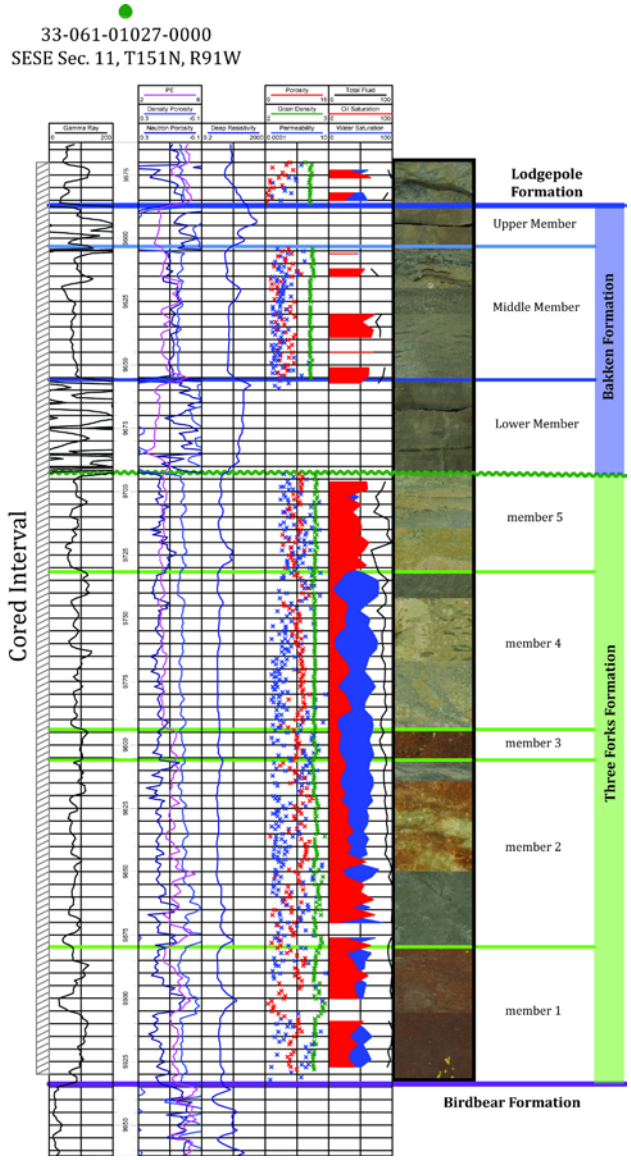
Proven & Probable Reserves

- **24 million bbls**

Basement & Salt Involvement

Three Forks Cored-based Saturations





Three Forks Questions

Core-based data show variations in saturations

- **Processed by different labs**
  - **Continental – EOG cores - same lab**
- **Adjacent to the Lower Shale**
  - **Pronghorn or Upper Bench (Mbr 5)**
- **Due to structure?**
  - **Basement-related structures**
  - **Overpressuring**
- **Variation**
  - **Pore throat size?**
  - **Change in lithology?**

What is actually producing

- **Separate benches or fracture stimulating through the markers**

Observations

- Rocks
  - Mixed clastic-carbonate sequence of the middle member
  - Storage within the middle member
  - Potential for a large amount of oil from fractured
    - Bakken shales, Middle Member, Three Forks
- Tectonic Elements
  - Basement structure with known associated
- Folds and faults
  - Overprinting
  - Salt Tectonics
- Source System
  - Geochemistry
    - Mature source system that is overpressured
    - Rock-Eval Data, Mineralogy, etc.
  - Wide Variety of Estimates
  - Lodgepole, Bakken, and Three Forks
  - Lateral migration
    - Single Continuous Front
    - Existing Faults
- Determine What is Producing and How
  - Bakken?
  - Three Forks & Lodgepole Potential?

#33-053-01599 – 10835 ft

Conclusions

Conventionals to Horizontal Wells

- **Salt-based mud system to Oil-based mud system**
- **Natural Fractures or Stimulated**
- **Frac out of zone into water-bearing zones**
- **Sensitivity to fluids and mineral related problems**
- **Fracture communication**

Multiple and Long Lateral Horizontal Wells

- **Single to Multiple Stages**
- **Variety of Lateral Length – Trend "Longer the Better"**
- **Multiple Pay Zones – Bakken – Three Forks**

Williston Basin

- **Variety of Other Producing Formations**
  - **Unknown Potential**