Assessment of upward hydrocarbon charge potential into the Three Forks Formation in the Williston Basin

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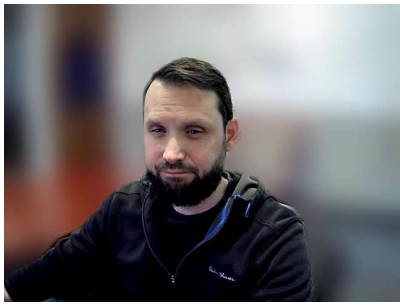
MUDTOC Consortium, Spring 2022

4/14/2022



Outline

- Three Forks as research objective
- History of Three Forks development
- Three Forks as part of Bakken Petroleum System
- Oil saturation trends
- Birdbear oils
- Birdbear as source rock
- Three Forks as part of potential Birdbear petroleum system
- Oil-source correlation focused research questions

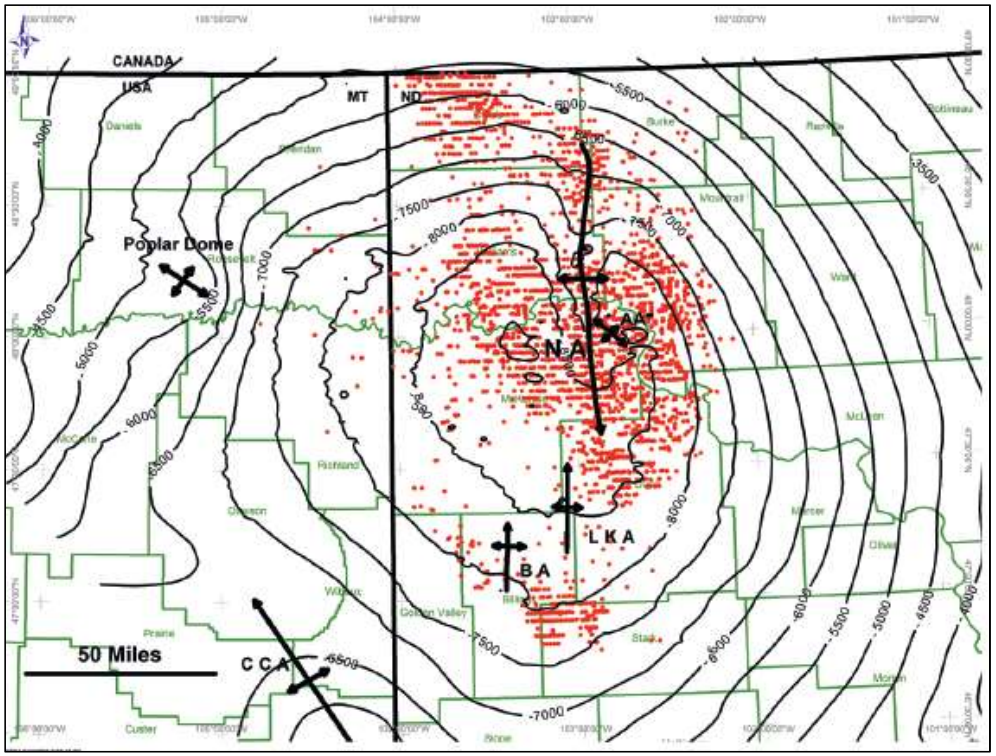
Three Forks as Research Objective

- Resource not fully developed yet (and far less developed than Middle Bakken)
  - USGS Assessment (2013), mean recoverable: 3.7 BBO and 3.6 TCF gas
  - Produced to date: 1.3 BBO and 2.3 TCF gas

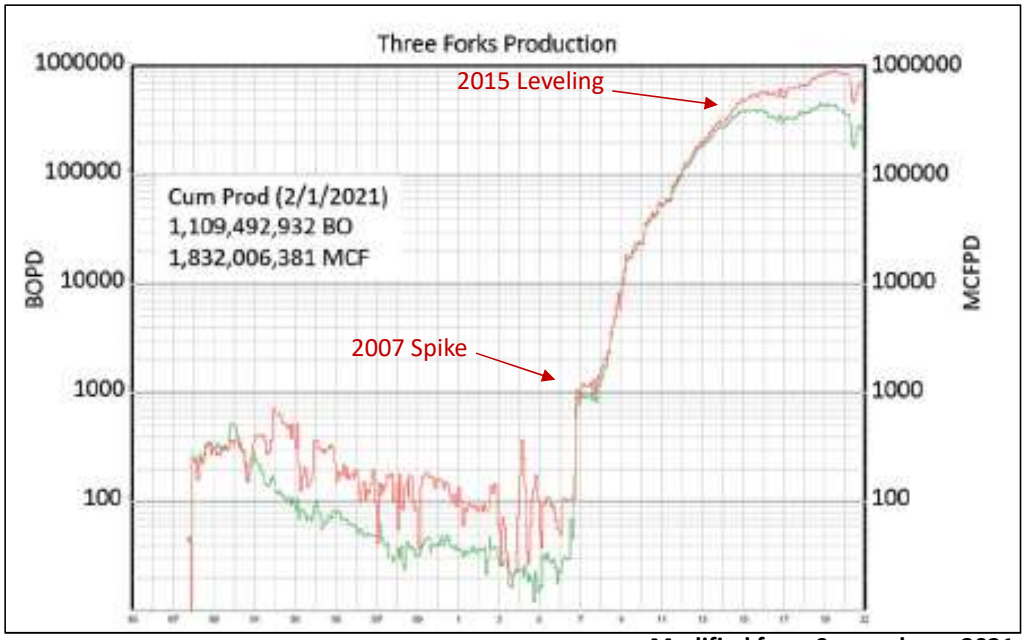
- Upper Three Forks member is historical target
  - ~ 95% of wells drilled in UTF
  - Closest in proximity to world class source rock - Lower Bakken shale
  - Middle and Lower Three Forks have some commercial success, but not well understood
  - Potential hydrocarbon sourcing from deeper horizons may play a roll

Three Forks Development

Three Forks Structure, CI = 500'



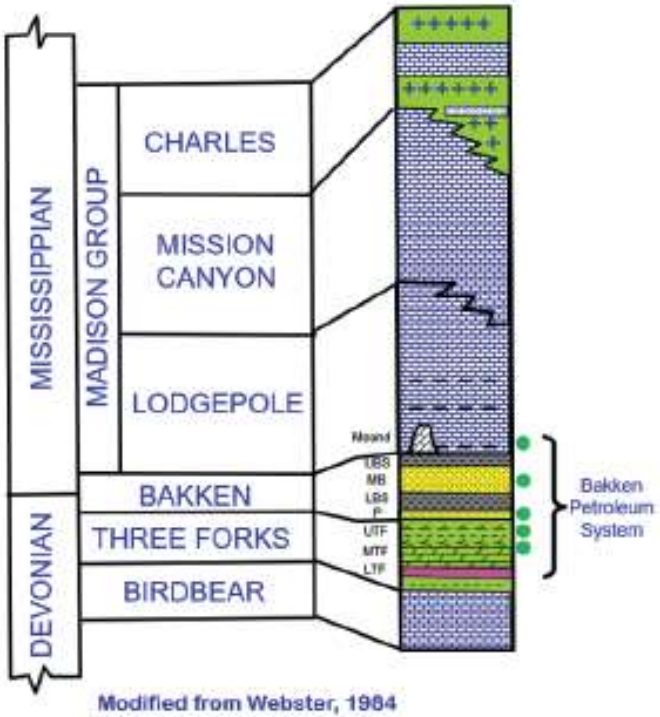
Sonnenberg, 2021



Modified from Sonnenberg, 2021

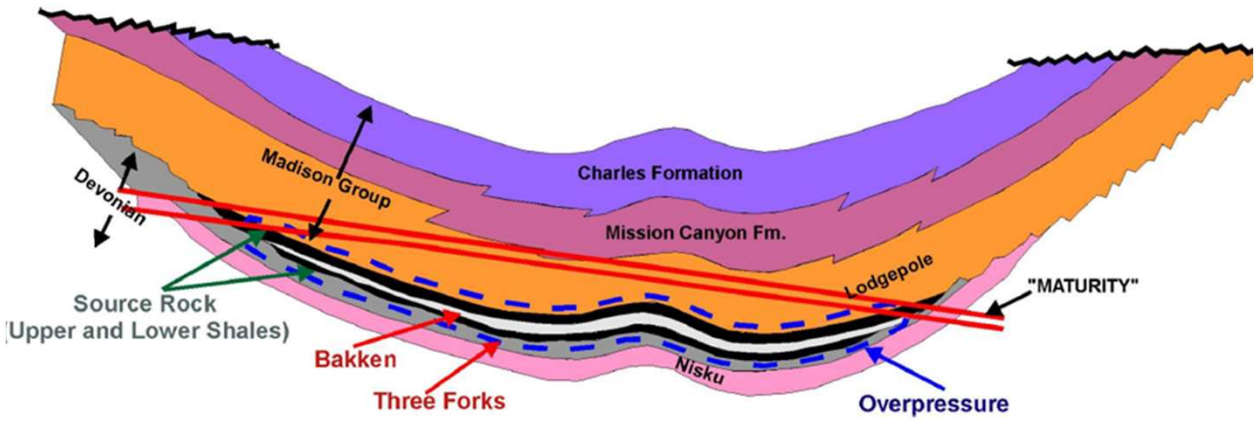
- TF wells mainly basin-center and along structural features
- Identified as viable secondary target to Middle Bakken
- Production spiked in 2007-2008 with unconventional development
- Production leveled off in 2015 with price downturn

TF in Bakken Petroleum System



Modified from Webster, 1984

Sonnenberg, 2021



Reservoirs:
Middle Bakken & Three Forks

Source Beds:
Upper & Lower Bakken Shales

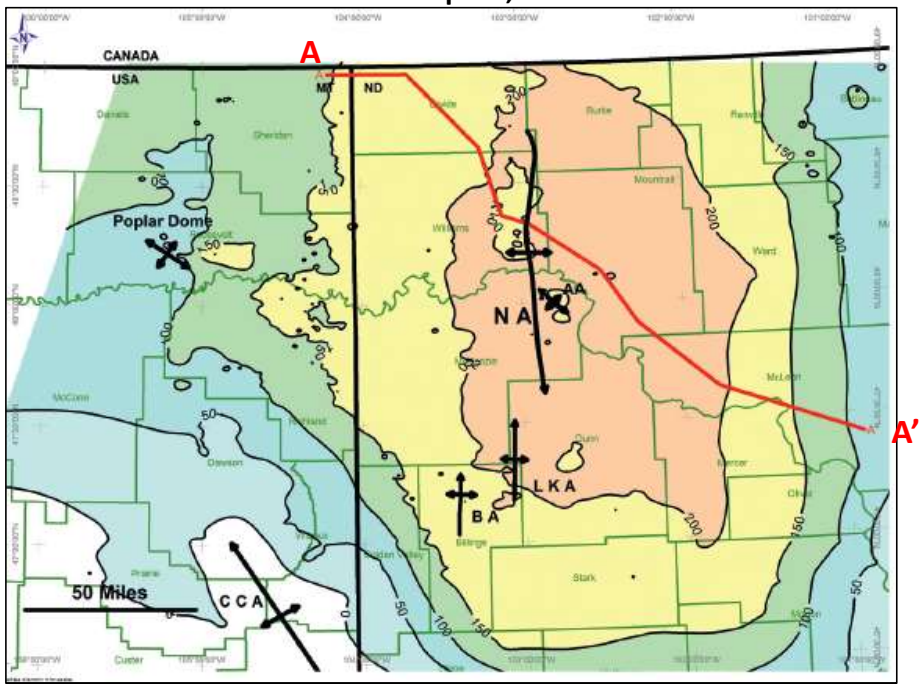
Sonnenberg, 2021

Three Forks characteristics:

- Thought to be sourced solely from LBS – downward migration and charge
- Upper Three Forks identified as main reservoir interval
- Indications that Lower and Middle TF may be significant reservoirs too

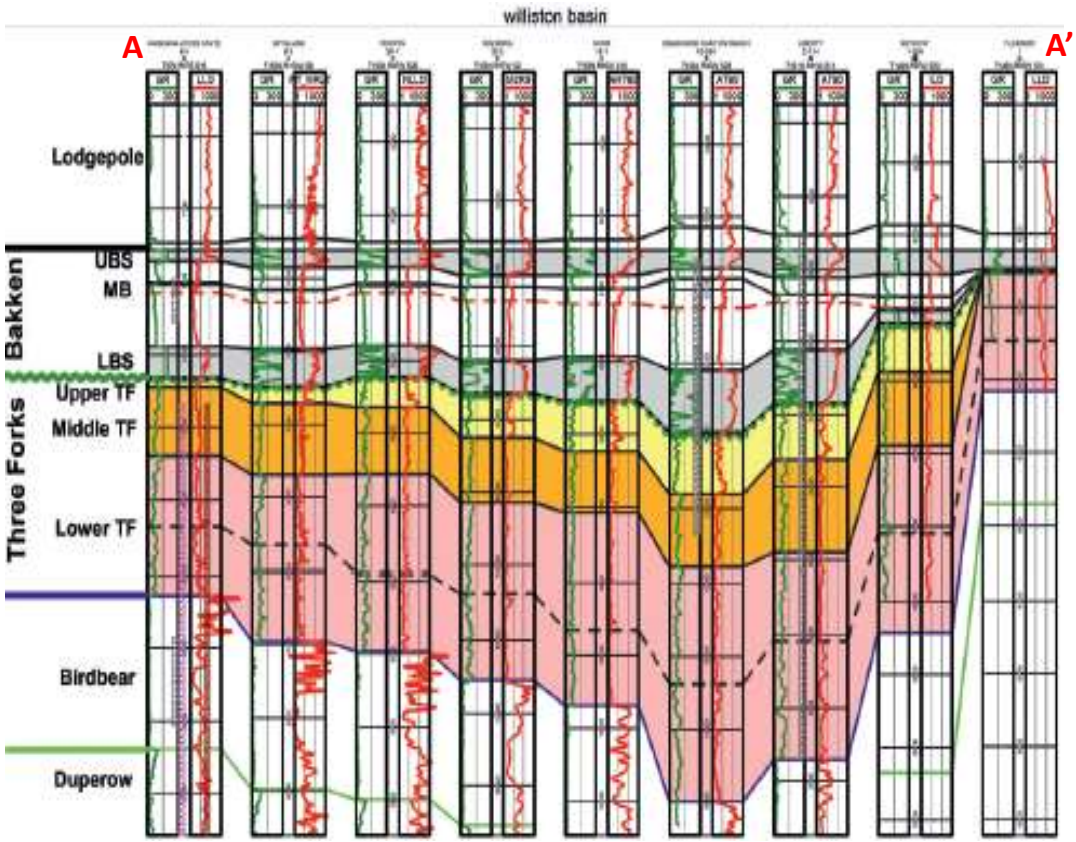
Three Forks Stratigraphy

Three Forks Isopach, CI = 50’



Sonnenberg, 2021

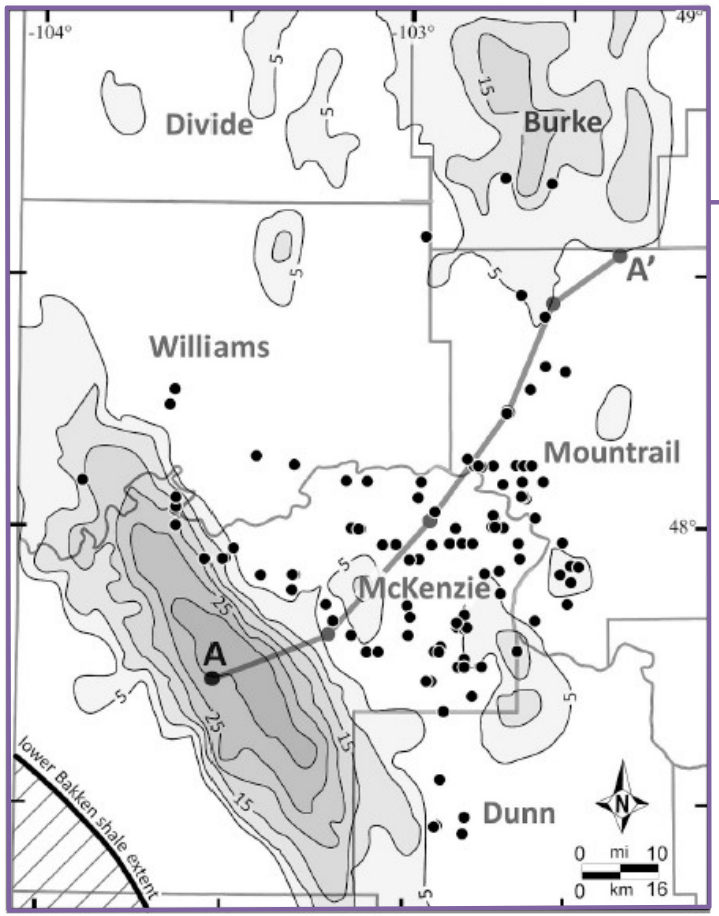
- Isopach map is of the total Three Forks Interval
- Thickness ranges from wedge-edge to more than 225 ft
- Structural features control thickness patterns



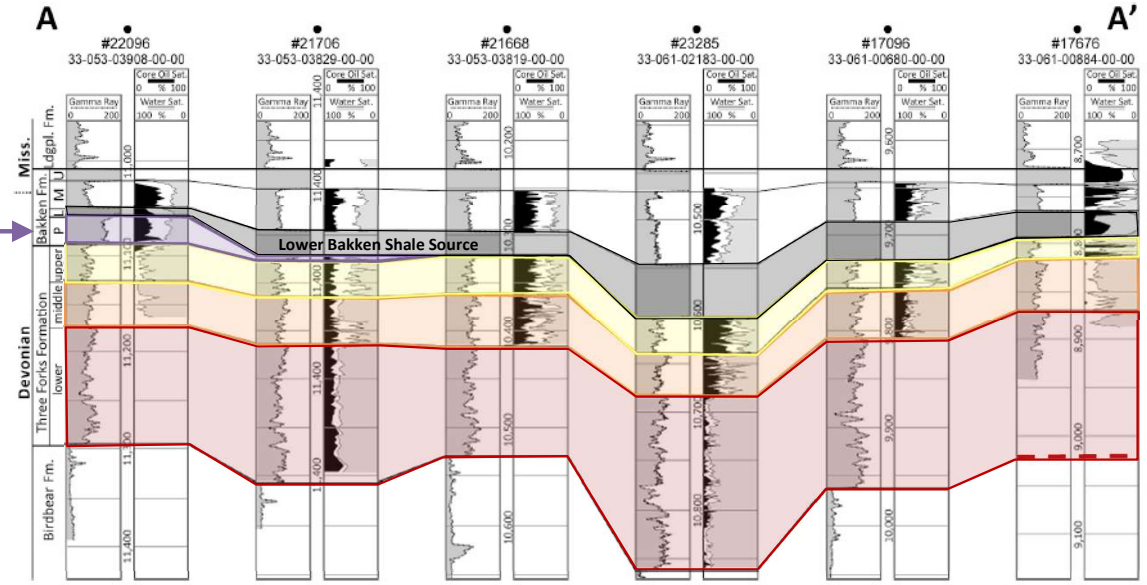
Sonnenberg, 2021

Three Forks Reservoir Characteristics

Pronghorn Isopach, CI = 5’



Nesheim, 2019



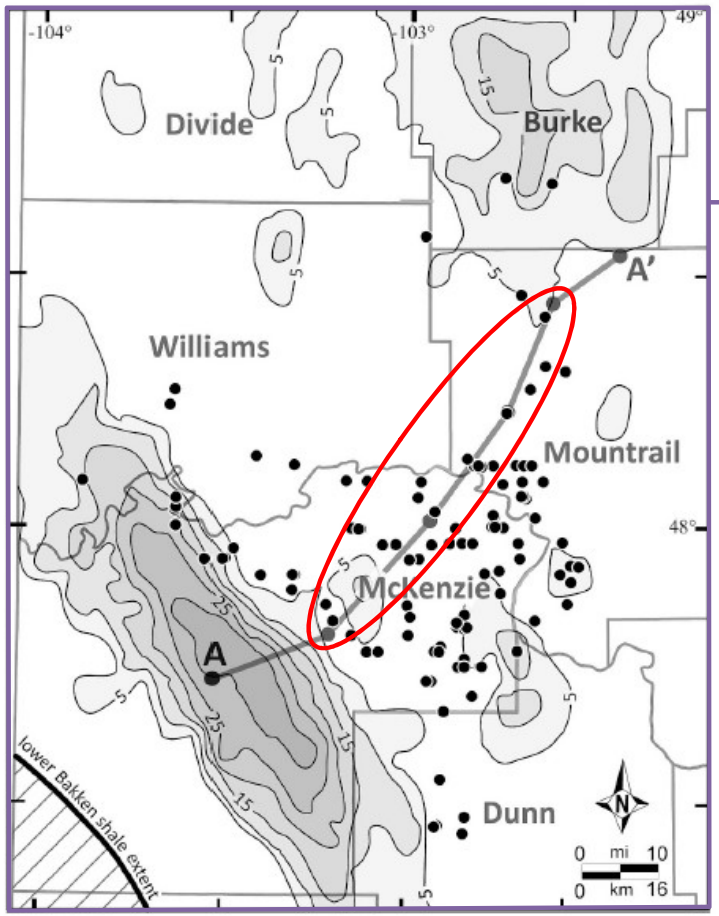
Modified from Nesheim, 2019

Three Forks Properties

- Argillaceous, calcareous, silty to very-fine-grained dolostones and dolomitic mudstones
- 20-30% Siliciclastic, 20-60% Dolomite, 0-30% Calcite, 15-50% Clay, and up to 30% evaporites (anhy.)
- Avg Porosity: 6-7%
- Avg Permeability: 0.1-1.0 md
- HC saturations: variable

Observed TF Oil Saturation Trends

Pronghorn Isopach, CI = 5’



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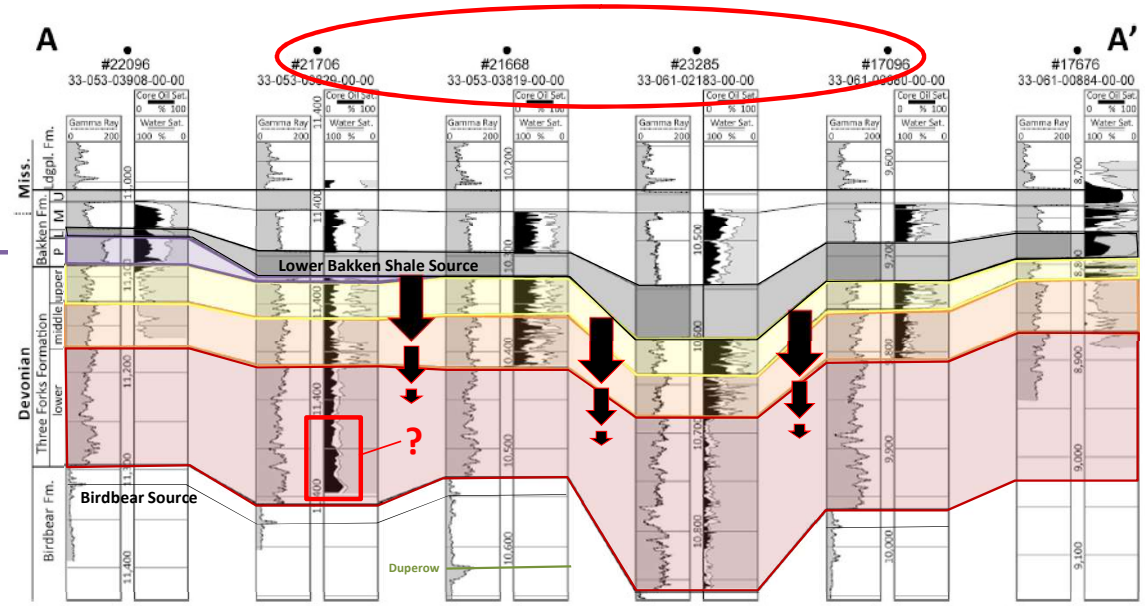


Modified from Nesheim, 2019

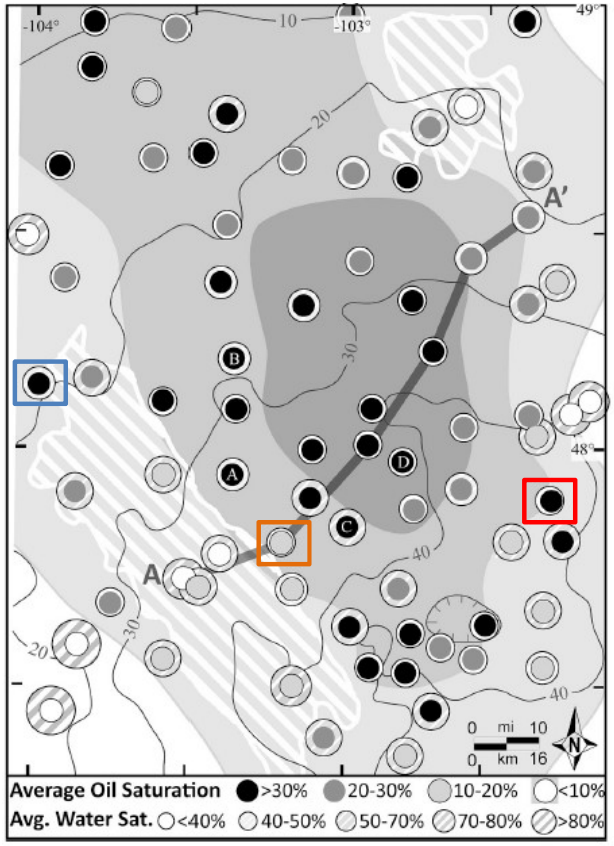
HC Saturation observations

- Three Forks members have oil charge where Pronghorn member of Bakken is absent and where Lower Bakken Shale is thickest and thermally mature
- Upper member typically has greatest oil saturation
- Saturation level decreases with depth/lower members
- #21706 has elevated saturation in basal member

= Decreasing oil saturation trend with depth

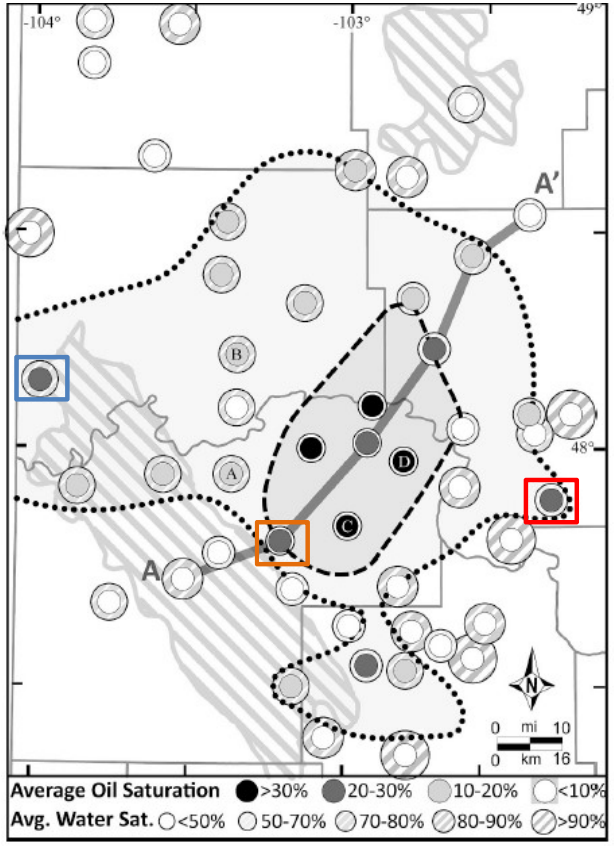
TF Members Avg Core-plug Saturation Maps

Upper Three Forks



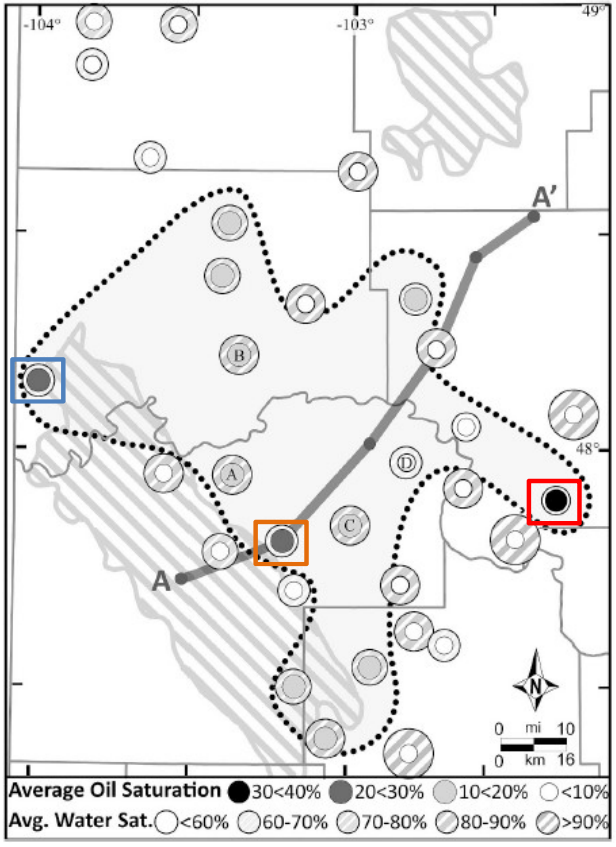
- Most elevated average oil saturations, and increasing towards basin center and increased LBS maturity

Middle Three Forks



- Decreased, although good average oil saturation; aerial extent shrinking and concentrated toward basin center

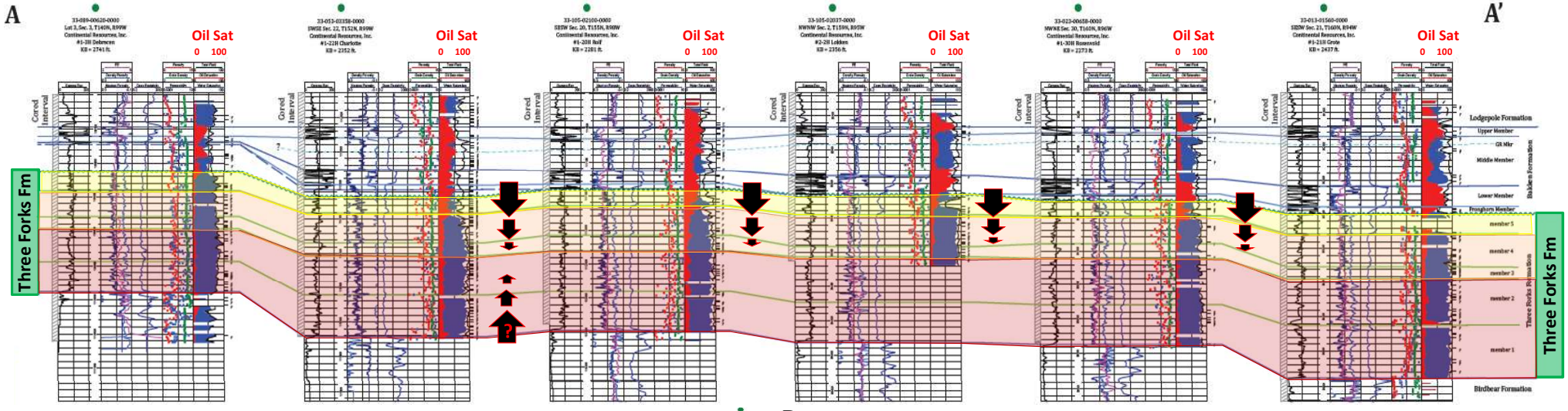
Lower Three Forks

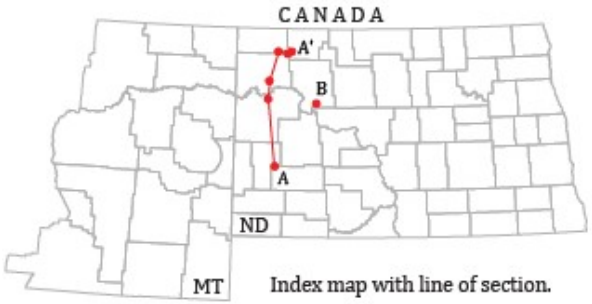


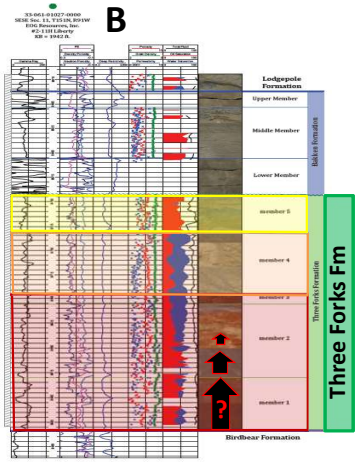
- Lowest average oil saturations; however less data and some local examples of elevated oil saturation

Modified from Nesheim, 2019

NDGS G.I. No. 165 Observed TF Oil Sat Trends





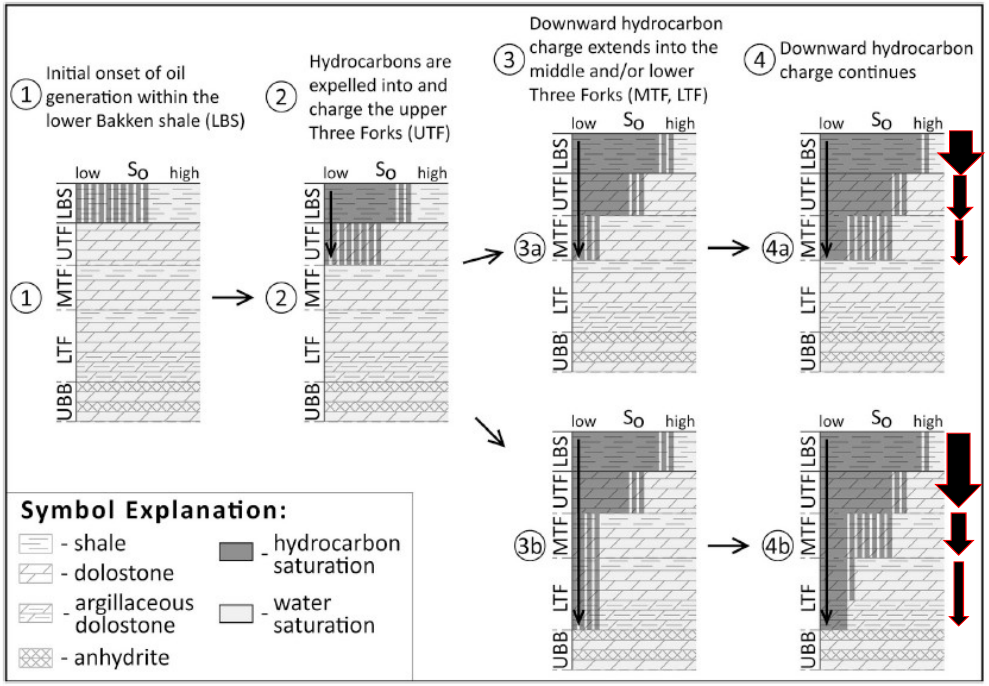


= Decreasing oil saturation trend with depth

= Decreasing oil saturation trend with shallowing

Modified from J. LeFever et al., 2013

Oil Sat Model vs. Local Sat Trend Exceptions



Nesheim, 2019

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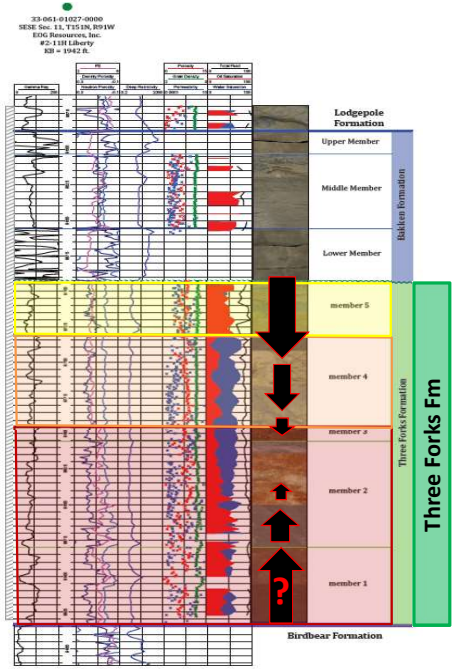
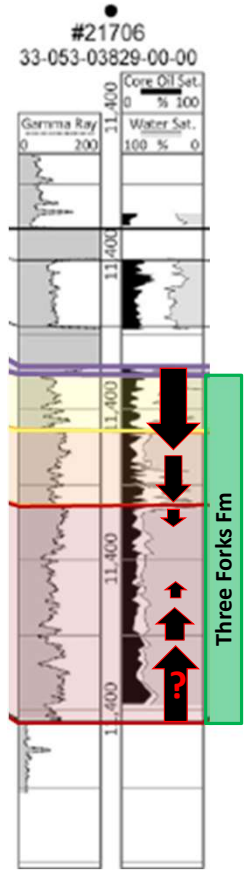


J. LeFever et al., 2013
Dunn County



Nesheim, 2019
McKenzie County

Potential Deeper Sources for Lower TF Charge

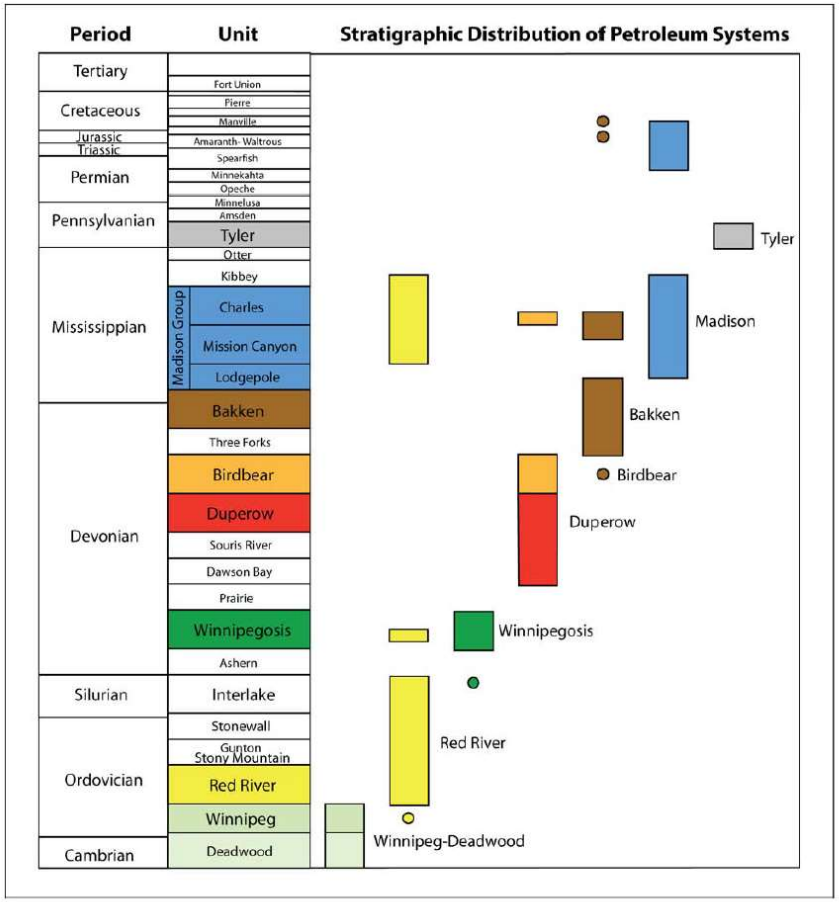


Figure 2. Stratigraphic column of the Williston Basin showing the petroleum systems in color (excluding gas systems) and the stratigraphic distribution of the petroleum system fluids. Circles represent minor occurrences or a single oil analysis. Systems without a documented oil-source correlation are considered hypothetical and include the Winnipeg, Duperow, and Birdbear. The Deadwood petroleum system is speculative because a good oil-prone source rock has not been identified.

Lillis, 2013

P. Lillis (2013) WB Devonian Petroleum Systems and Observations:

- Three Forks reservoirs thought to be sourced by the overlying Lower Bakken Shale
- Oil analyses from Upper TF member correlate to LBS source rock
- Given elevated oil saturations in Lower TF, maybe underlying source also contributes...
- Winnipegosis, Duperow, and Birdbear all have source rock character, and produced oils
- Birdbear most probable underlying source for Lower TF oils if not migrated from Bakken

Source Rock Analysis of Birdbear in Canadian WB

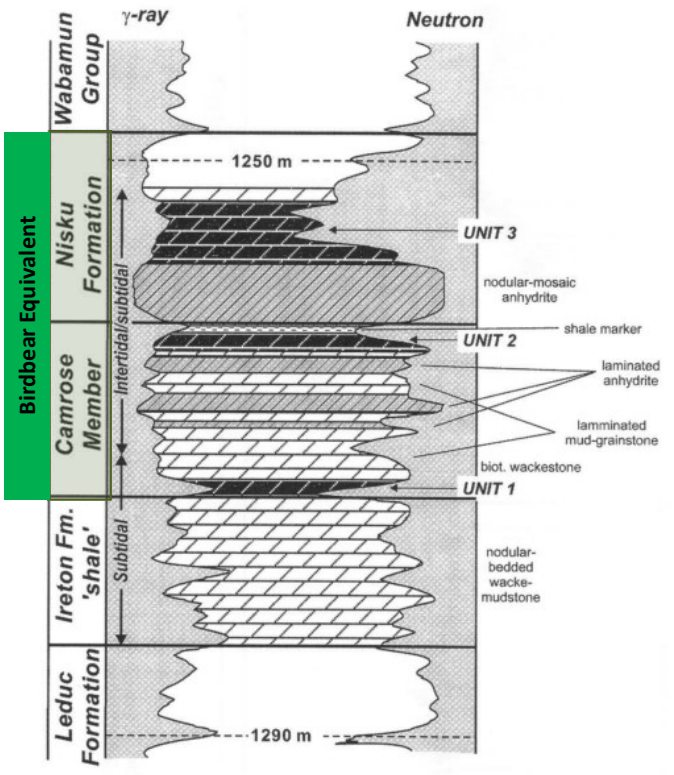
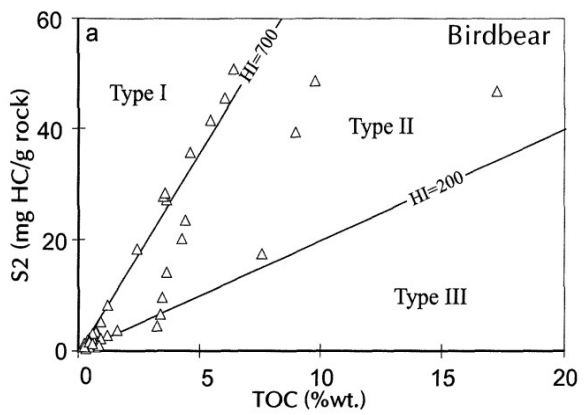
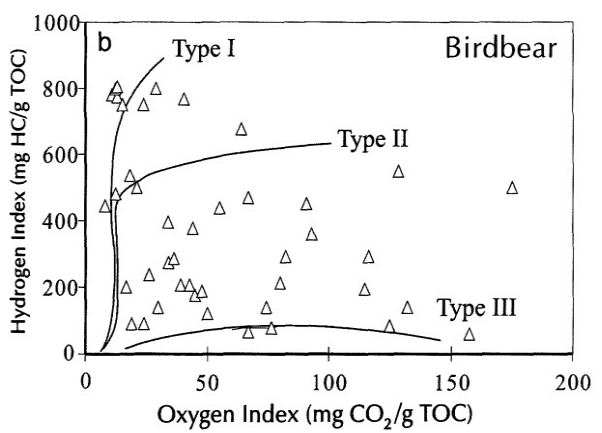


Fig. 18. A typical example of the log signature and lithology present in the Camrose Member and Nisku Formation of southern Alberta. All three main potential source intervals (units 1, 2, 3 - in dark) are present in well Coho Hamilton Medhat 9-9-11-7W4.

Modified from Fowler et al., 2001

Birdbear Formation samples from southern Saskatchewan



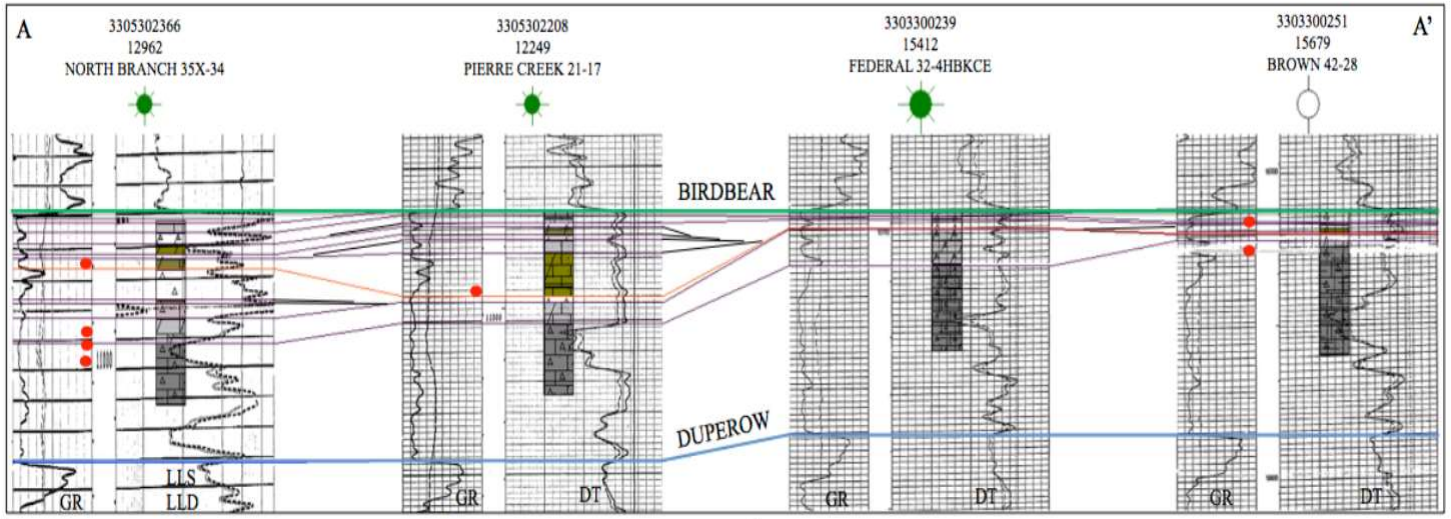


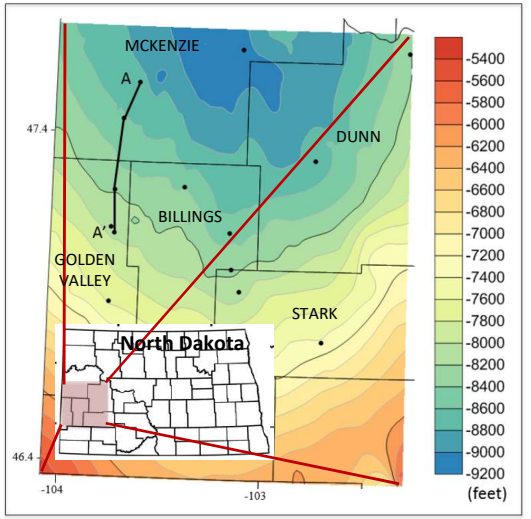
Fowler et al., 2001

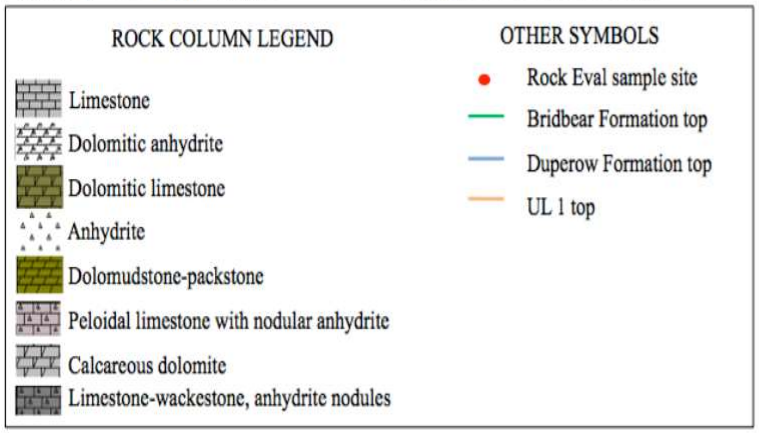
<u>Source rock characteristics of BB:</u>

- Birdbear Fm of southern Saskatchewan equivalent to Camrose Member/Nisku Fm. in southern Alberta (Strat column to left)
- Recognized as possible oil-prone source rock throughout Williston Basin
- Generally, thin organic-rich beds dispersed throughout formation, interbedded with carbonates and evaporite facies
- Contains Type I and Type II kerogen with TOC values up to 6% in Type I SR and up to 17% in Type II SR
- Oil extracts from BB show very similar character to BB reservoired oils
- Strong possibility that BB oils are from BB source

SR Character of Birdbear in western North Dakota



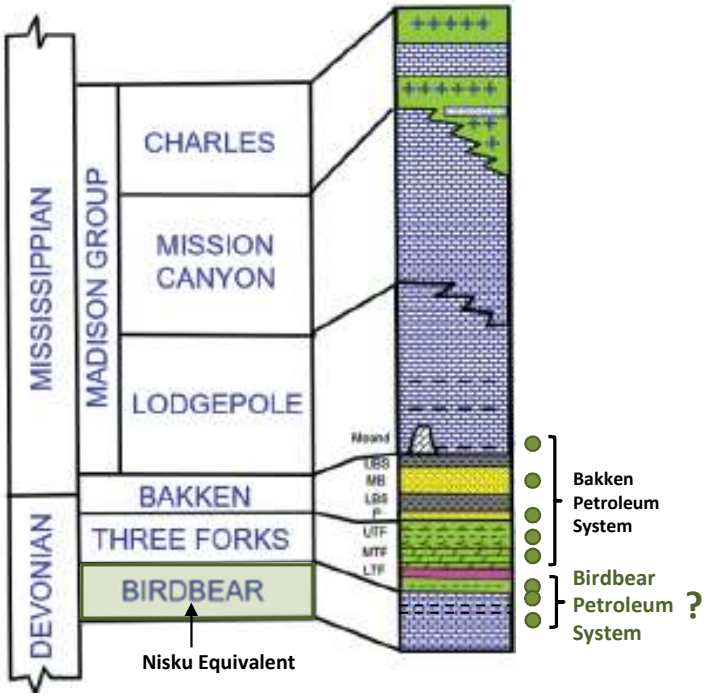




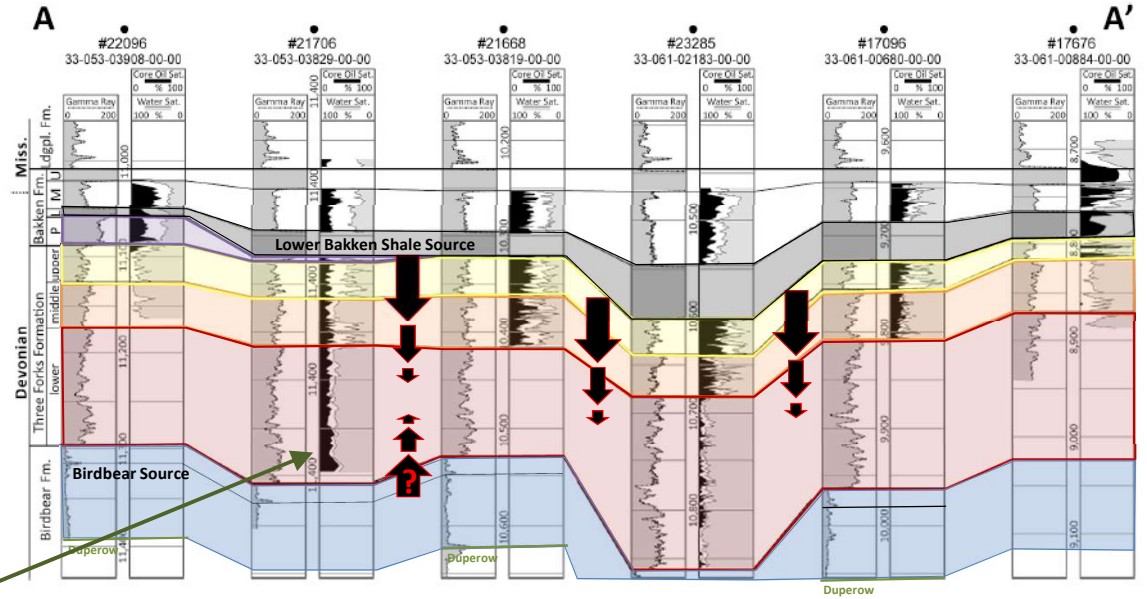
API #	NDIC #	WELL NAME	DEPTH (ft)	TOC	S1	S2	S3	Tmax (°C)	HI	OI	S2/S3	S1/TOC X 100	PI	LITHOFACIES
3308900646	21139	ZENT 30-138-95 A 1H	10004.50	2.88	2.43	9.65	0.22	439.00	334.84	7.63	43.86	84.32	0.20	L 6
3308900646	21139	ZENT 30-138-95 A 1H	10006.80	5.37	2.12	20.90	0.31	440.00	389.34	5.77	67.42	39.49	0.09	L 6
3303300308	21734	OLSON 12-139-104 A 1H	10511.50	2.71	1.51	7.03	0.36	439.00	259.03	13.26	19.53	55.64	0.18	L 8
3303300251	15679	BROWN 42-28	10716.00	1.57	0.97	6.26	0.29	438.00	397.97	18.44	21.59	61.67	0.13	L 7
3303300251	15679	BROWN 42-28	10726.00	1.67	3.85	5.19	0.30	443.00	310.04	17.92	17.30	229.99	0.43	L 2
3305302336	12962	NORTH BRANCH #35X-34 BN	10987.00	1.58	0.97	2.50	0.32	453.00	158.73	20.32	7.81	61.59	0.28	L 2
3305302336	12962	NORTH BRANCH #35X-34 BN	10965.10	3.49	1.21	7.58	0.29	450.00	217.19	8.31	26.14	34.67	0.14	UL 2
3305302336	12962	NORTH BRANCH #35X-34 BN	10991.20	2.45	0.85	4.30	0.32	450.00	175.51	13.06	13.44	34.69	0.17	L 2
3305302336	12962	NORTH BRANCH #35X-34 BN	11000.10	2.27	1.27	4.32	0.26	449.00	190.31	11.45	16.62	55.95	0.23	L 2
3300700016	859	GOVT-M.S. PACE #1	11199.00	1.52	0.47	0.82	0.39	445.00	54.02	25.69	2.10	30.96	0.36	*
3305302208	12249	PIERRE CREEK 21-17	10992.00	6.87	1.93	14.29	0.31	452.00	208.01	4.51	46.10	28.09	0.12	L5

B. Engleman, 2015 – University of North Dakota MS Thesis

Birdbear Petroleum System?



Modified from Sonnenberg, 2021



Modified from Nesheim, 2019

Guiding Questions for Source of TF Oils

Birdbear Petroleum System

- Does Birdbear have a Source-Oil correlation?
- Does geochemical fingerprint match previously observed Birdbear oil characteristics?

Three Forks Oils

- What are the geochemical characteristics of oils from each of the benches in the Three Forks?
- Does geochemical fingerprinting match with Birdbear source or Bakken source better?
- Are there indicators of fluid mixing/mixed source?

Overarching Three Forks Analysis

- What implications are drawn from Source-Oil correlation work in the Three Forks with regard to its reservoir characteristics and potential variance in regional/local trends?

Updated Three Forks Project Research Questions

Reservoir Characteristics and Petrophysical Response

- How do reservoir properties vary between Lower, Middle, and Upper Three Forks?
- What are the typical petrophysical responses to reservoir properties?
- How do reservoir properties vary laterally?
- What are their controls?

Depositional Environment Models for Three Forks Formation

- What are key differences between current models: 1) restricted, shallow-marine vs. 2) playa lake?
- What are DE models' implications on subsurface reservoir geometry?

Regional Distribution of Reservoir "Sweet spots"

- How are sweet spots defined/identified?
- What are their geological controls?
- How are they distributed regionally?
- Any untested potential?

Next Steps

1. Continue compiling available, public Three Forks rock data
2. Continue developing analytical strategies: reservoir characterization, oil-source correlation, and depositional model
3. Regional Three Forks mapping using well log database
4. Thesis proposal

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