Using an Uncertainty Assessment Approach for Estimating Recoverable Reserves from the Bakken Petroleum System in North Dakota*

Cosima Theloy[1], Jay E. Leonard[2], China O. Leonard[2], and Paul W. Ganster[2]

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Abstract

In the mid 1990's Platte River Associates pioneered a technique of applying uncertainty to the inputs of a basin simulator, hence providing distributions of results rather than discrete output values. This study presents an approach for using an uncertainty-based assessment method for estimating the recoverable reserves and Yet-To-Find reserves from the Bakken and Three Forks reservoirs in North Dakota.

The Bakken is regarded as an unconventional tight oil play with the characteristic of a continuous type basin-centered accumulation. Production data reveals, however, that not all areas are equal and that certain regions stand out as sweet spots while others exhibit fairly high water cuts. The project is based on 28 well models, which have been porosity-calibrated and adjusted for the prevalent thermal regime. A geothermal anomaly in the deep part of the basin has been described by Price et al. (1984). Regional grids were used to capture as much geological detail as possible and served as input for a 3D surface model and play fairway analysis.

An uncertainty assessment approach was utilized for calculating the recoverable reserves and Yet-To-Find reserves from the Bakken and Three Forks reservoirs. The method used in this case study is built on placing uncertainty on various input parameters influencing the volumetric calculation. Often, critical values such as initial hydrogen index and thus initial TOC are based on educated guessing. In fact, there many values which are not absolutely known. By placing a range of uncertainty on each of the variables, hundreds to thousands of simulations can be run, using either the Monte Carlo or Latin Hypercube sampling methods. The results are displayed in reverse cumulative probability plots and tornado charts, as well as maps of the P10, P50, and P90 values. This study is an extension to the work presented by Theloy et al. (2015).

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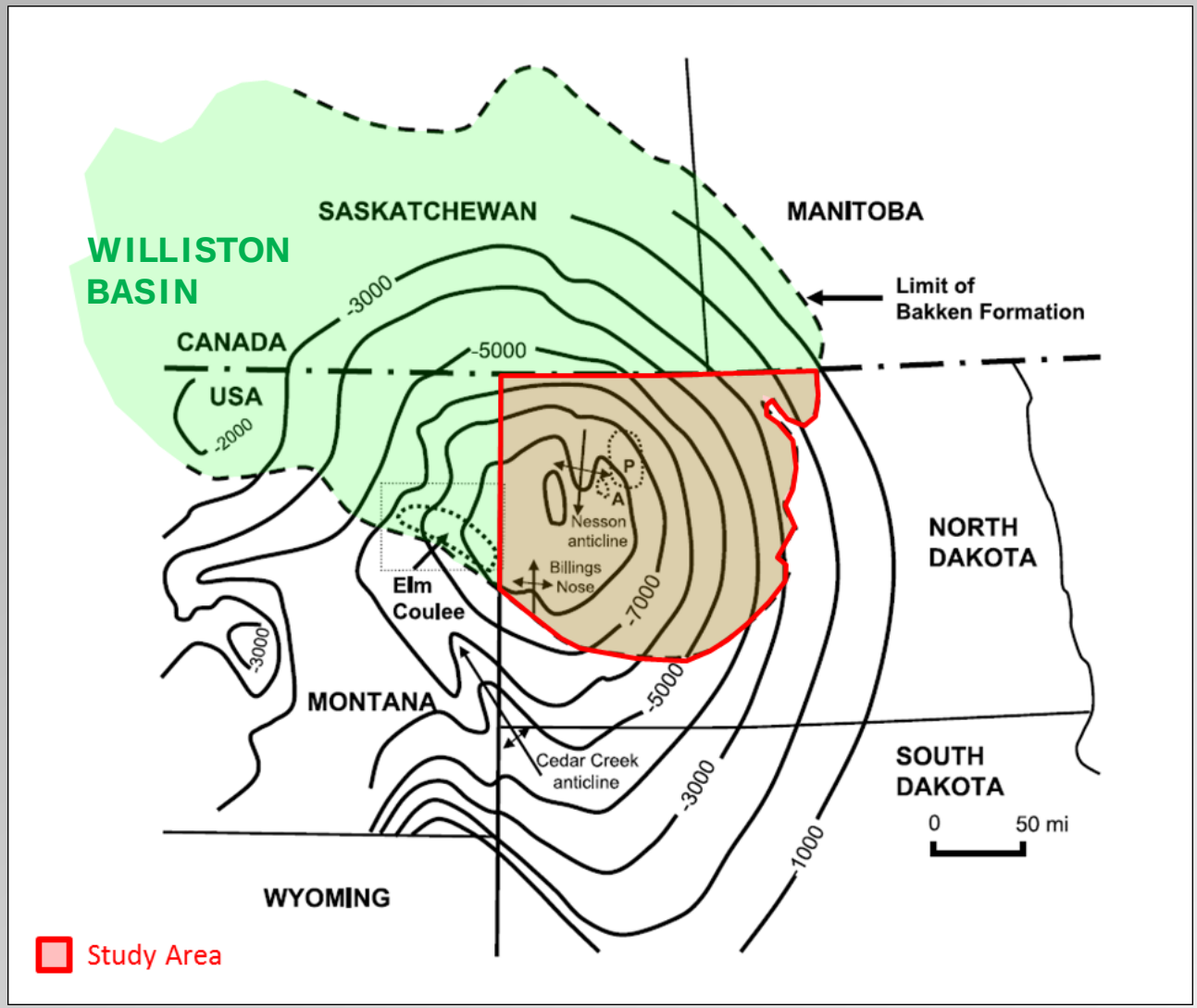
Outline

- Bakken Overview
- Bakken Production and Resource Estimates
- Workflow and Data Input
- Construction of 28 well models
- Defining Play Extents
- Uncertainty Assessment
- Summary

Location Map



modified from Sonnenberg and Pramudito (2009)

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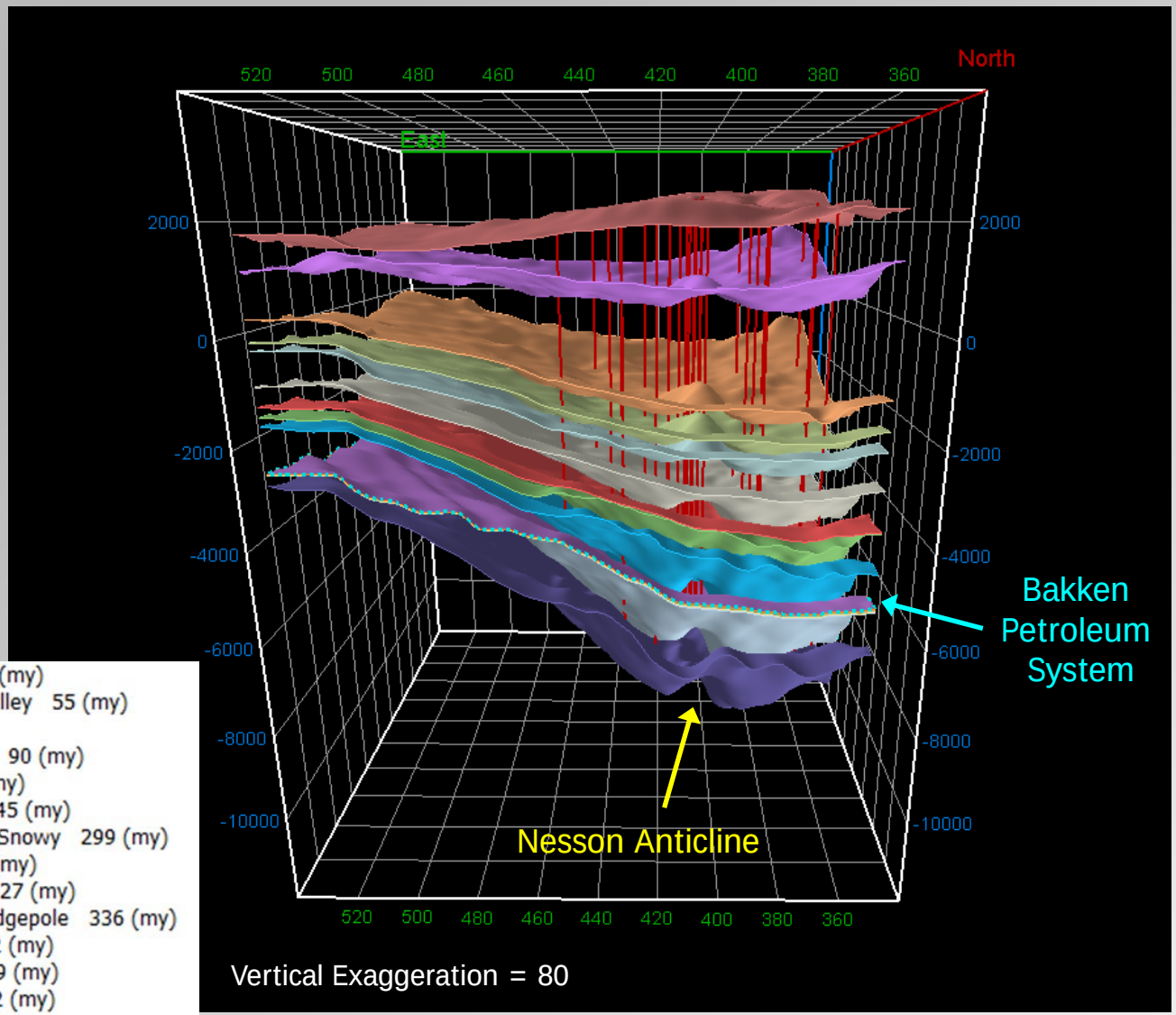
Williston Basin (ND)



- Laramide Uplift 0 (my)
- Fox Hills-Golden Valley 55 (my)
- Pierre 76 (my)
- Greenhorn-Mowry 90 (my)
- Inyan Kara 115 (my)
- Swift-Spearfish 145 (my)
- Broom Creek - Big Snowy 299 (my)
- Kibbey Lime 324 (my)
- Madison-Ratcliff 327 (my)
- Mission Canyon-Lodgepole 336 (my)
- Upper Bakken 352 (my)
- Middle Bakken 359 (my)
- Lower Bakken 362 (my)
- Three Forks 375 (my)
- Model Bottom 385 (my)

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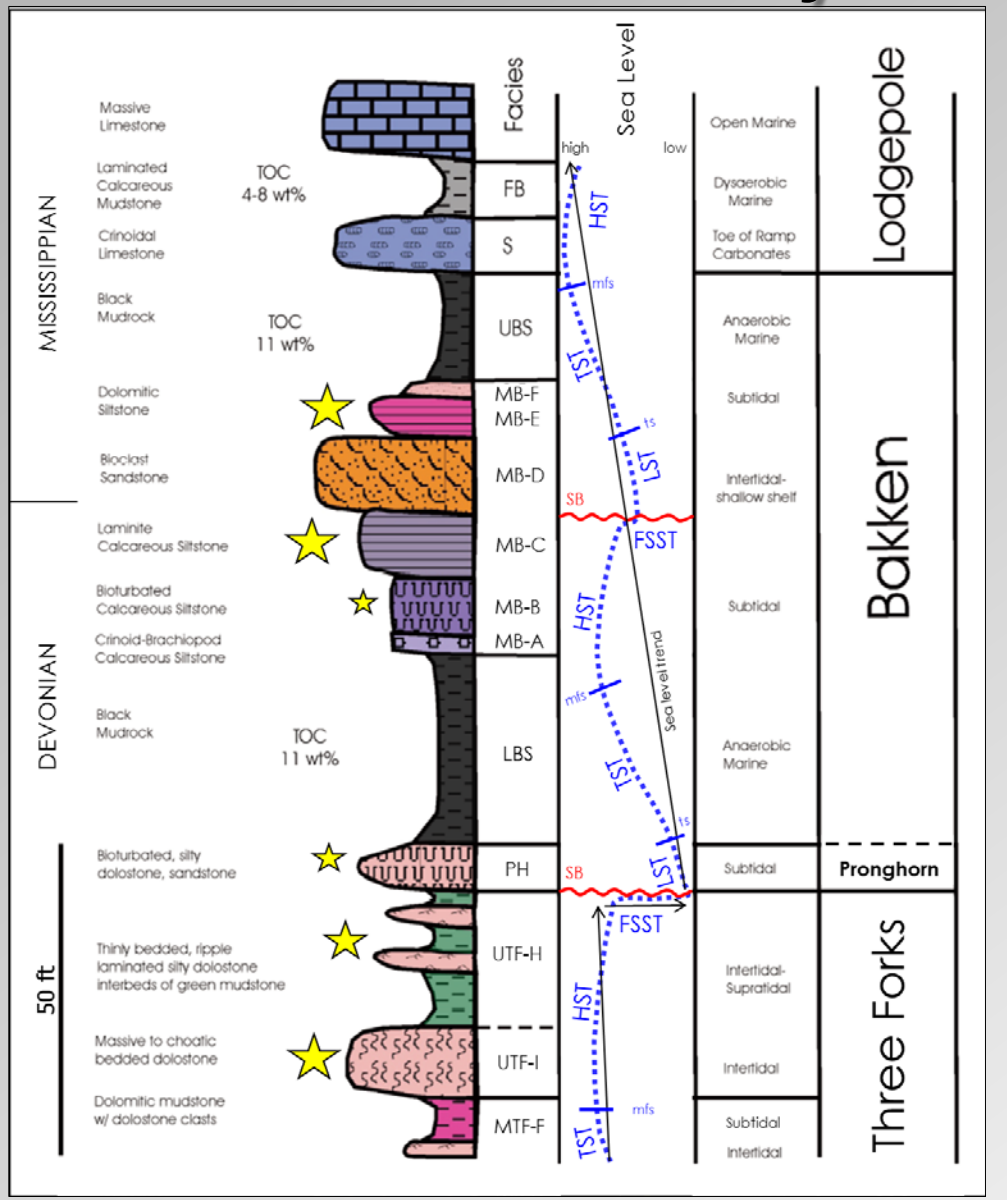
Bakken Petroleum System

Stratigraphy

★ Stars indicate main reservoir units



Lodgepole

Upper Bakken

Middle Bakken

Lower Bakken

Pronghorn

Three Forks

Theloy (2014), modified from Sonnenberg et al. (2011)

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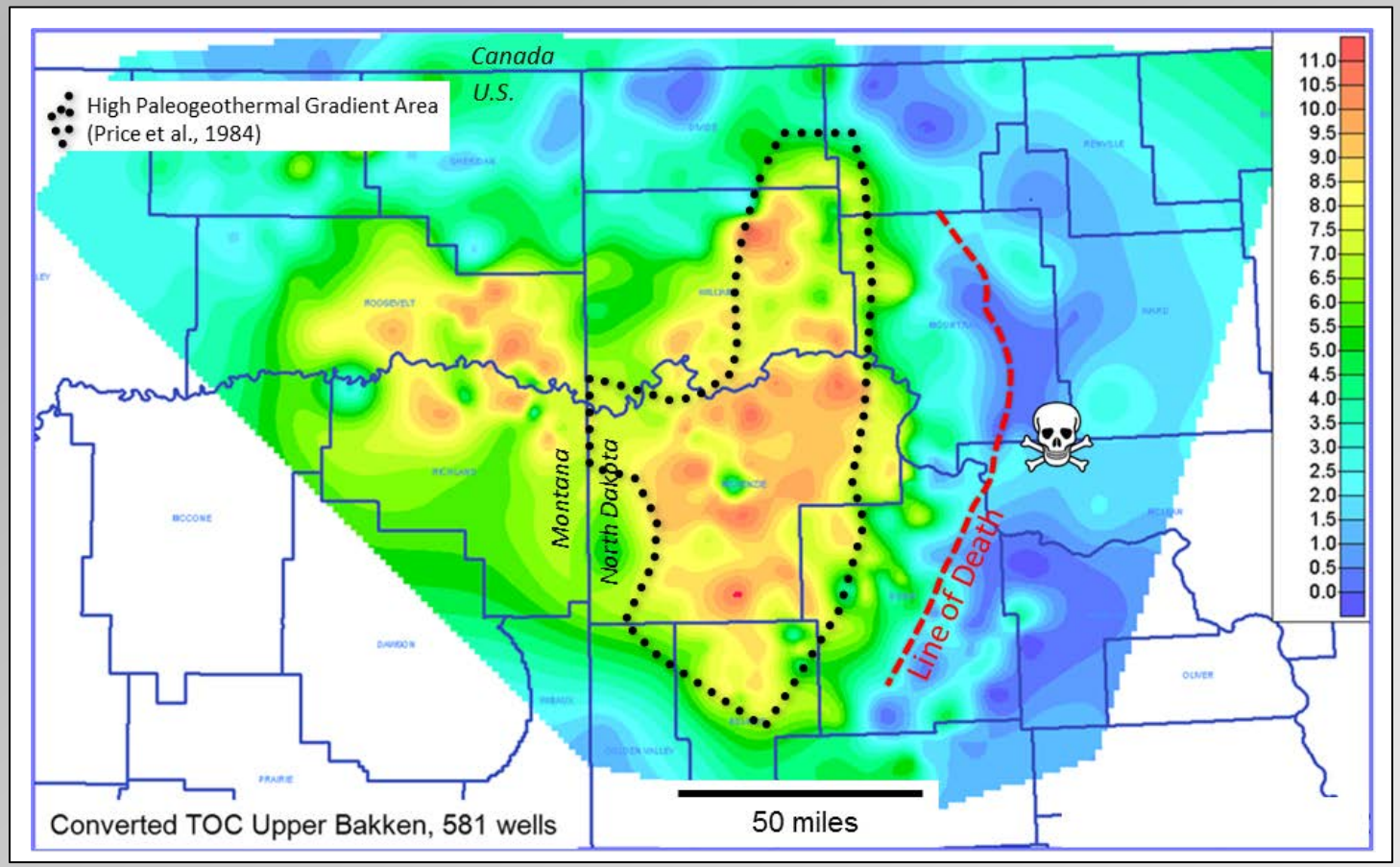
The Source Kitchen



Map of converted or 'consumed' TOC during hydrocarbon generation shows the mature source pod. Geothermal gradients are higher in the center of the basin.
"Line of Death" stems from oil and water production data (on next slide).

modified from Theloy (2014)

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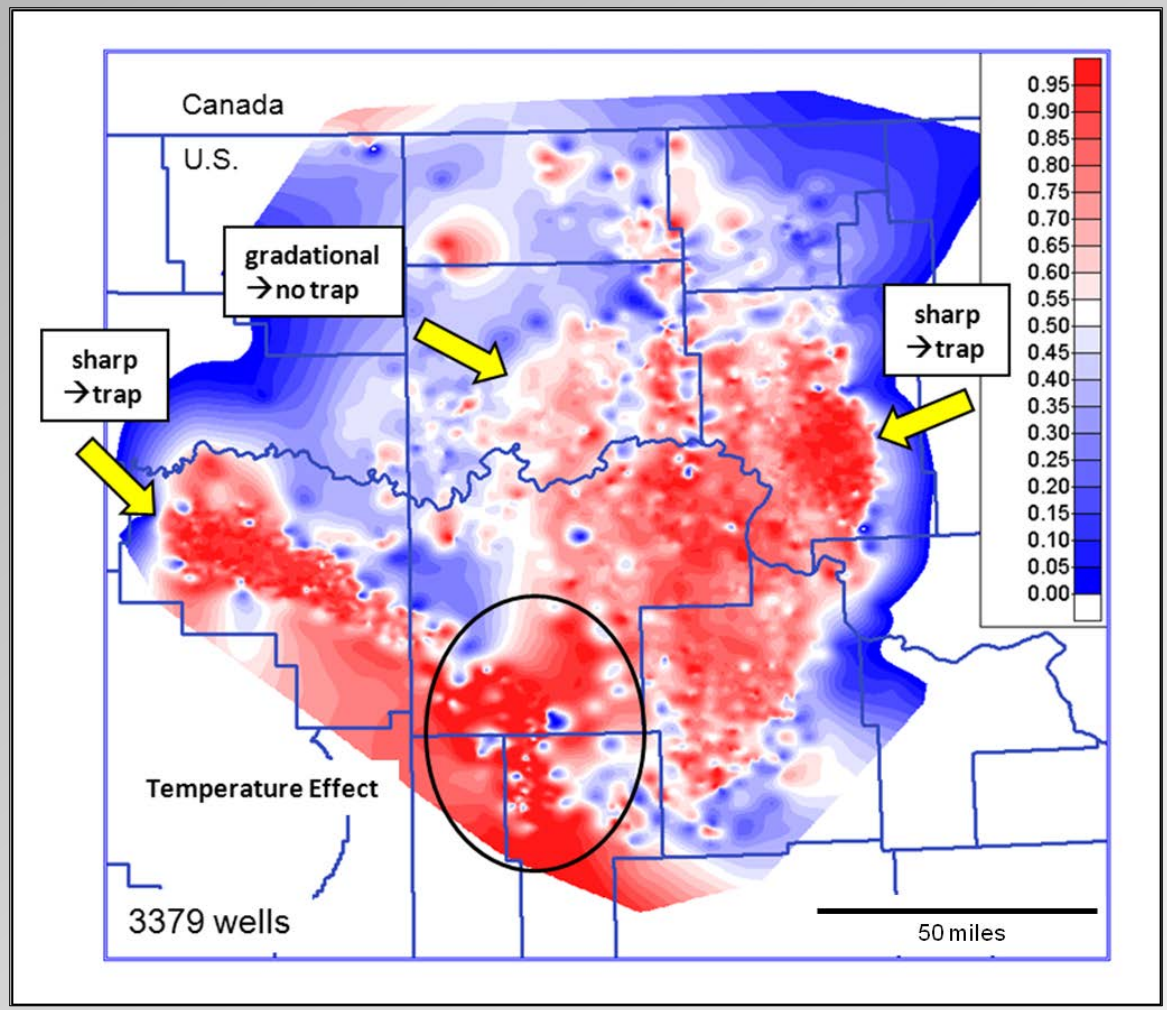
Bakken production – sweet spots

Illustration of oil-rich sweet spots in the basin



Oil/ (Oil + Water) Ratio from Cumulative Production Data

Theloy (2014)

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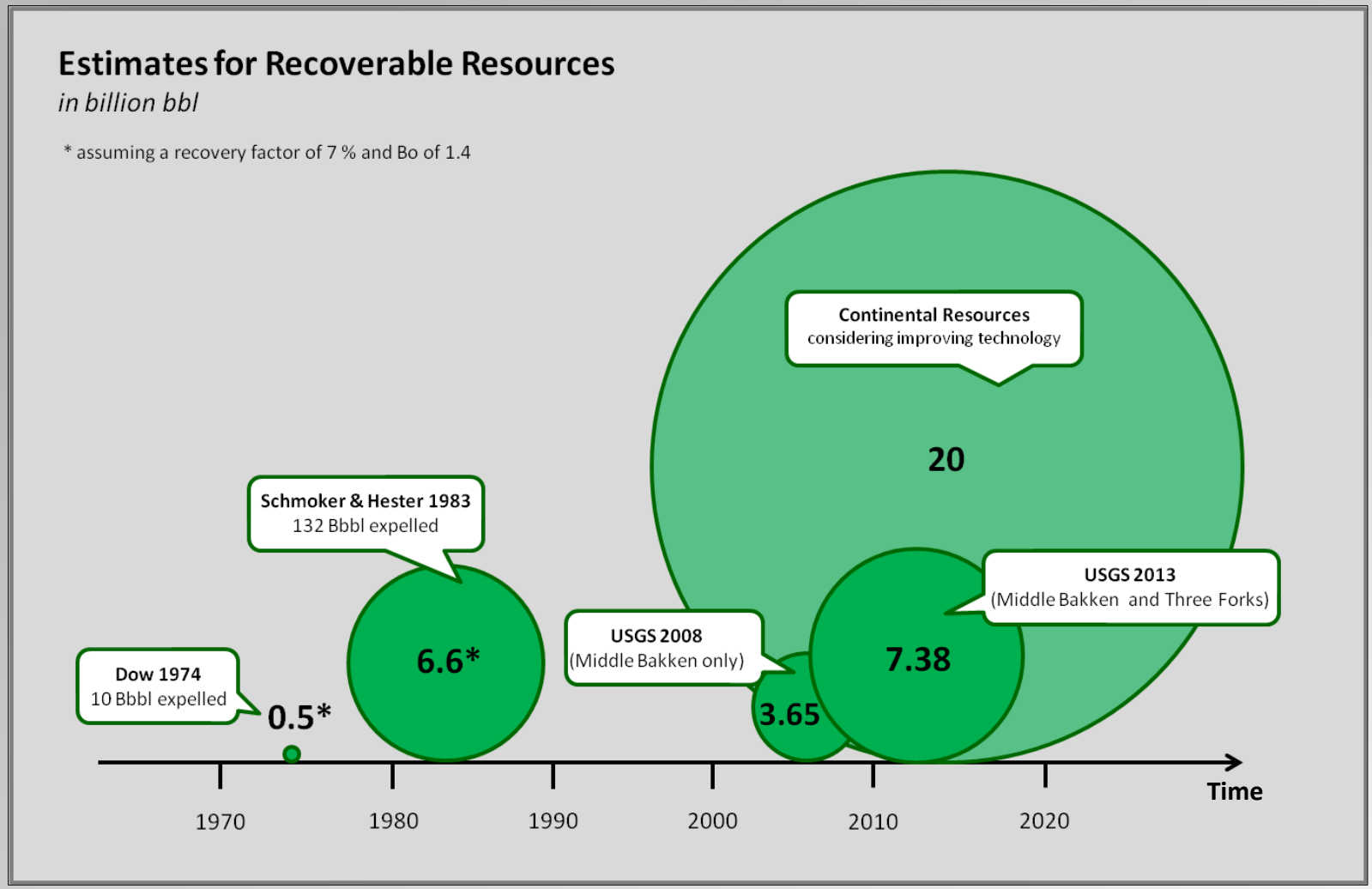
Estimates for recoverable resources



Theloy et al., 2015

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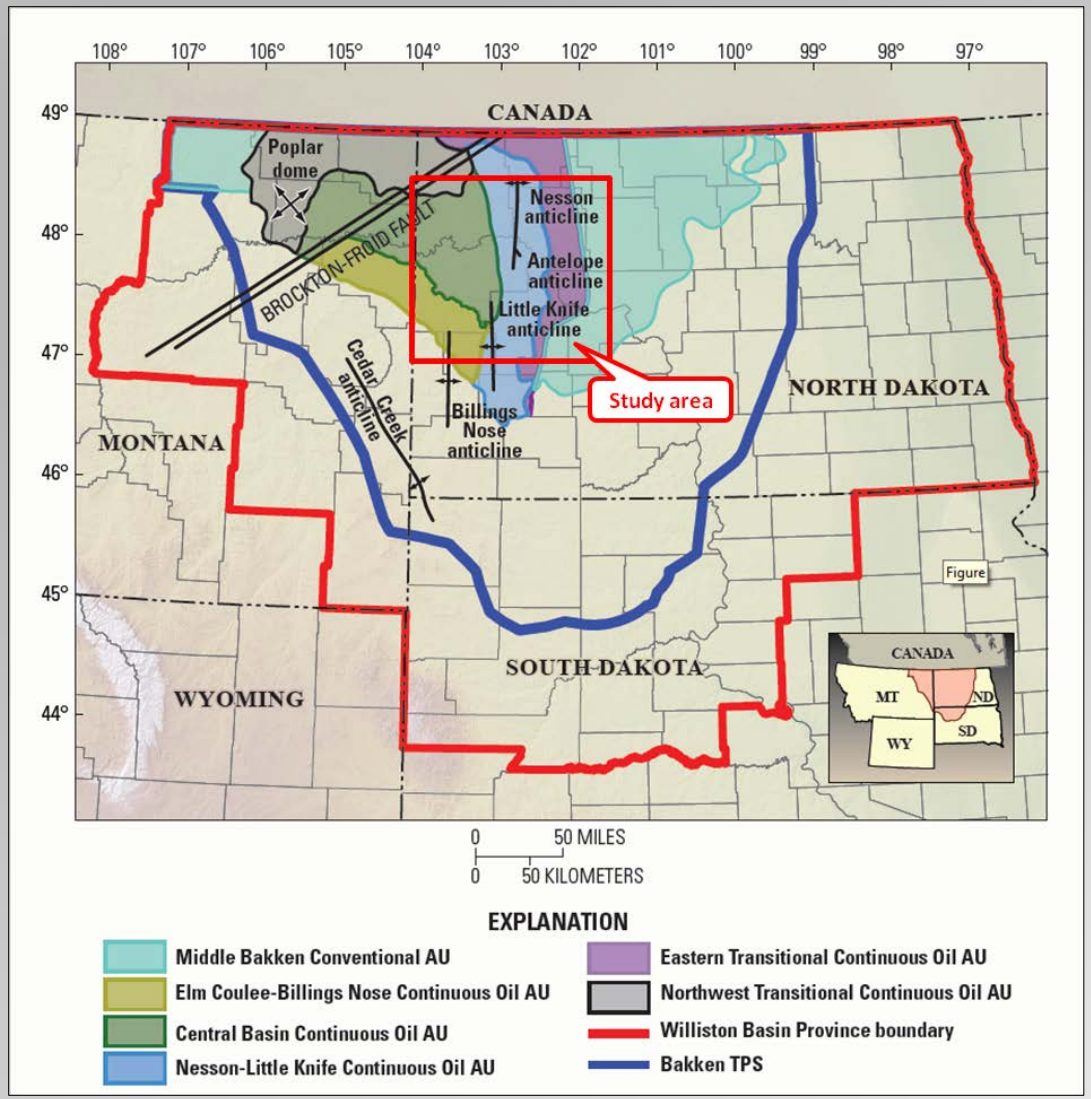
USGS Bakken-Three Forks Assessment



In 2013, the USGS estimated that about 7.4 billion barrels could be recovered from the Bakken-Three Forks system with existing technology.

Gaswirth et al. (2013)

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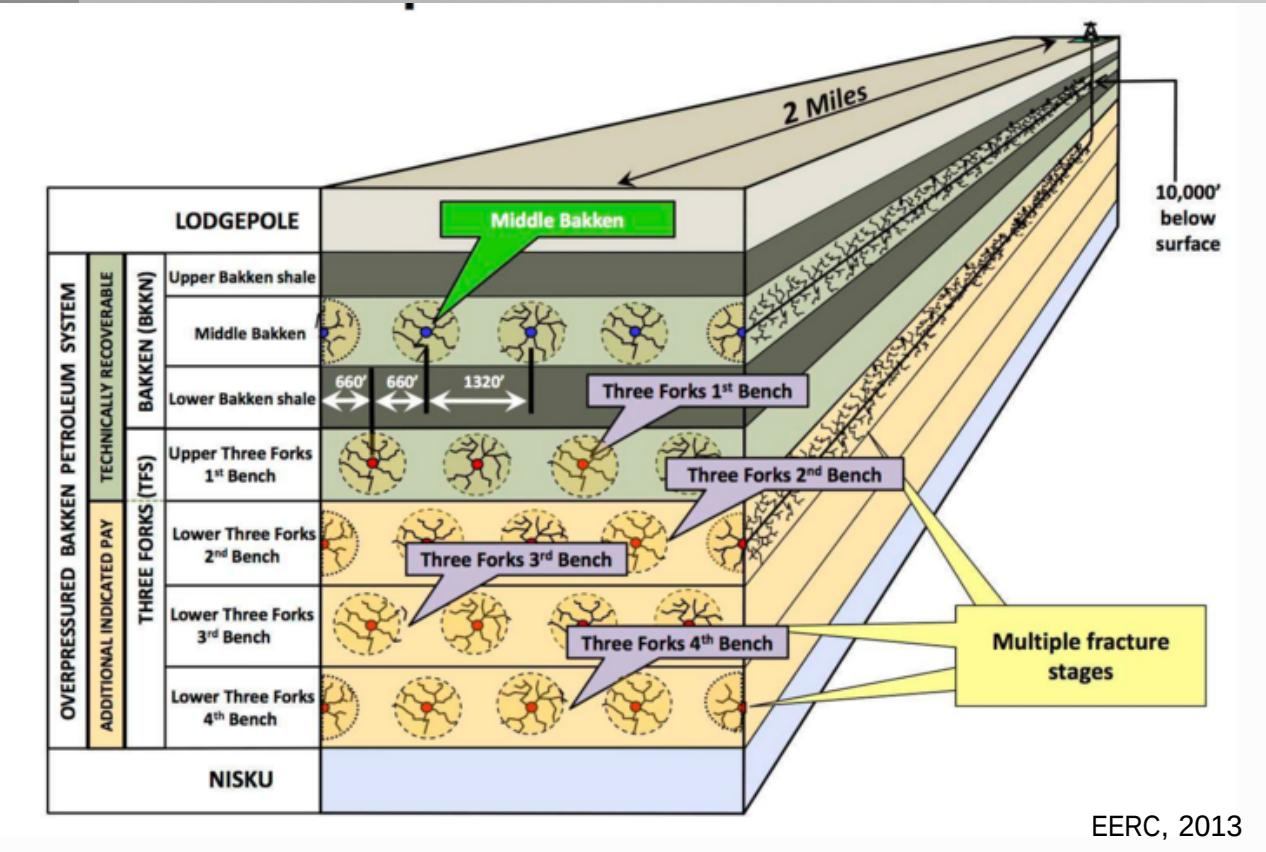
Continental's completion strategy

Spacing Optimization



EERC, 2013

Continental claimed that with improving drilling and completion technology as much as 20 billion barrels could be recovered.

Wilmoth, 2014

Multi-well spacing design by Continental Resources for Middle Bakken and Three Forks benches in a 1280 acre unit.

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Outline

- ❑ Bakken Overview
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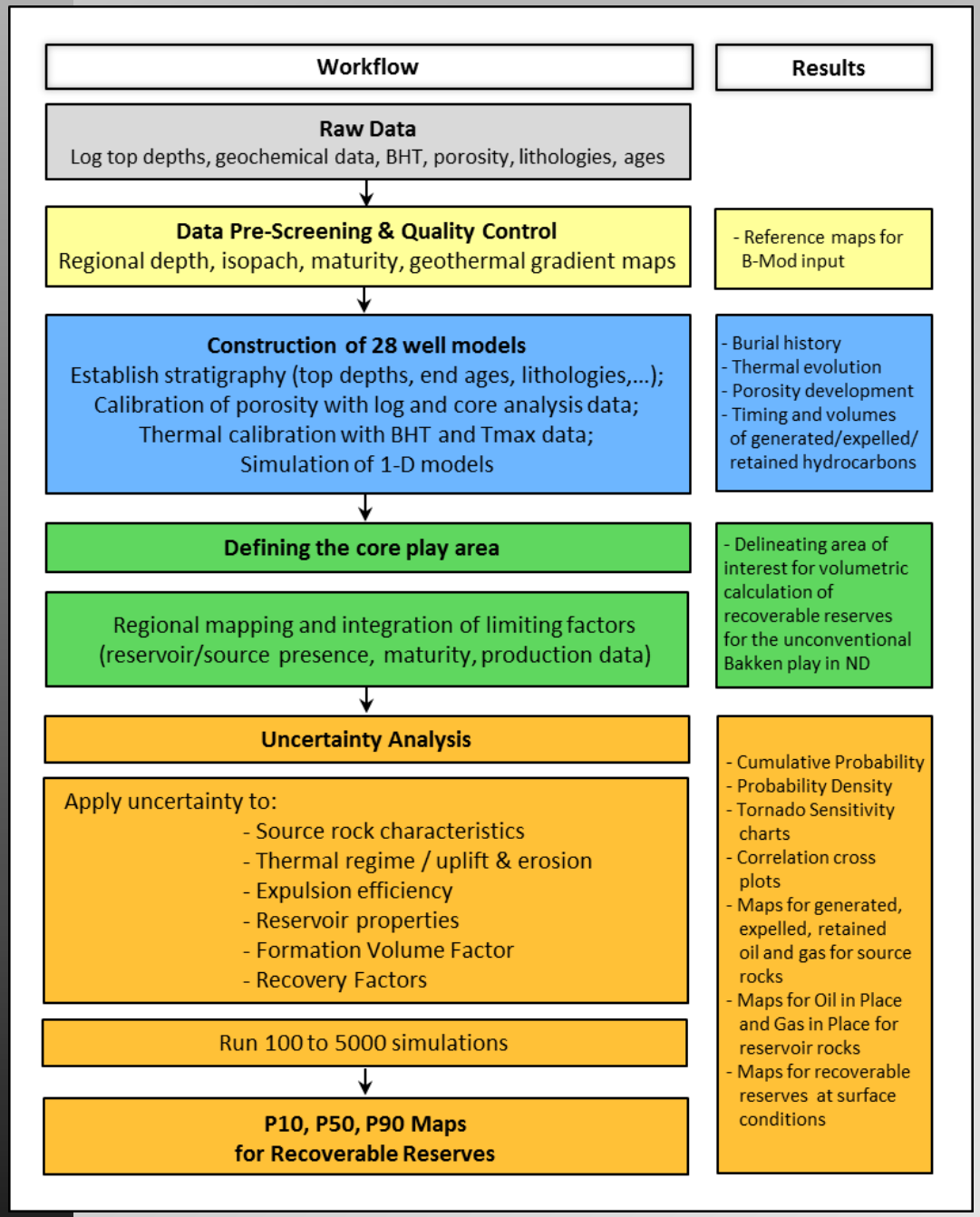
- ❑ Workflow and Data Input
- ❑ Construction of 28 well models
- ❑ Defining Play Extents
- ❑ Uncertainty Assessment
- ❑ Summary

Workflow for determining recoverable reserves



Uncertainty Assessment

modified from Theloy et al., 2015

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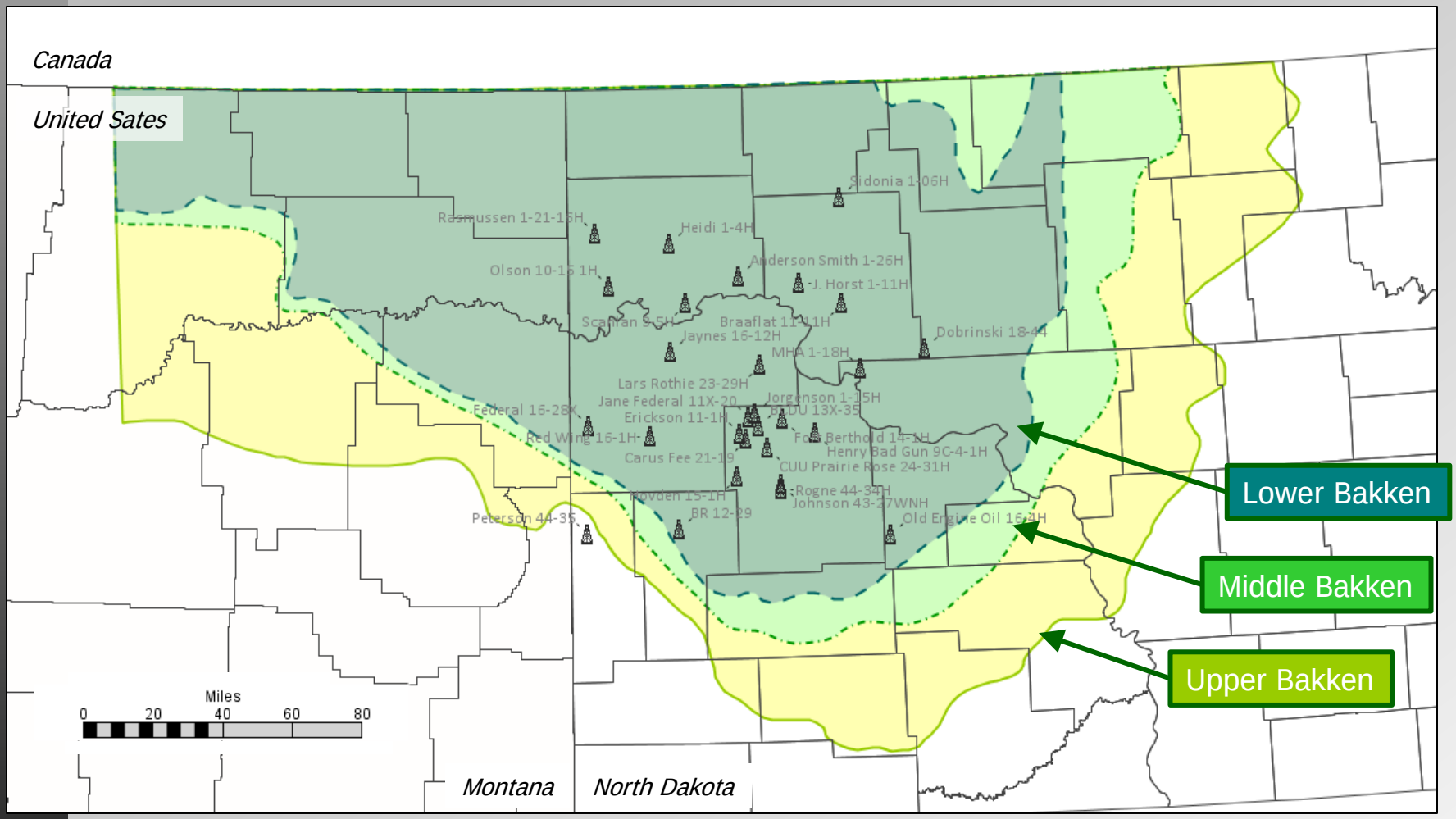
Well model locations



Well locations shown with depositional extents of the Bakken members

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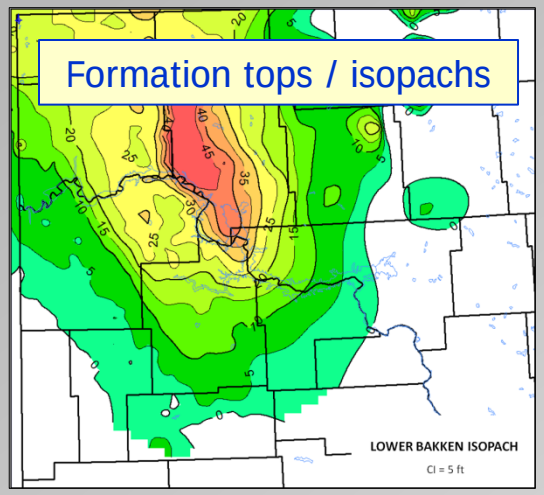
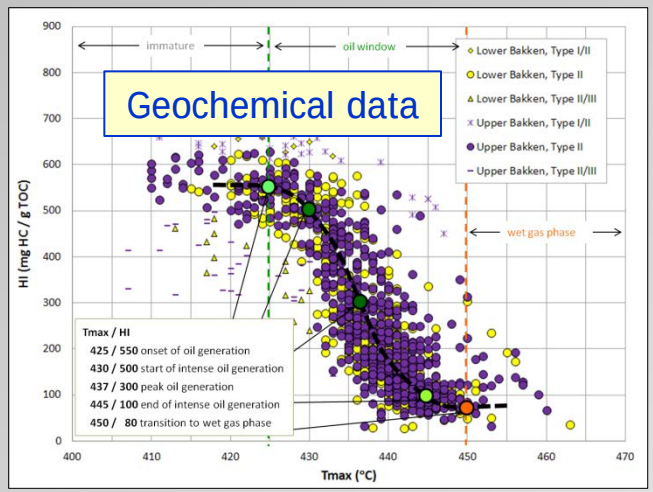
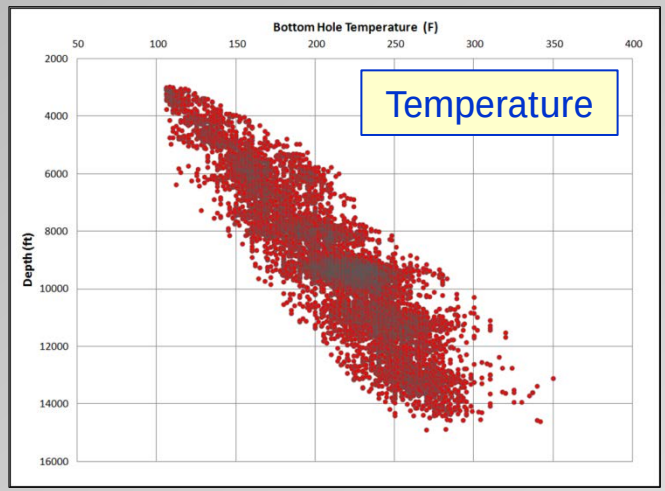
Construction of 28 well models

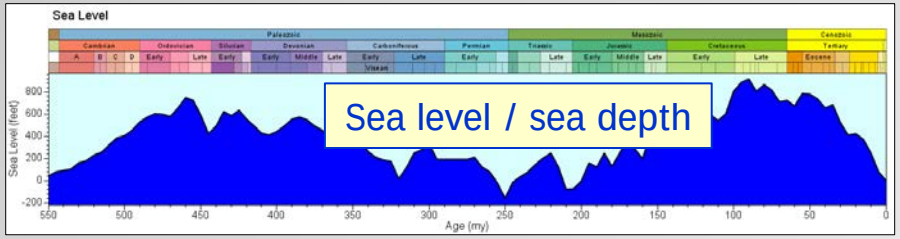
Data Input

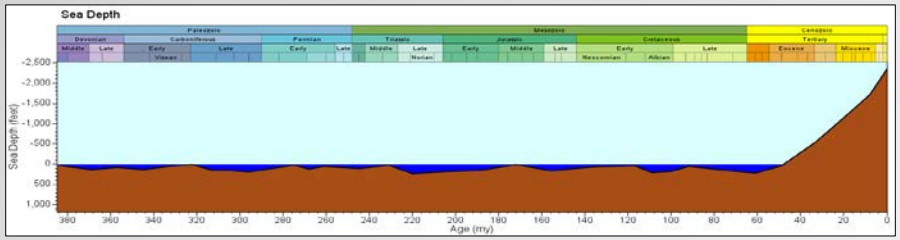




Theloy (2014)







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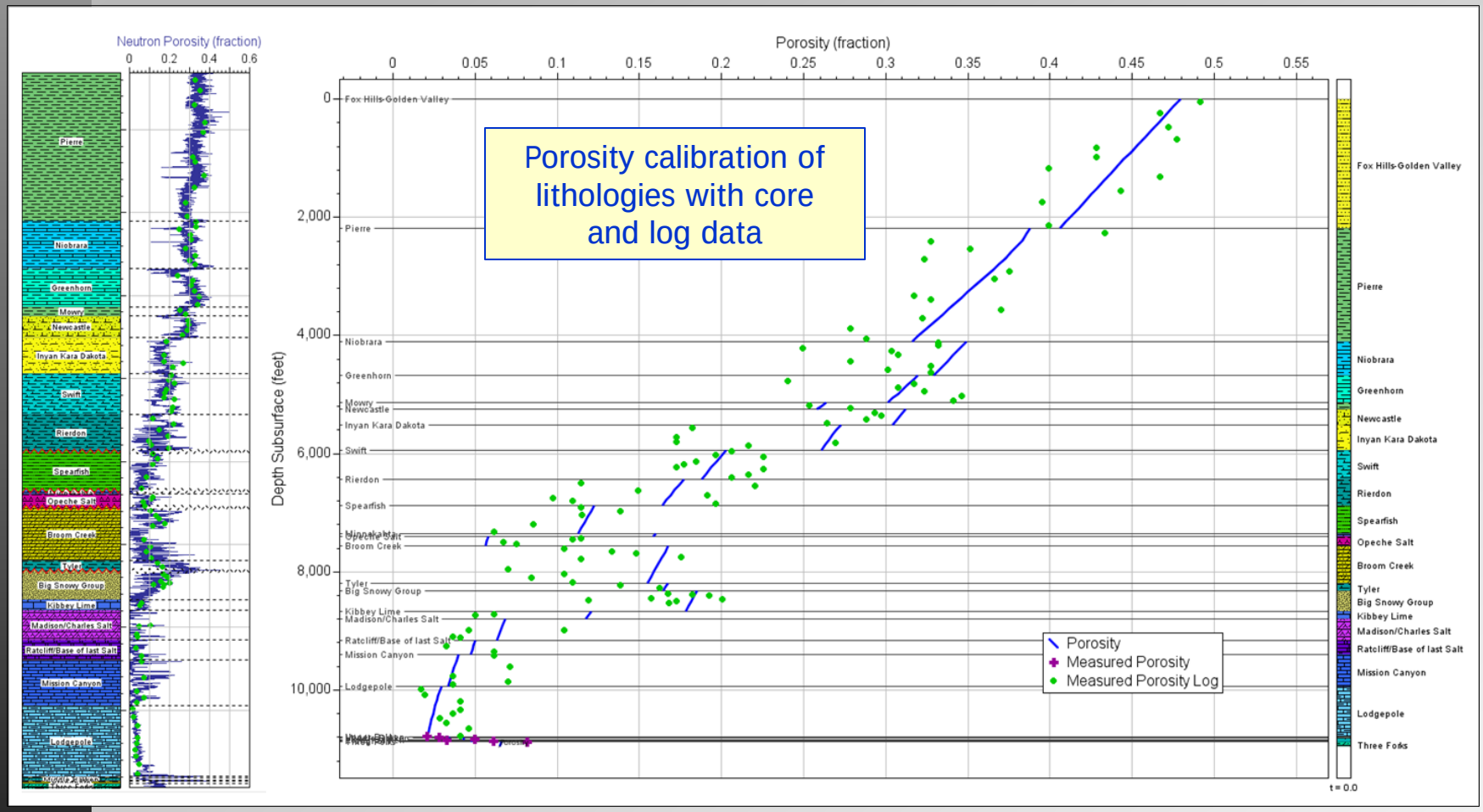
Calibration of well models

Porosity Calibration



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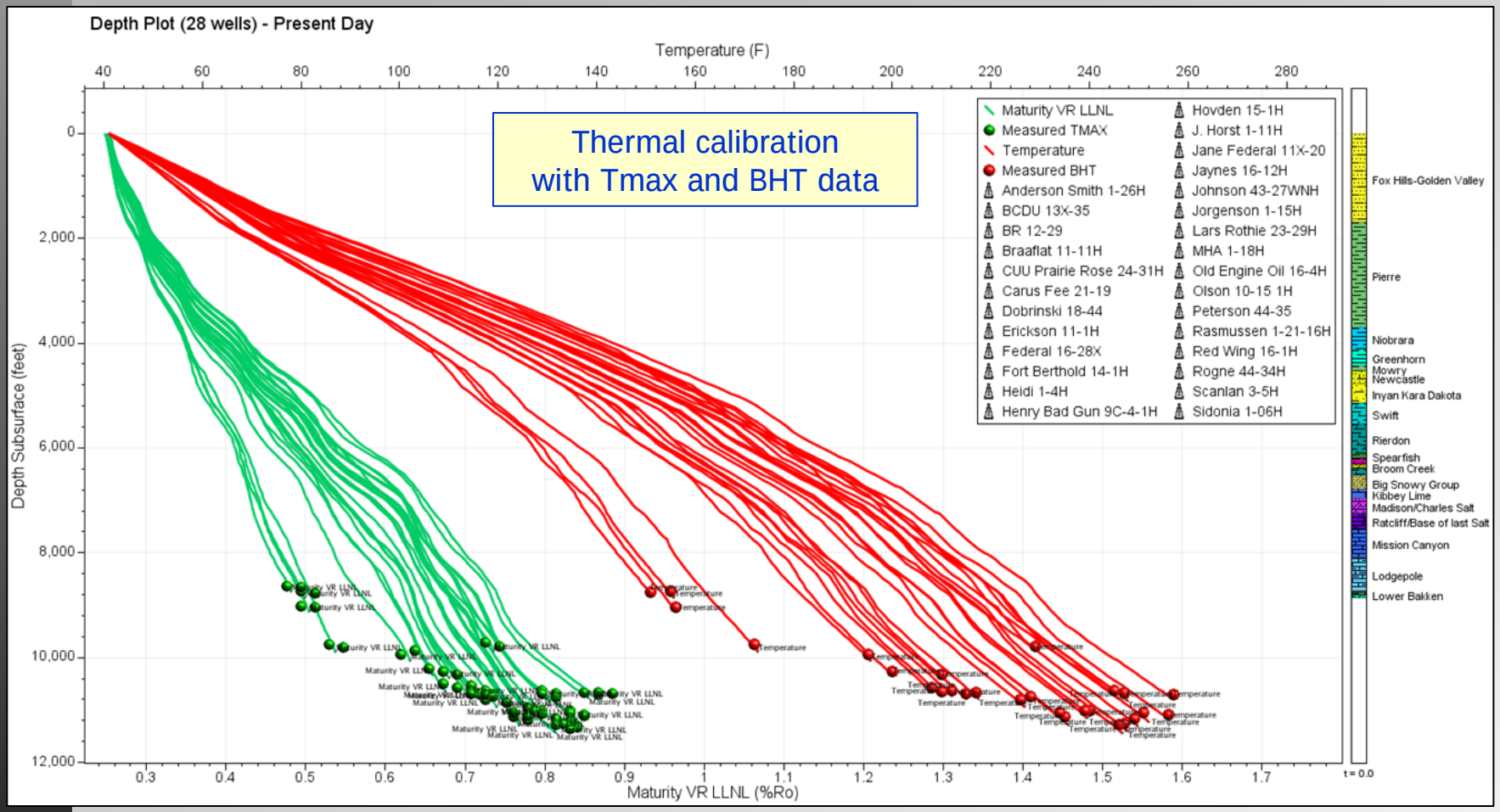
Calibration of well models

Thermal Calibration



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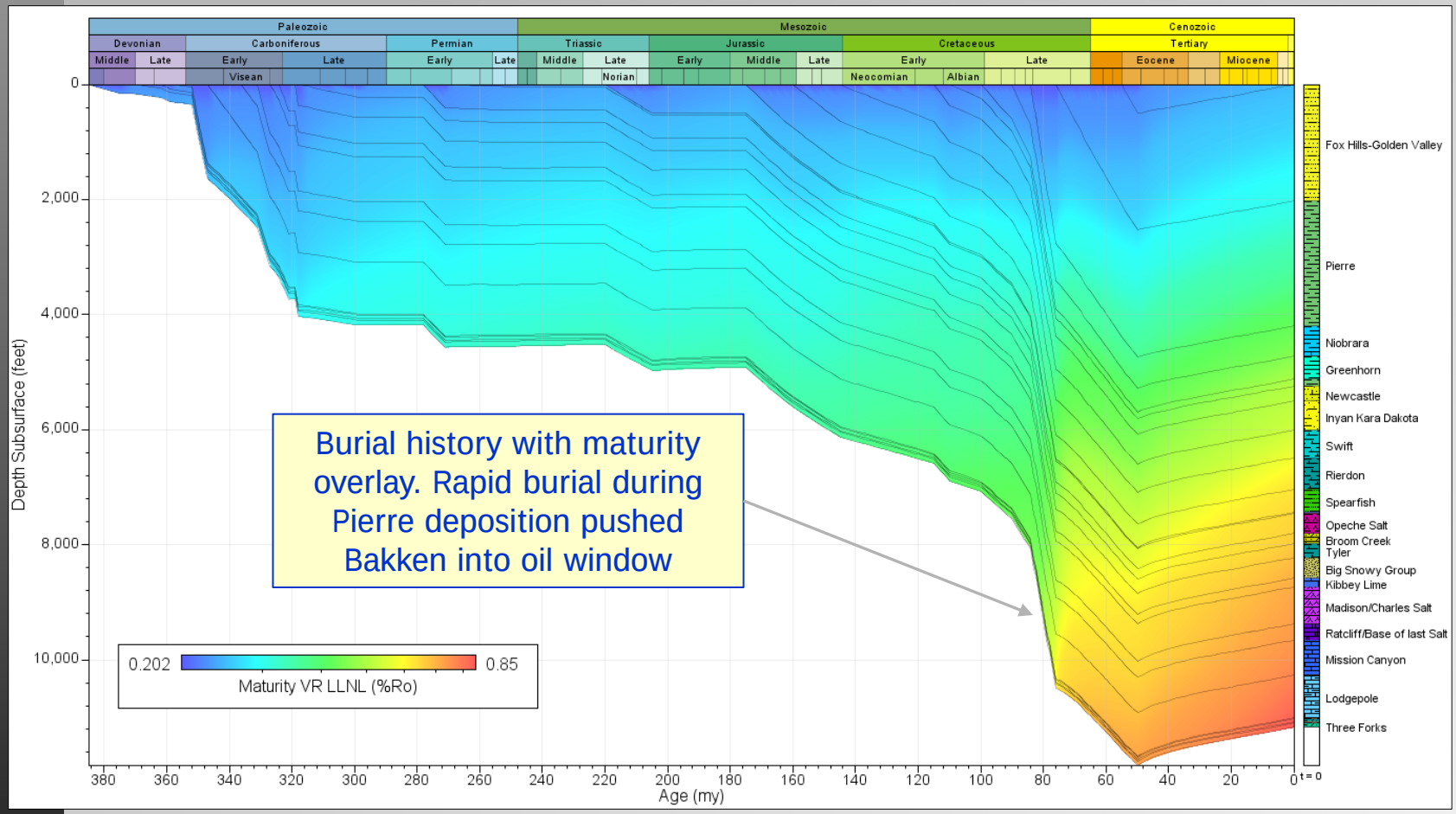
Modeling Results

Burial History



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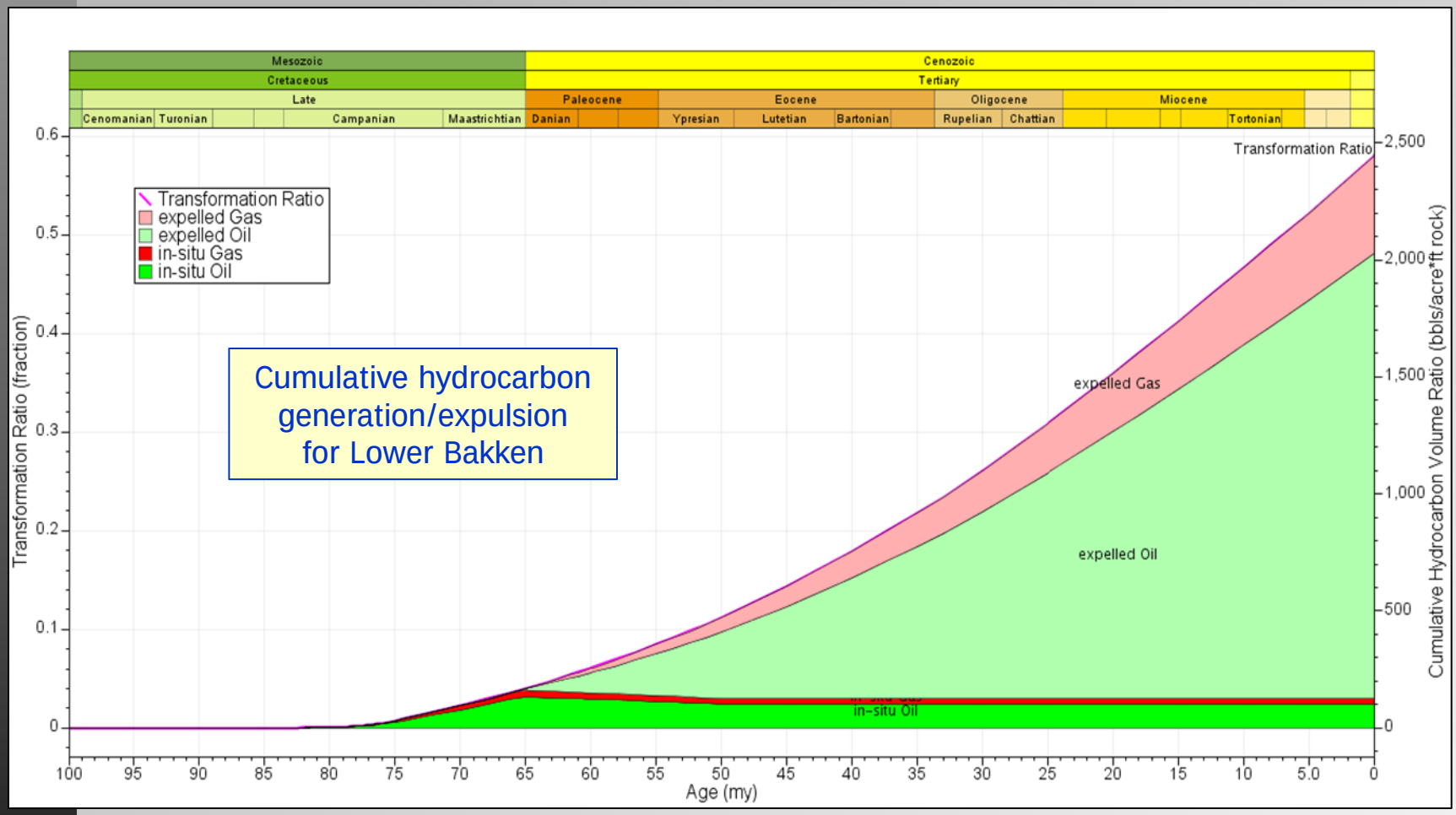
Modeling Results

Hydrocarbon Generation



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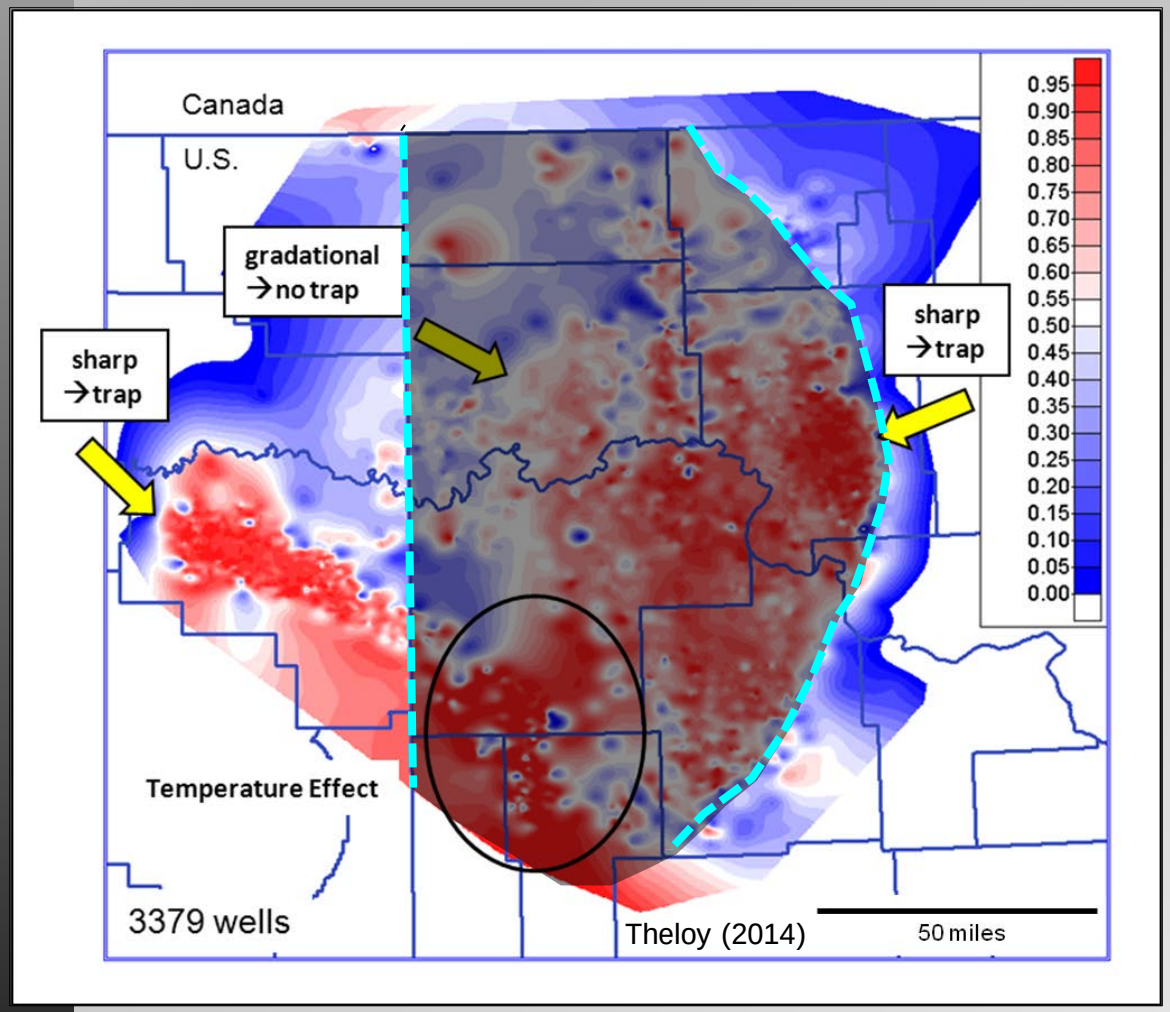
Defining the core play extents (ND)



- State Line
- Production data

Oil/ (Oil + Water) Ratio from Cumulative Production Data

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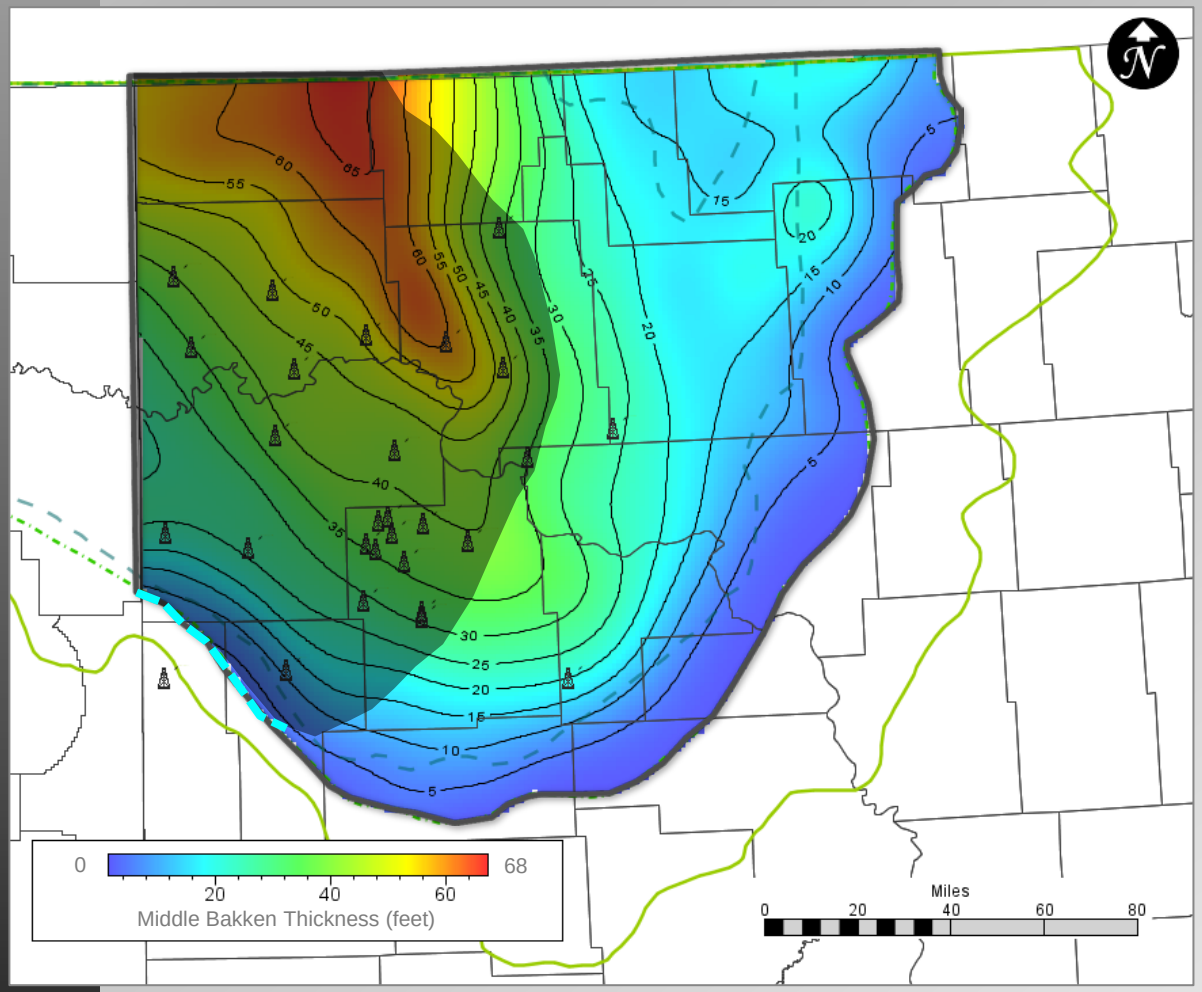
Defining the core play extents (ND)



- State Line
- Production data
- Reservoir limits

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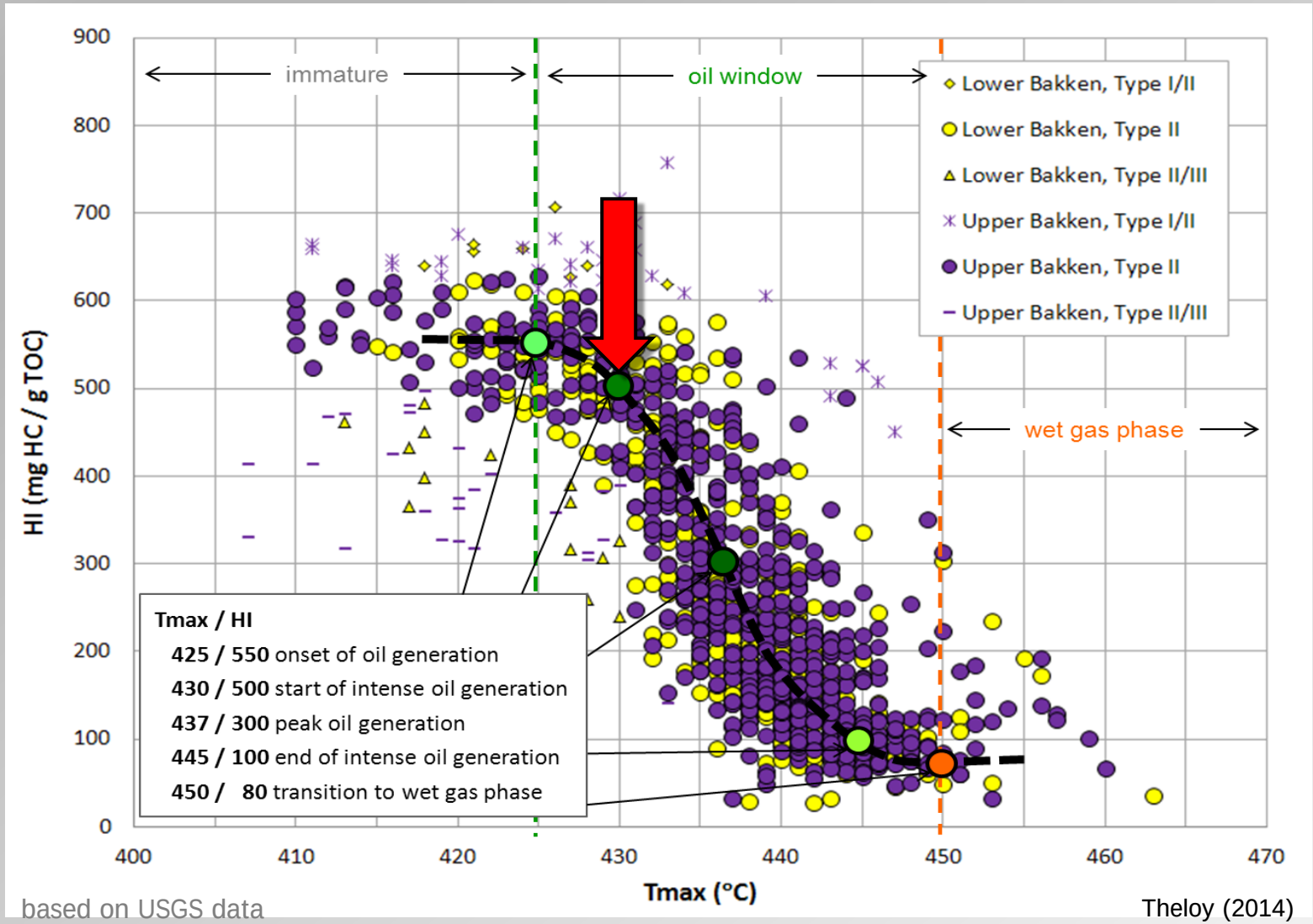
Bakken maturity



based on USGS data

Theloy (2014)

Average maturation path for kerogen type II Bakken source rocks.

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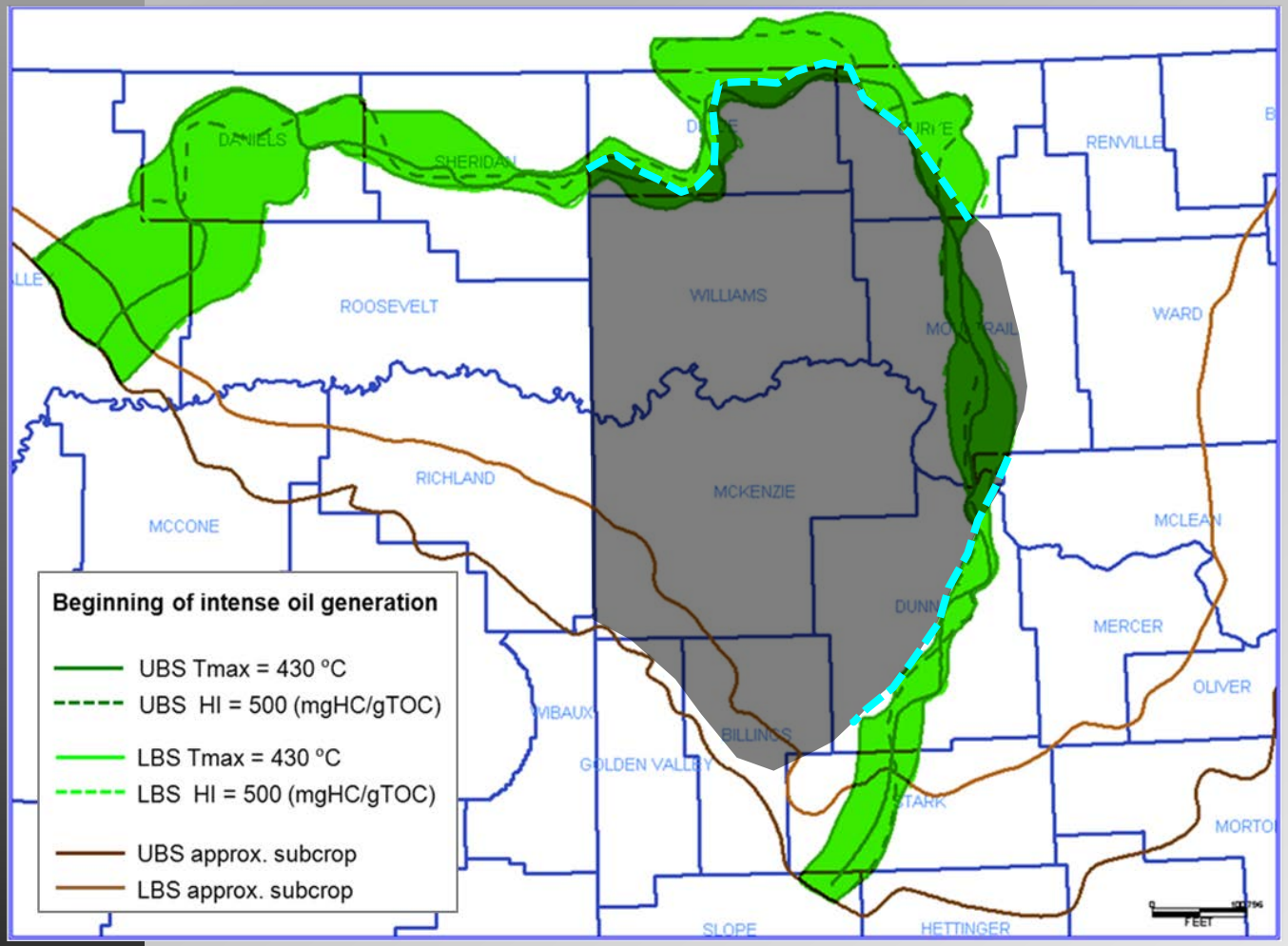
Defining the core play extents (ND)



- State Line
- Production data
- Reservoir limits
- Maturity limits

Area for Resource Estimates

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

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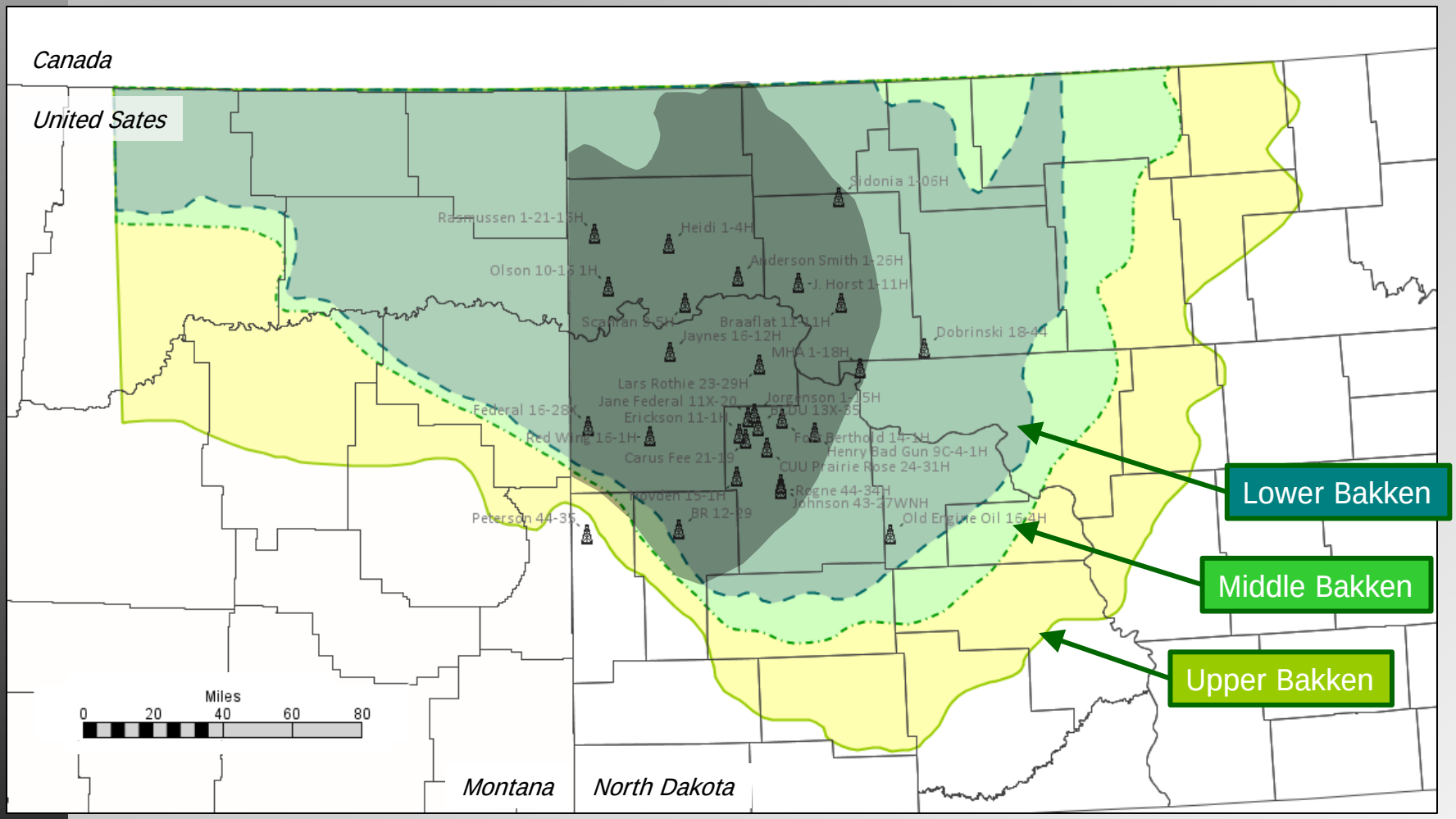
Uncertainty Assessment Area



Core area shown with respect to well locations and depositional extents of the Bakken members.

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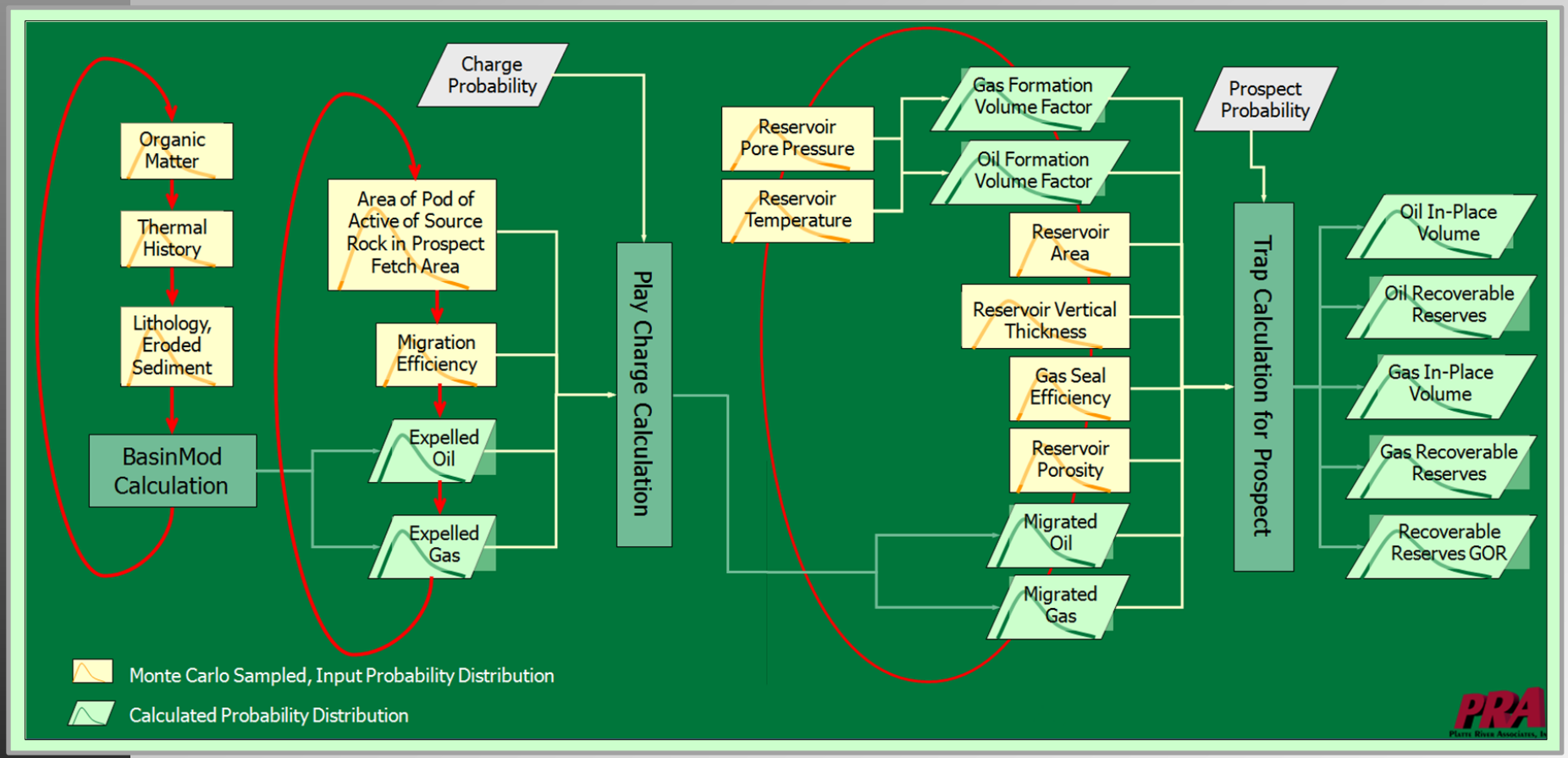
Uncertainty Assessment

Instead of using a single value enter a range of values → Latin Hypercube



Leonard et al. (2007)

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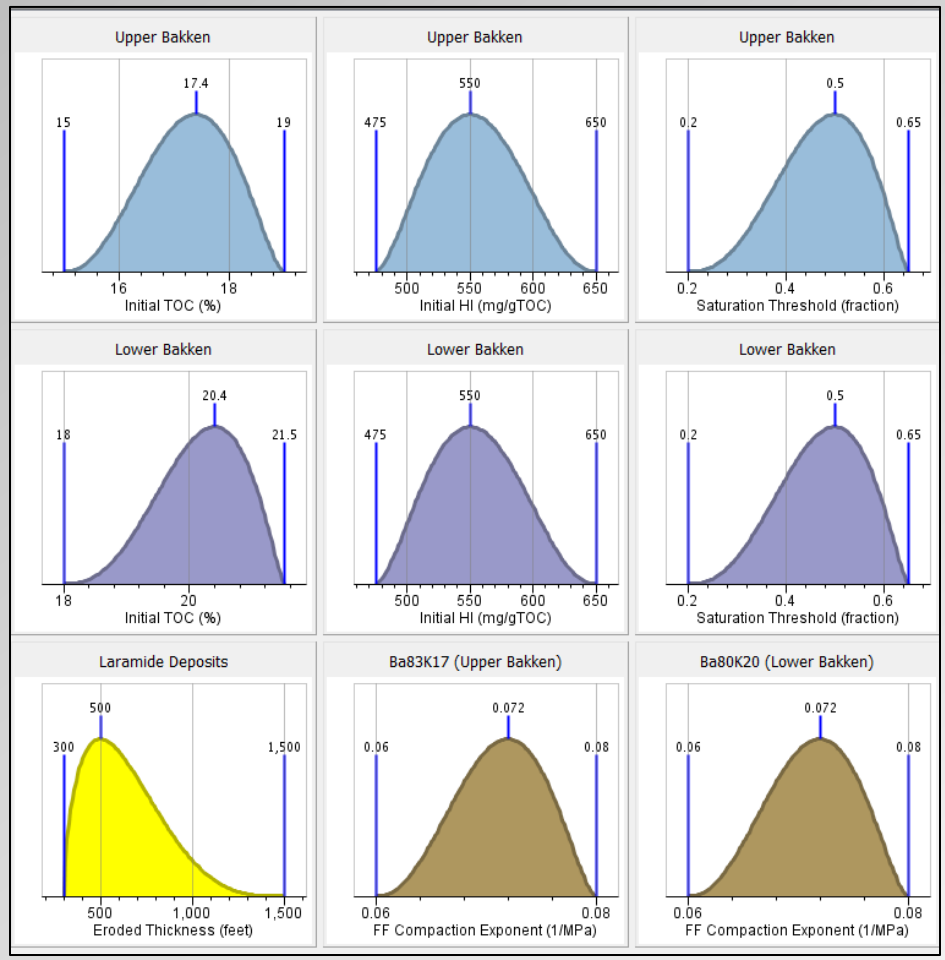
Uncertainty Assessment Input

Apply Uncertainty to Charge Parameters

- Initial TOC
- Initial Hydrogen Index
- Expulsion Efficiency
- Uplift & Erosion



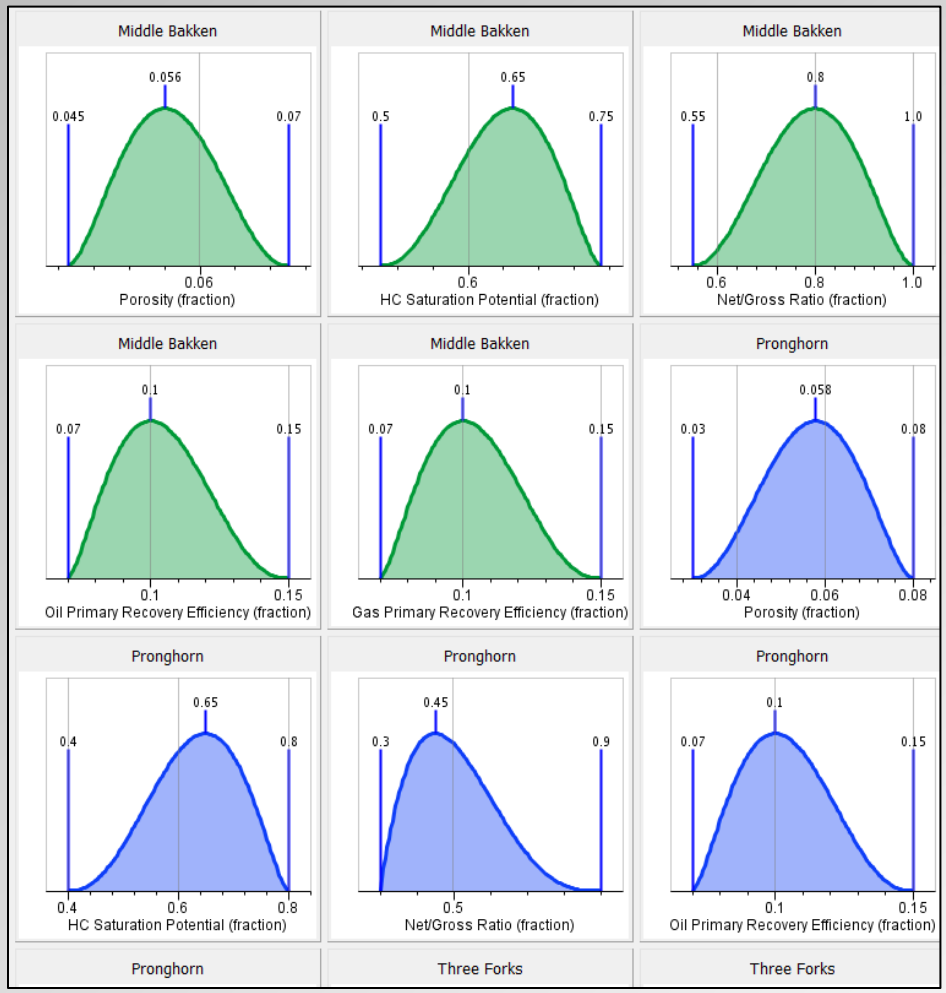
for Upper Bakken and Lower Bakken shales

Uncertainty Assessment Input

Apply Uncertainty to Trap Parameters

- Porosity
- HC Saturation
- Net/Gross Ratio
- Oil Recovery Factor
- Gas Recovery Factor

for Middle Bakken, Pronghorn and Three Forks reservoirs



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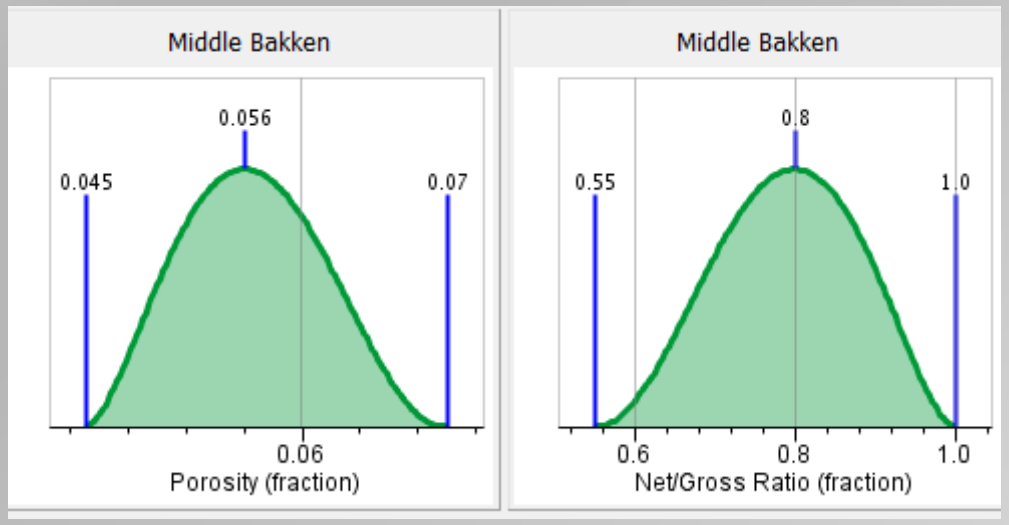
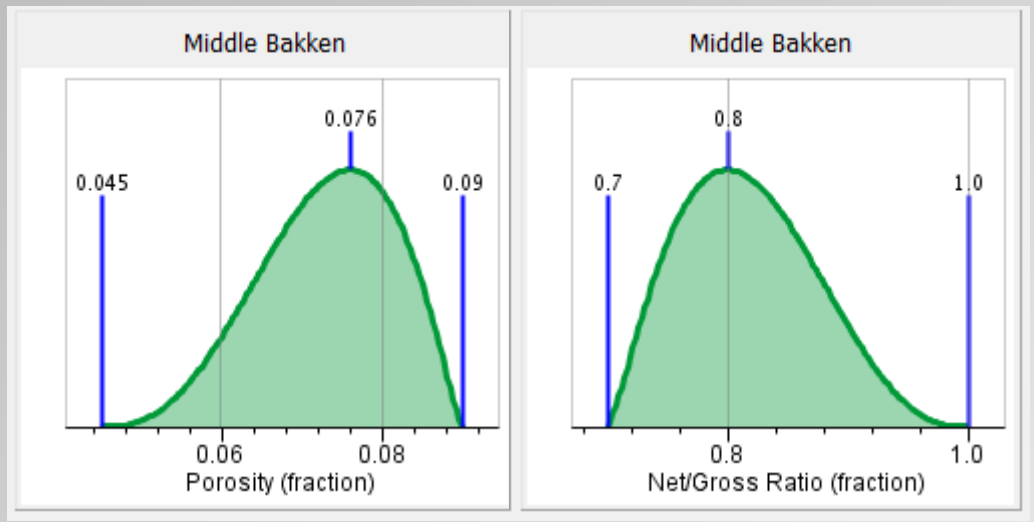
Uncertainty Assessment Scenarios



Base Case Scenario

(using core porosity)



Higher Φ Scenario

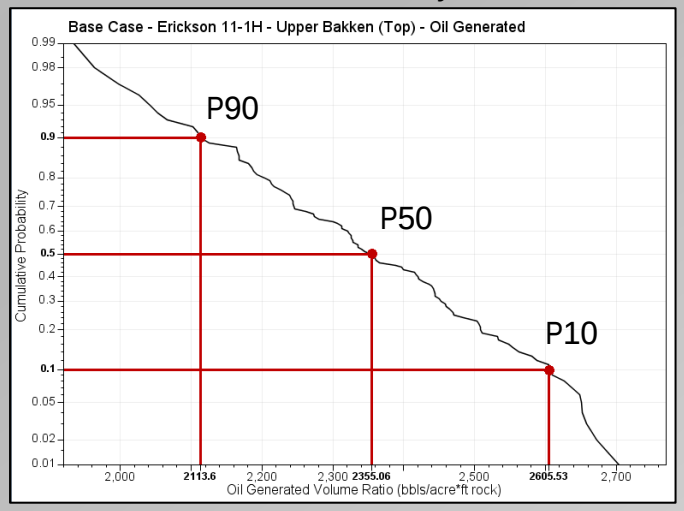
plus ~2%

accounting for pressure induced fractures

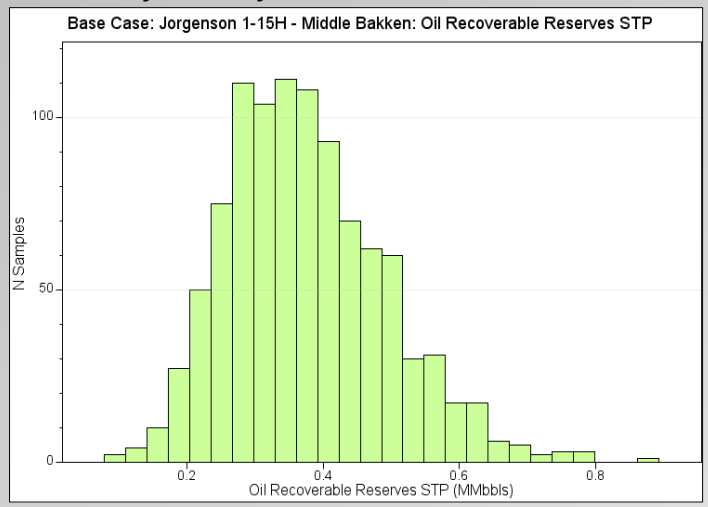
Uncertainty Assessment Results

Individual Well Results

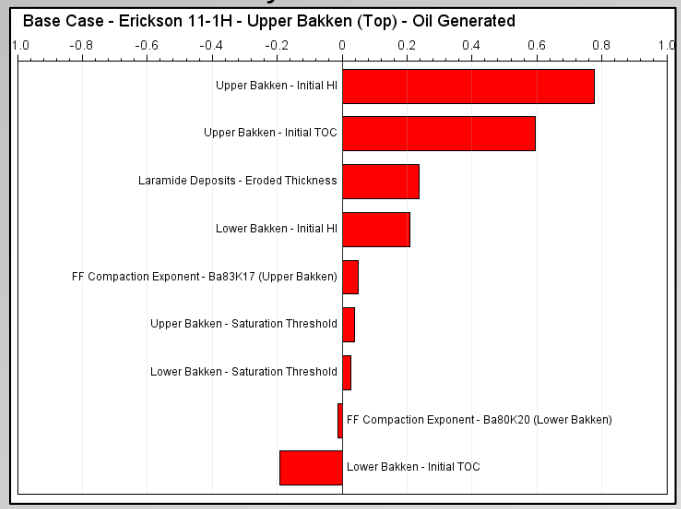
Reverse Cumulative Probability



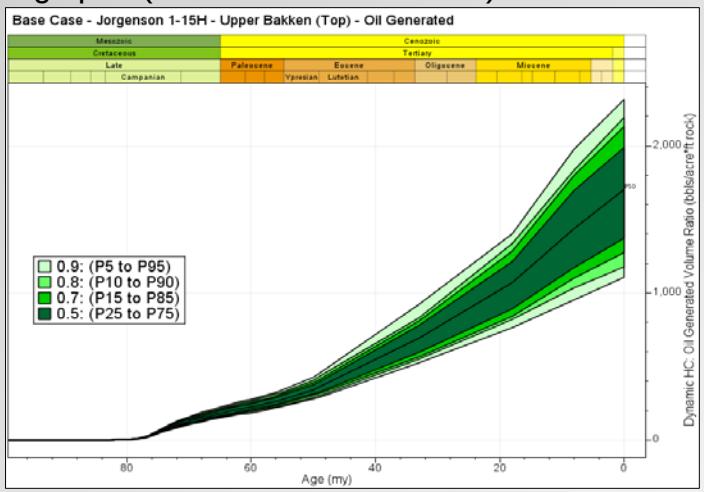
Probability Density



Tornado Sensitivity Chart



Age plot (with heat flow variation)



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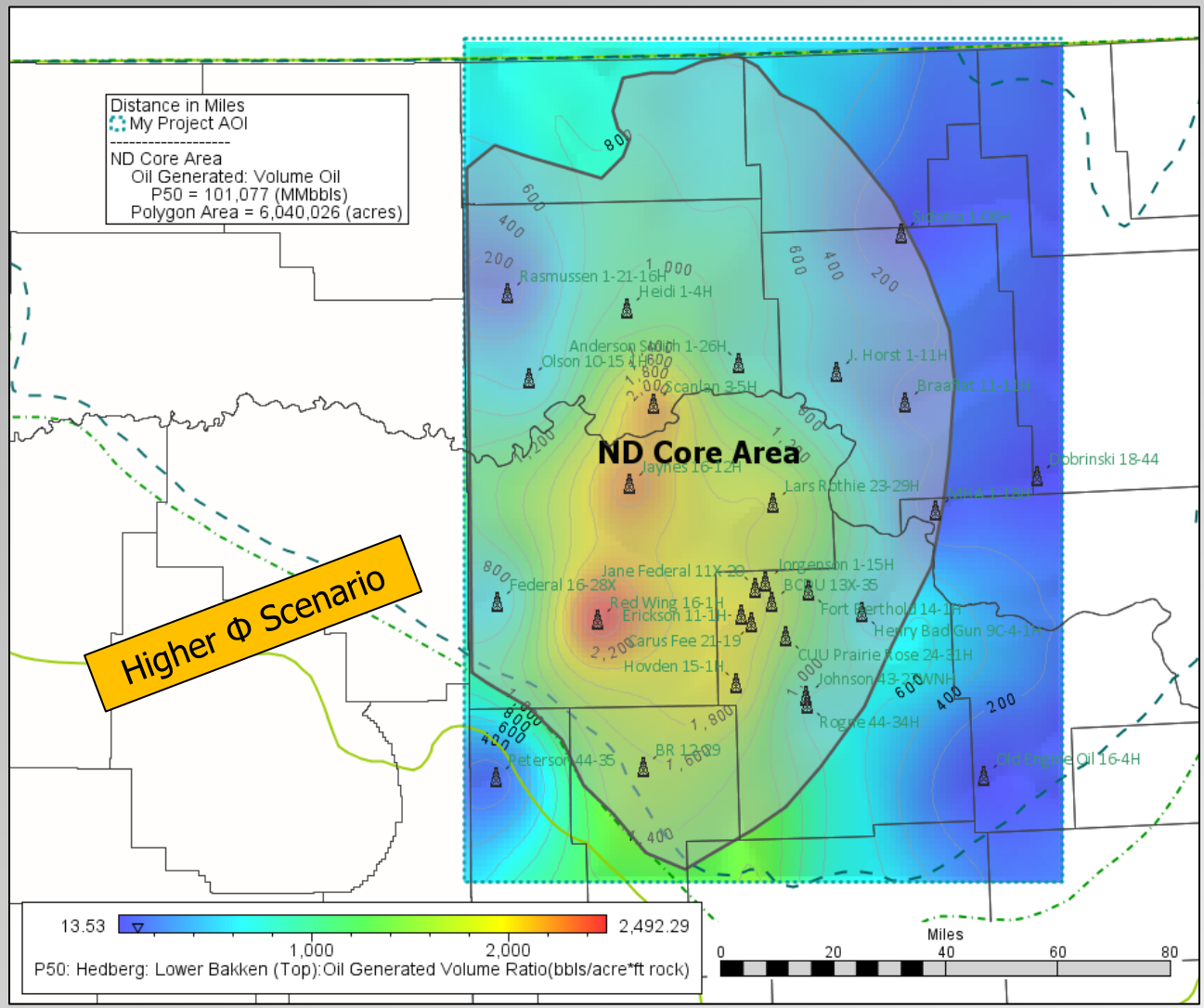
Mapped Results

Uncertainty Assessment Maps

P50 Lower Bakken Oil Generated = 101 billion bbls



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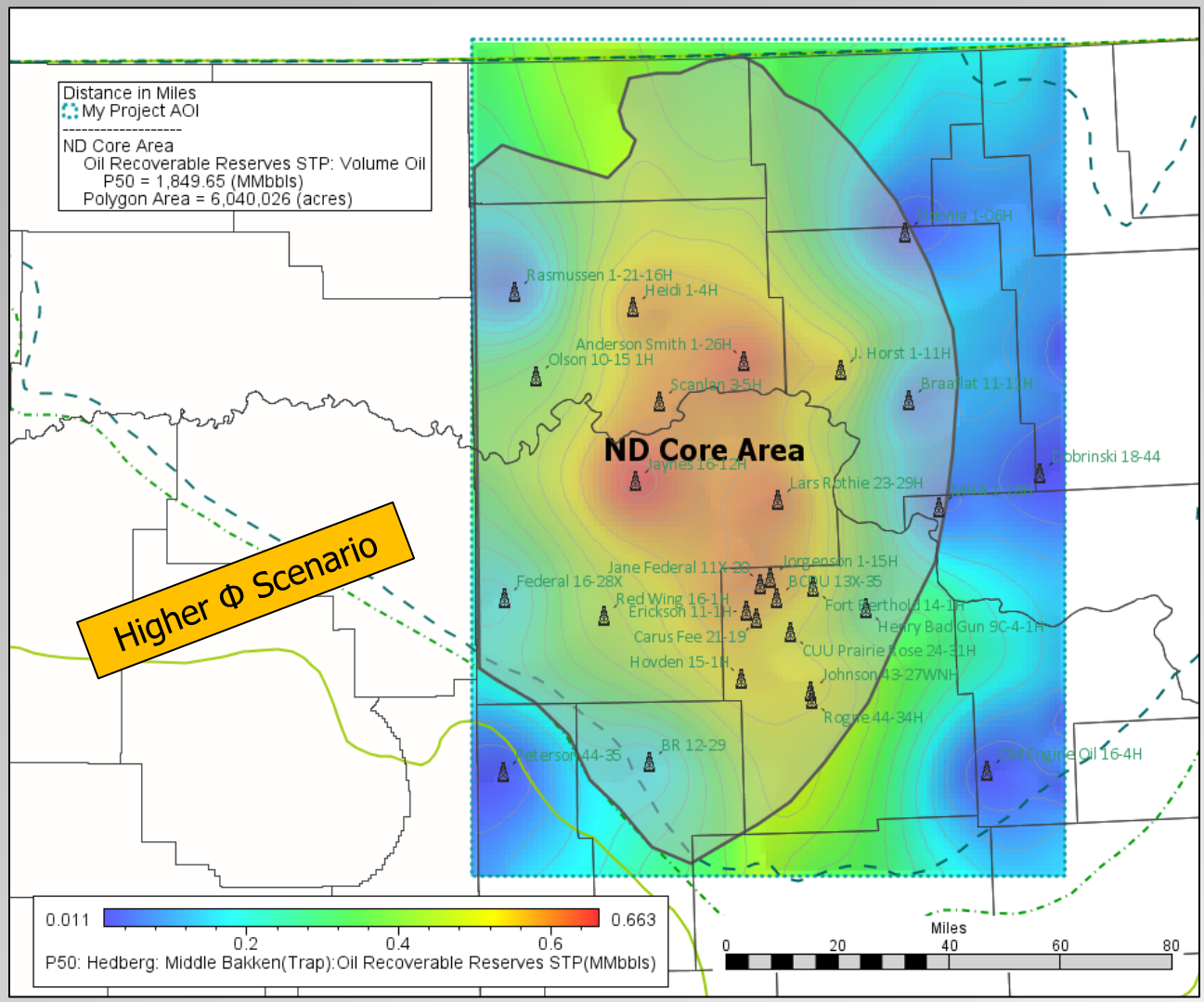
Mapped Results

Uncertainty Assessment Maps

P50 Middle Bakken Oil Recoverable @ STP = 1.85 billion bbls



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How do scenarios compare?

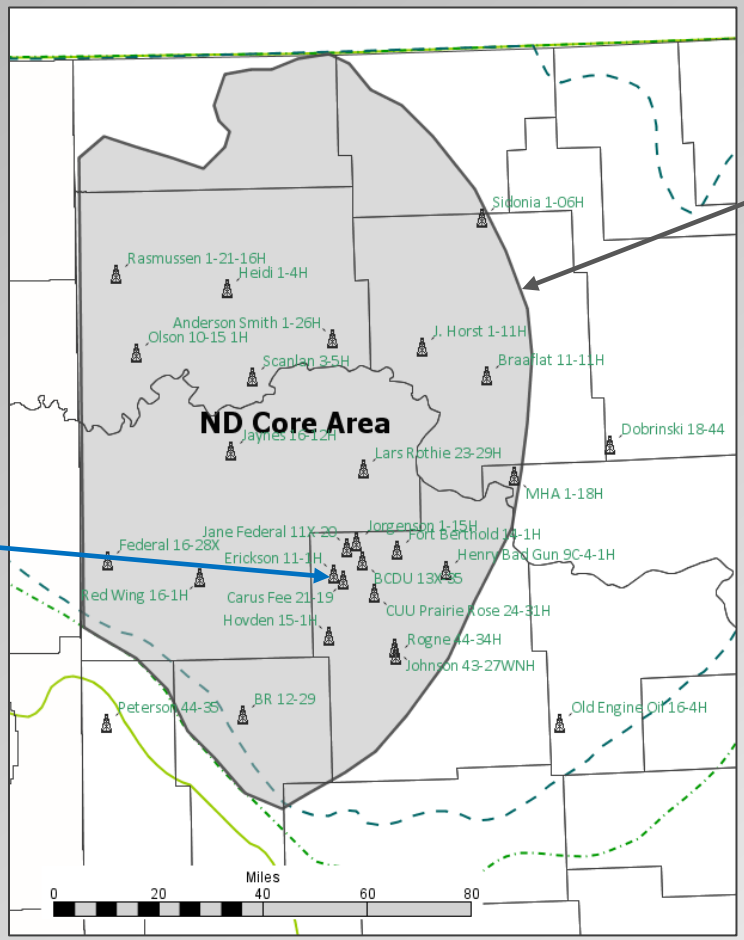
P50 Oil Recoverable @ STP for 1280 acres and ND core area

Area = 1280 acres

Base Case Scenario
MB = 441,300 bbls
PH = 160,900 bbls
TF = 587,700 bbls
Total = 1.20 MMbbls

Higher Φ Scenario
MB = 634,400 bbls
PH = 208,600 bbls
TF = 856,700 bbls
Total = 1.70 MMbbls

(Erickson 11-1H)



Area = 6,040,026 acres

Base Case Scenario
MB = 1,566 MMbbls
PH = 114 MMbbls
TF = 1,747 MMbbls
Total = 3,427 MMbbls

Higher Φ Scenario
MB = 1,850 MMbbls
PH = 118 MMbbls
TF = 2,099 MMbbls
Total = 4,067 MMbbls

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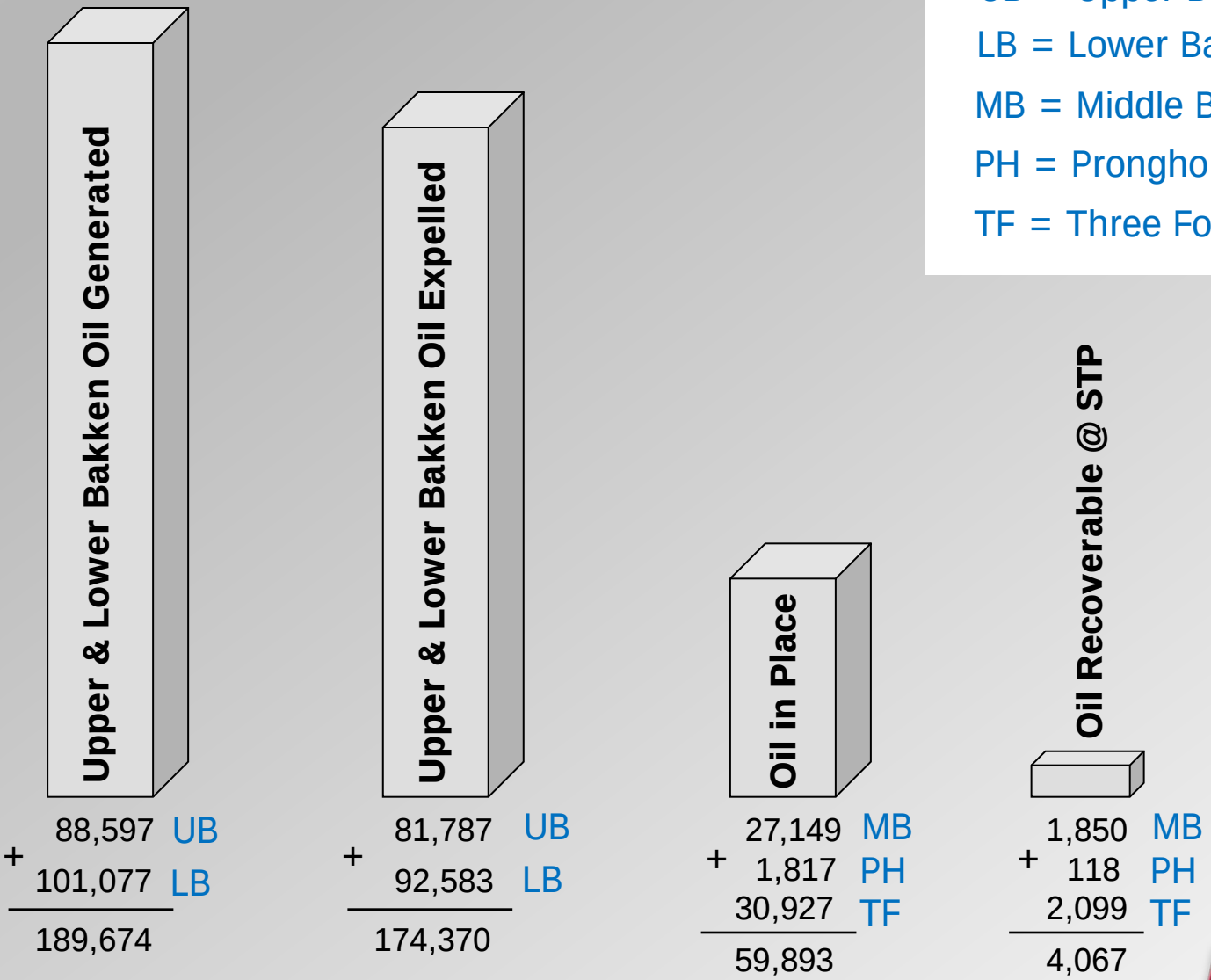
Charge to Trap Volumes

Higher Φ Scenario in Million bbls:

UB = Upper Bakken
LB = Lower Bakken
MB = Middle Bakken
PH = Pronghorn
TF = Three Forks



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Summary and Conclusions

	Area of Interest	Oil Recoverable @STP (MMbbls)			Gas Recoverable @STP (Bcf)			
		P95	P50	P5	P95	P50	P5	
Base Case Scenario	ND Core Area	1,745	3,427	5,585	1,994	2,620	3,433	
Higher Φ Scenario	ND Core Area	2,071	4,067	6,336	2,528	3,614	4,698	
USGS Assessment 2013	Continuous Bakken Petroleum System	4,417	7,046	11,430	3,427	6,366	11,244	

- In North Dakota about 3.4 to 4 billion bbls of oil and 2.6 to 3.6 Tcf of gas seem to be reasonable estimates for technically recoverable reserves.
- It is difficult to compare the USGS assessment results directly with the Uncertainty Assessment estimates due to different area sizes. Overall, they appear to be within the same ballpark range, with the Uncertainty Assessment results potentially being slightly lower.
- Continental's estimate would require extremely high recovery rates per area unit.

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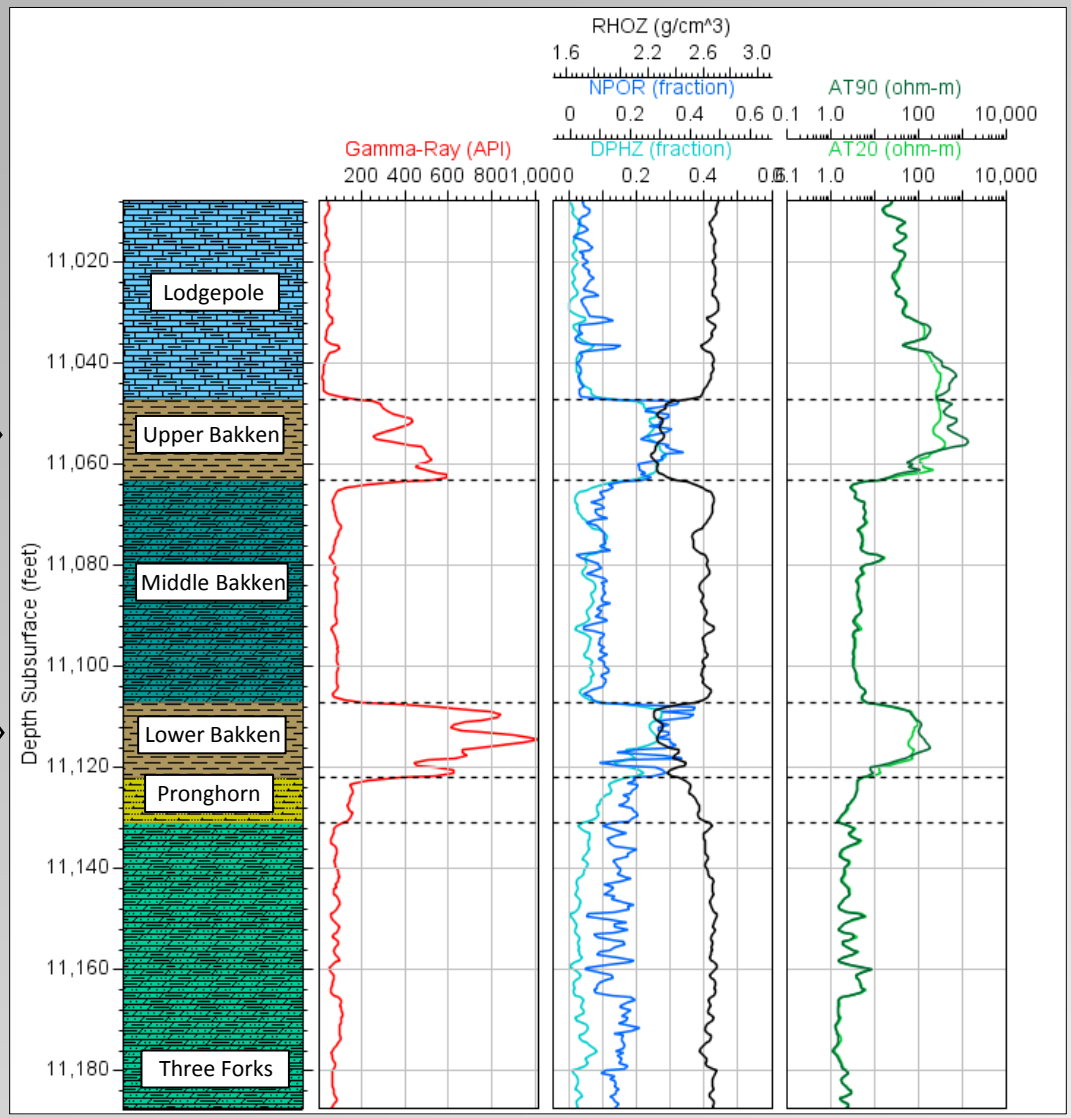
Type Log

Bakken Petroleum System



Hot Shale

Hot Shale

Seal

Source

Reservoir

Source

Reservoir

Reservoir

modified from Theloy et al., 2015

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