

# **Unconventionally Conventional - Facies and Sequence Stratigraphy of the Upper Devonian - Lower Mississippian Bakken Formation Reservoir, Williston Basin, North Dakota<sup>\*</sup>**

**Sven Egenhoff<sup>1</sup>, Aaron van Dolah<sup>1</sup>, and Ali Jaffri<sup>1</sup>**

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<sup>\*</sup>Adapted from oral presentation at AAPG Convention, New Orleans, Louisiana, April 11-14, 2010

<sup>1</sup>Geosciences, Colorado State University, Fort Collins, CO ([sven@warnercnr.colostate.edu](mailto:sven@warnercnr.colostate.edu))

## **Abstract**

The Upper Devonian-Mississippian Bakken Formation in the Williston Basin is one of the most prolific onshore petroleum systems in the continental U.S. It consists of a middle mixed carbonate-siliciclastic member, sandwiched between the two organic-rich Bakken shales. The focus of this study is to highlight the facies architecture and sequence stratigraphy of the middle Bakken member that forms the reservoir. The middle Bakken shows ten depositional facies, most of them siltstones, and some sandstones with varying amount of ooids. These ten facies are arranged into four distinct parasequences with the lower three showing an increase in depositional energy up-section; the top parasequence reflects laterally varying stacking patterns and a successive decrease in depositional energy. These four parasequences are traceable throughout the study area, although locally obliterated by bioturbation and/or erosion.

The lower three parasequences show an overall progradation of the sedimentary system, culminating in the deposition of sandstones and ooids. The upper, retrograding portion indicates a deepening of the basin, setting the stage for the deposition of the upper member black shales. While the parasequences represent fourth-order cycles, the shallowing from the lower member into the middle and the successive deepening into the upper member are interpreted as a fluctuation of third-order.

The main reservoir facies within the Bakken depositional system are oolites and sandstones representing nearshore sediments, and shoreface laminated and ripple-bedded siltstones. These rock types are concentrated at the tops of each parasequence, although depending on the position within the basin, not every parasequence top may show suitable reservoir characteristics. As the margins developed shallower facies earlier than the center, oil-prone oolites and sandstones occur in different stratigraphic levels along a

transect through the basin. A lateral correlation of oolite sandbodies from the basin margin to the depocenter will therefore likely cross time-lines and does not reflect original depositional geometries. The concentration of the oil in the now moderately porous (3-4%), but originally high-energy sandstone and ooid facies at the top of individual parasequences shows that the middle Bakken is a conventional and not an unconventional reservoir throughout the North Dakota portion of the Williston basin.

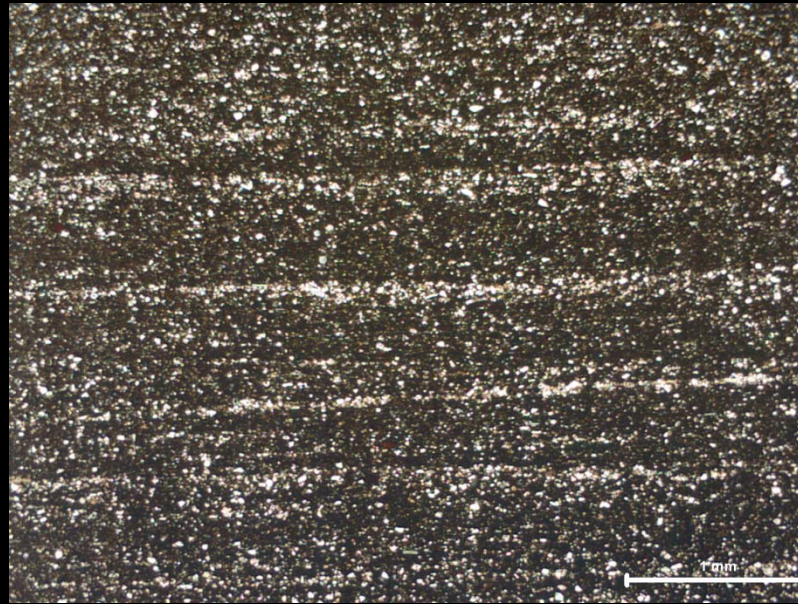
### **References**

Lefever, J.A., 1991, History of oil production from the Bakken Formation, North Dakota *in* W.B. Hansen, (ed.) 1991 Guidebook to geology and horizontal drilling of the Bakken formation, p. 3-17.

Lefever, J.A., C.D. Martiniuk, D.F.R. Dancsok, and P.A. Mahnic, 1991, Petroleum potential of the middle member, Bakken Formation, Williston Basin: Saskatchewan Geological Society, Special Publication, v. 6, p. 74-94, Report #11.

Sperr, J.T., 1991, Exploration models for Bakken shale reservoirs, Williston Basin, North Dakota and Montana *in* W.B. Hansen (ed.) 1991 Guidebook to geology and horizontal drilling of the Bakken formation, p. 143-149.

# Unconventionally conventional - facies and sequence stratigraphy of the Upper Devonian- Lower Mississippian Bakken Formation reservoir, Williston Basin, North Dakota



Sven Egenhoff, Aaron van Dolah & Ali Jaffri  
Colorado State University



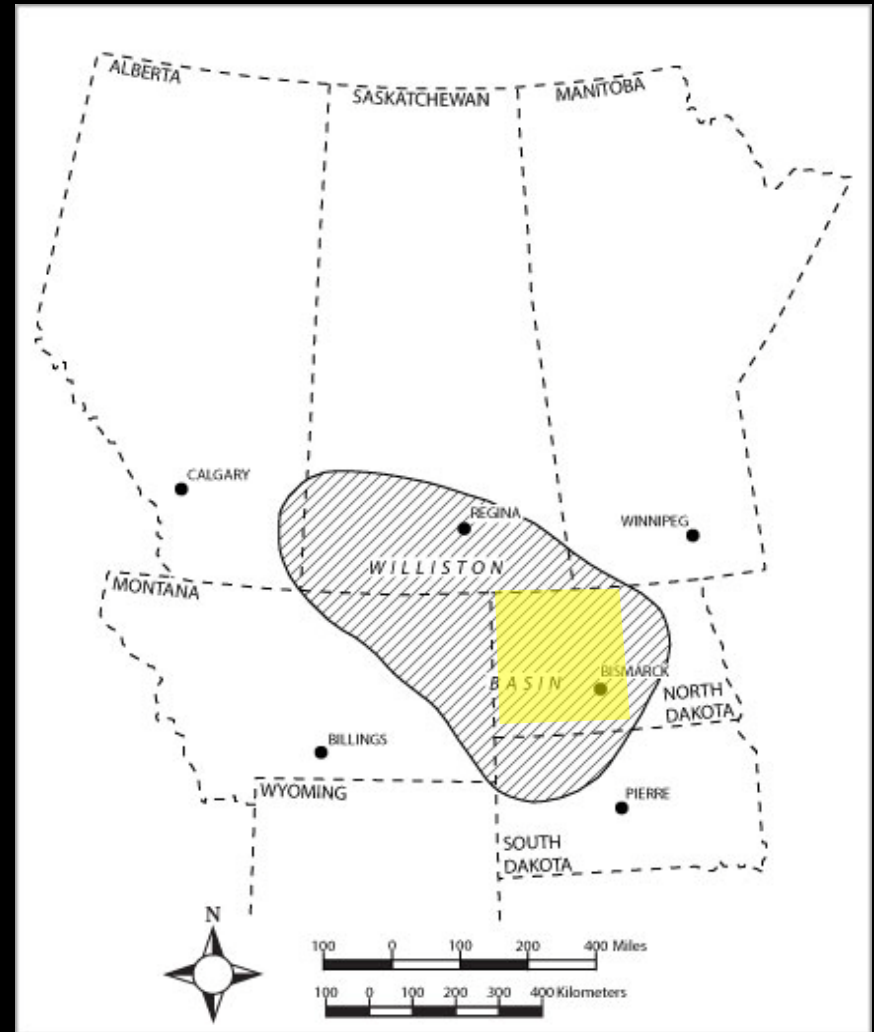
Many thanks to:



Pat Medlock, Brigham  
Ken Tompkins, Samson  
Rob Diedrich, St. Mary  
Julie LeFever, NDGS

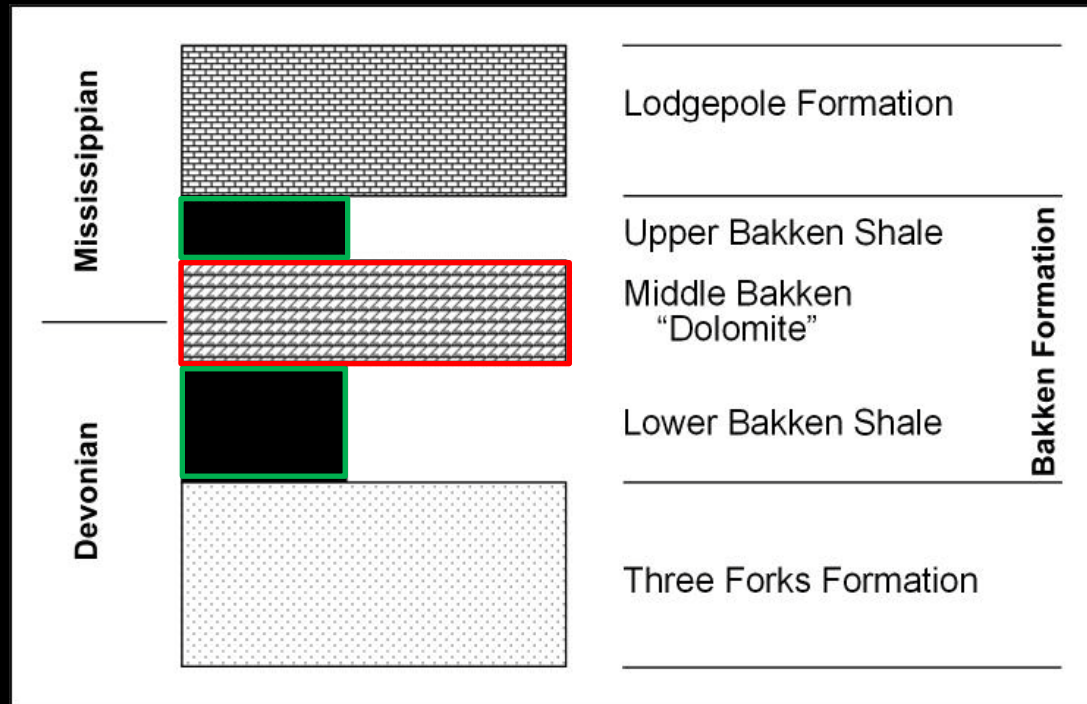
# Motivation

- Bakken Formation - important onshore US reservoir
- USGS estimate (2008): 3.65 billion barrels of undiscovered oil in the US



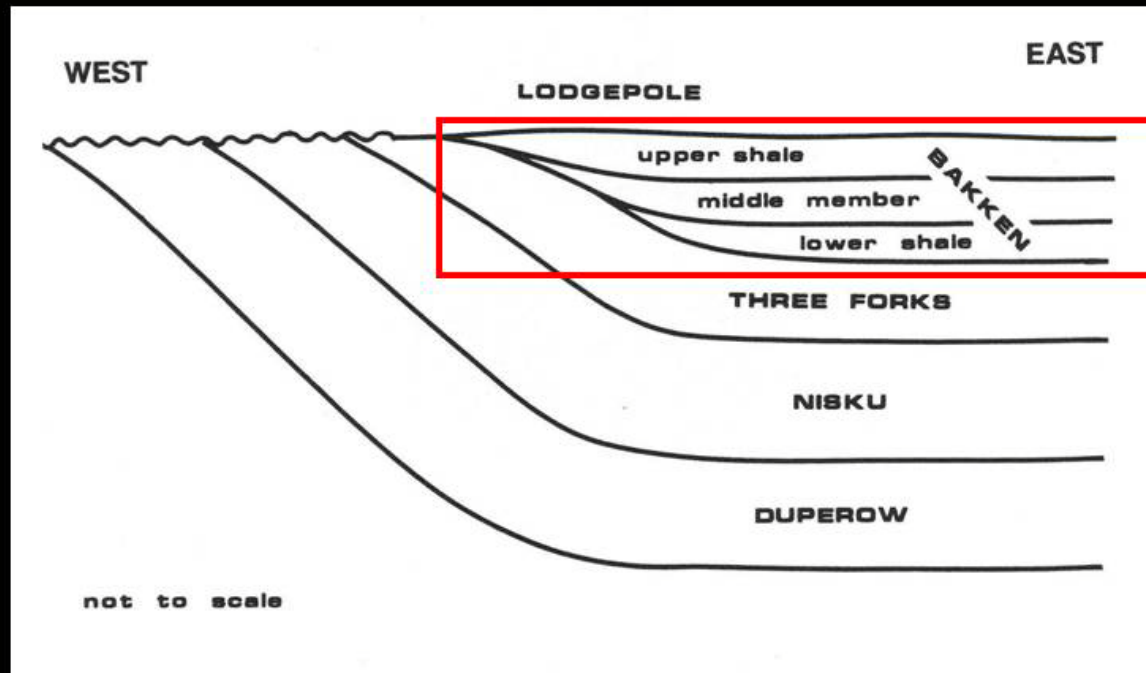
Modified from LeFever (1991)

# Motivation



- Devonian-Mississippian
- Main reservoir - focus of this talk
- Shales: source rocks = all oil originated there

# The Bakken Formation - classical subdivision

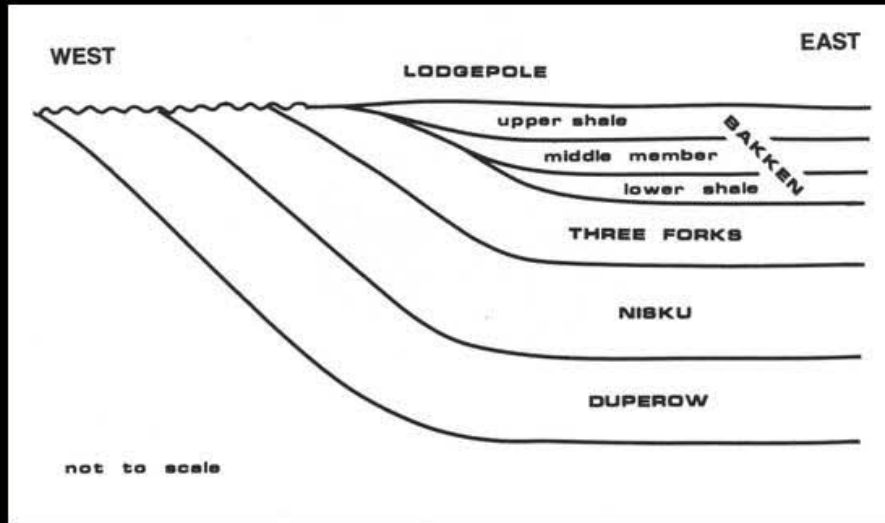


Sperr 1991

Notes by Presenter: We will change your view on this unit in only 10 minutes. It will transform from something completely static and unrealistic into something meaningful.



## Problem: layer-cake stratigraphy

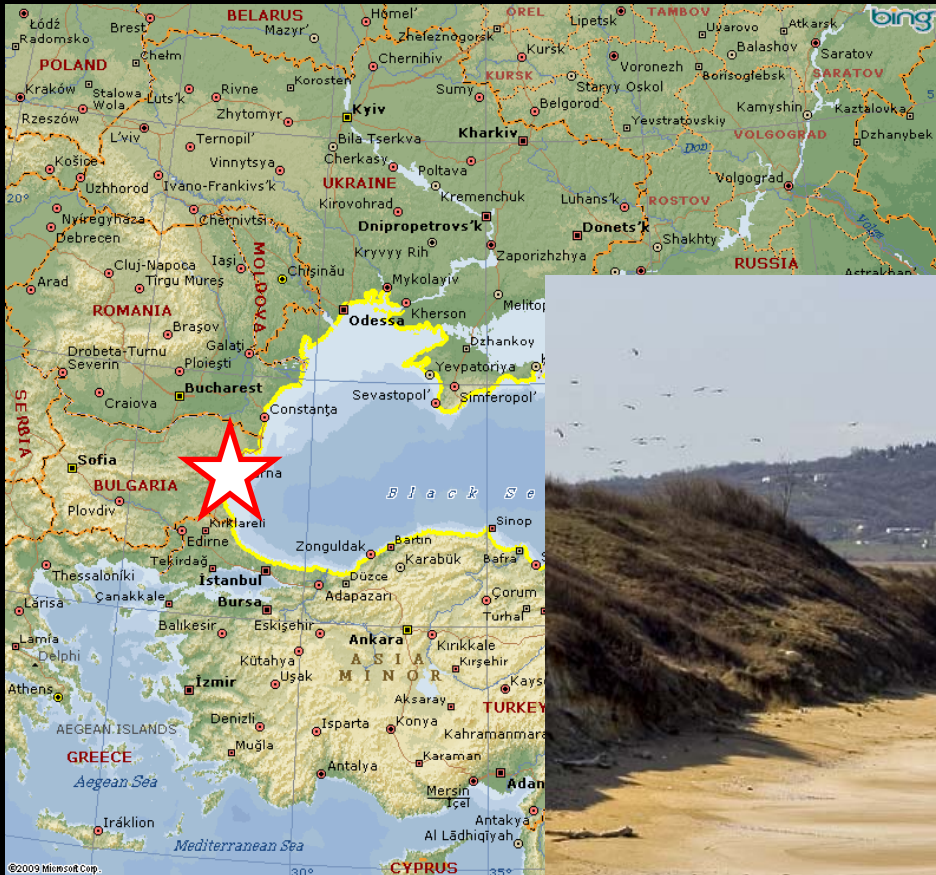


→ does not exist in natural systems

Notes by Presenter: We would not assume layer cake stratigraphy in any natural system.



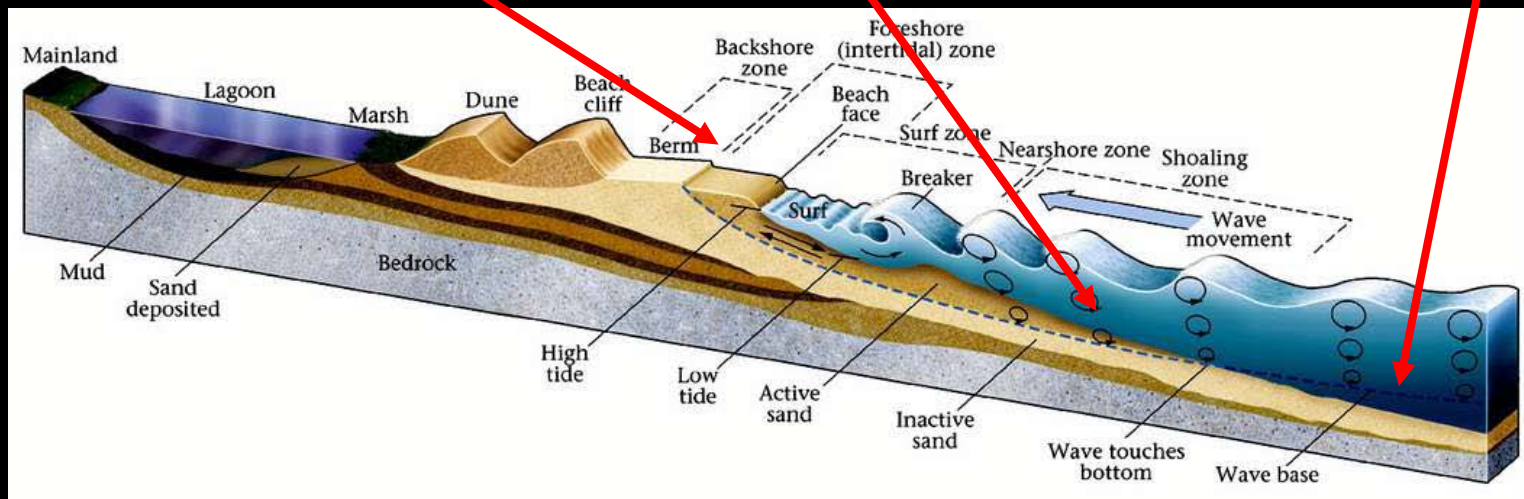
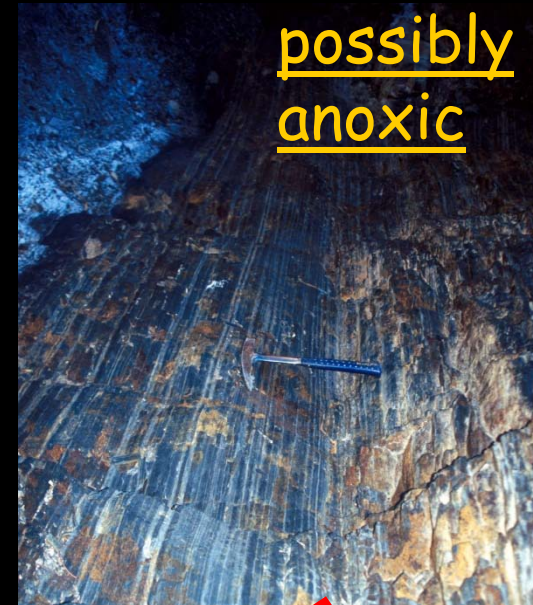
# Example Black Sea



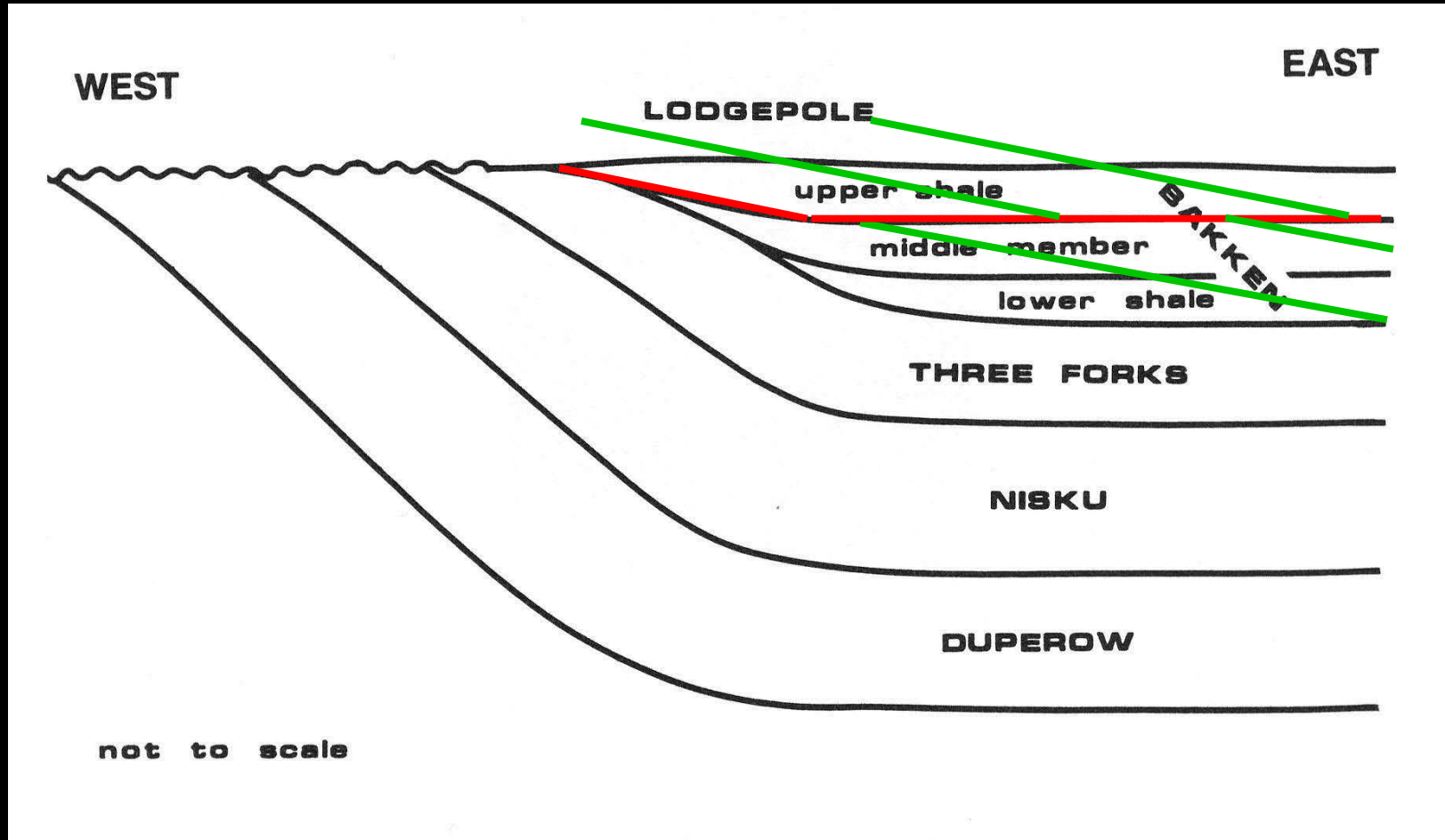
- 2248 m deep
- Anoxic basin



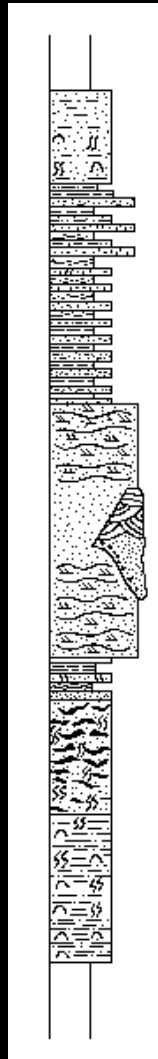
# What do natural systems deposit simultaneously?



# Application to the Bakken Formation



# Middle Bakken, the reservoir



*Upper Shale*

**Lithofacies 5 - Siltstone**

**Lithofacies 4 - Interbedded Dark Grey Shale  
and Buff Silty Sandstone**

**Lithofacies 3 - Sandstone**

*Productive*

**Lithofacies 2 - Interbedded Dark Grey Shale  
and Buff Silty Sandstone**

*Productive*

**Lithofacies 1 - Siltstone**

*Lower Shale*

*(From LeFever and others, 1991)*

Notes by Presenter (for previous slide):

There are five lithofacies within the middle member of the Bakken Formation that are correlative throughout North Dakota, Saskatchewan and Manitoba.

Briefly –

**Lithofacies 1** consists of light grey, greenish- grey, or brownish-grey argillaceous siltstone. It is generally massive, cemented with calcite, and has scattered pyrite nodules and fossils (crinoids and brachiopods). Locally the unit is burrowed. Porosity is intergranular.

**Lithofacies 2** consists of greenish-grey to brownish-grey, argillaceous siltstone or sandy siltstone to brownish-grey, very fine grained sandstone. Small scale clay drapes are present, as well as burrows. Productive

There are three parts to **Lithofacies 3**. The upper and lower third consists of wavy to flaser bedded, light to medium grey, argillaceous to sandy siltstones and brownish-grey, very fine-grained sandstones with local claystones. The middle third consists of a medium grey, dark grey, or greyish-tan, fine- to medium-grained sandstone that may be massive, cross-bedded, or thinly laminated. Productive

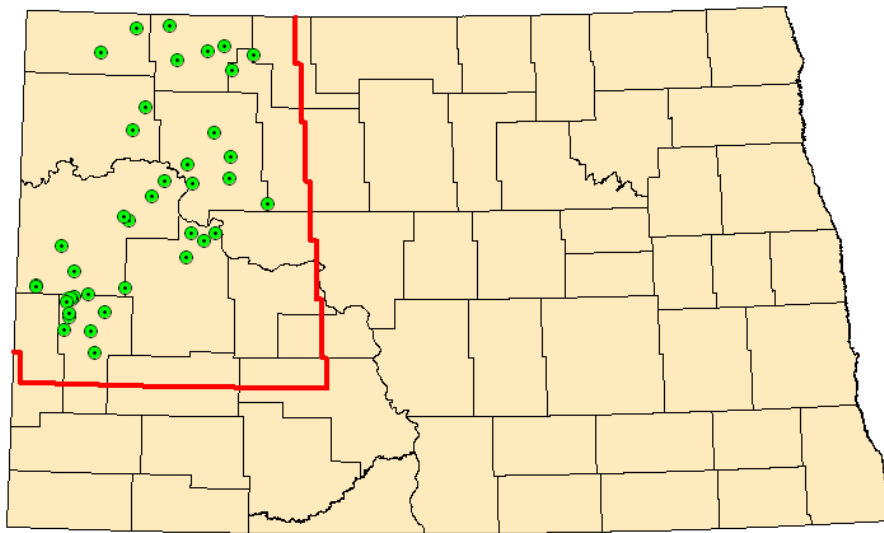
**Lithofacies 4** consists of alternating medium grey argillaceous siltstones, light to medium grey very fine-grained sandstones and dark grey shale. The unit is thinly laminated, display planar and cross-ripple laminations, moderately bioturbated in places, and locally cemented.

**Lithofacies 5** is a medium to light grey, massive to wispy laminated siltstone that is generally cemented.

# Middle Bakken sedimentology and stratigraphy

- 40 cores
- 11 facies, silt-dominated
- Mixed carbonate-siliciclastic system

Cores Examined and Well-Log Coverage



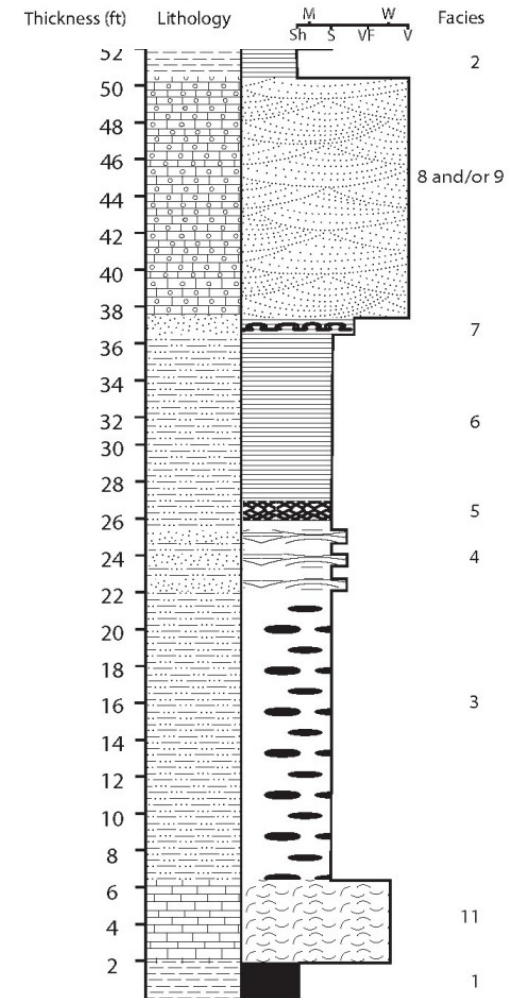
- Cores Examined
- County Boundaries
- Well-log Coverage



0 25 50 100 Miles

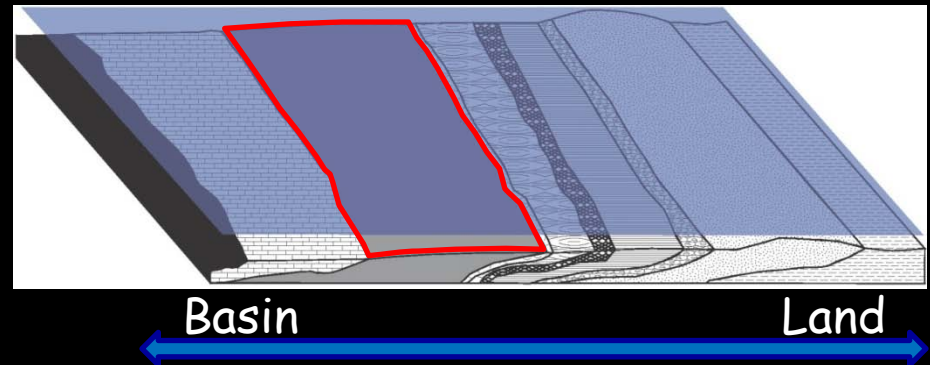
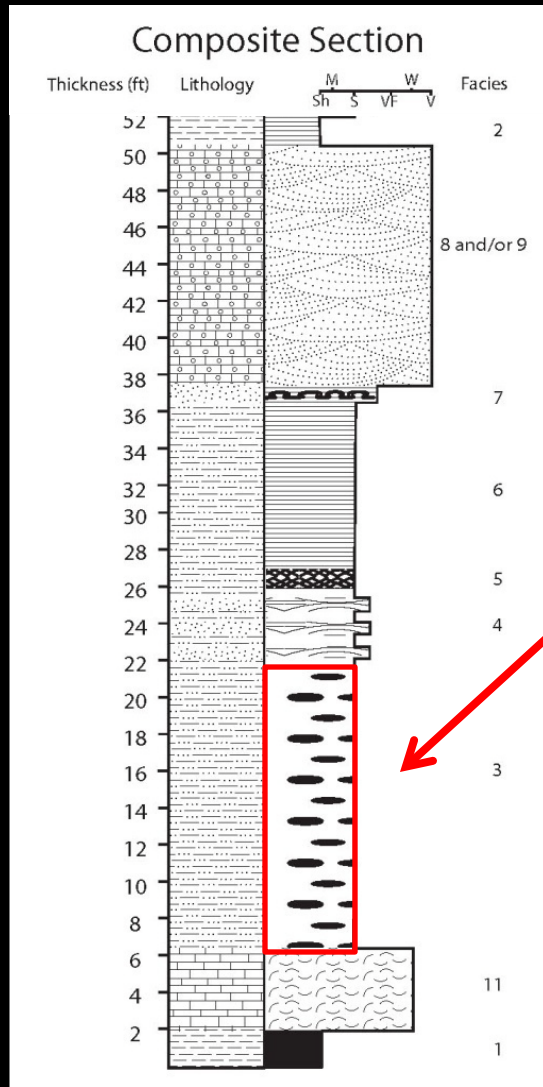
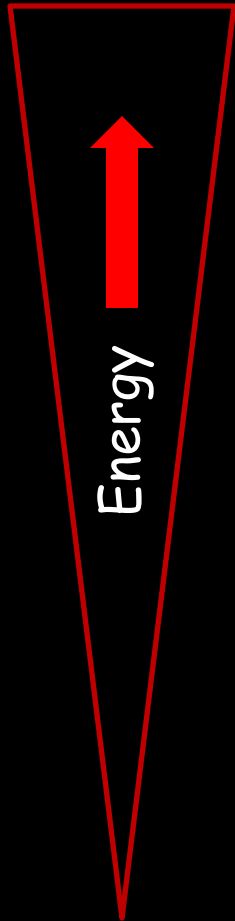
Energy

Composite Section



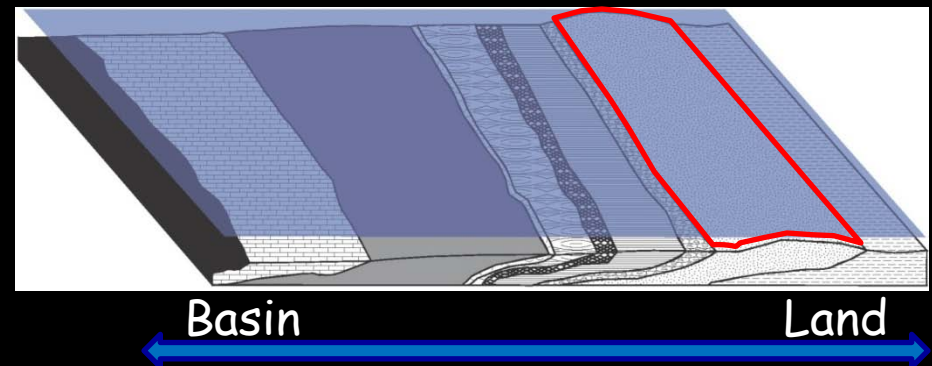
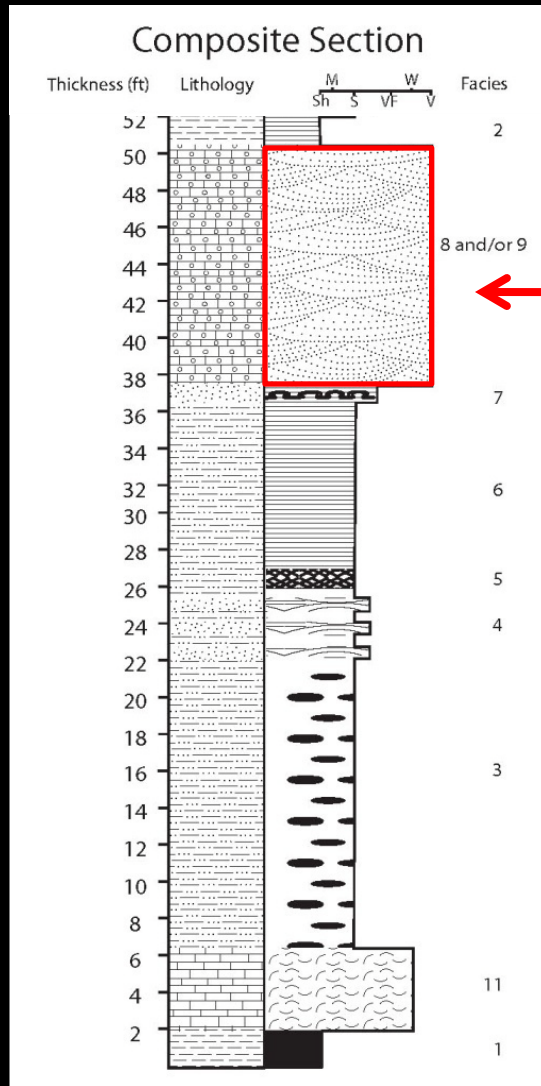
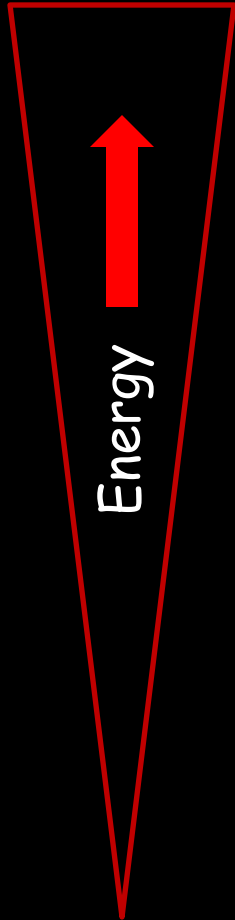


# Helminthopsis siltstones

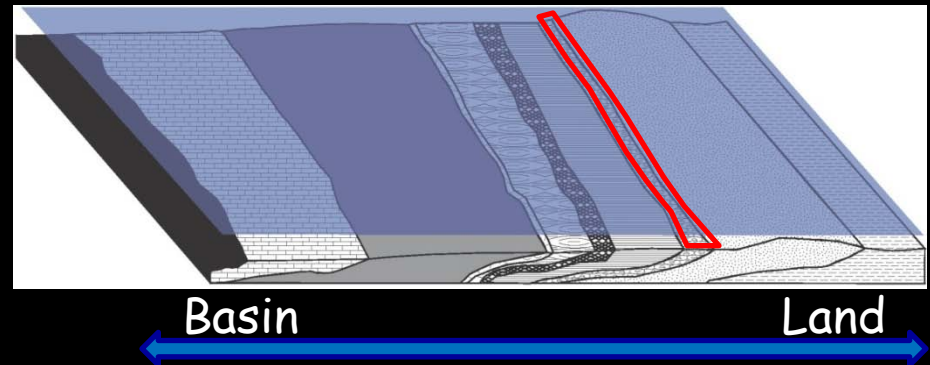
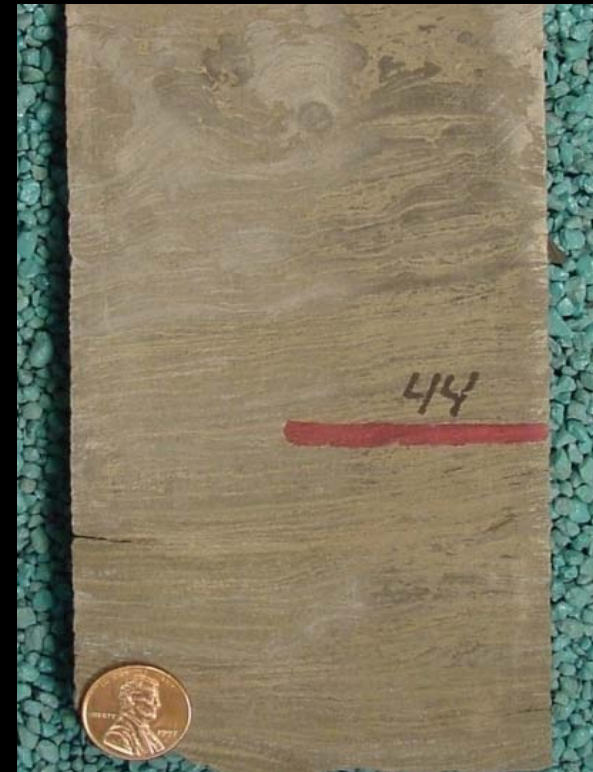
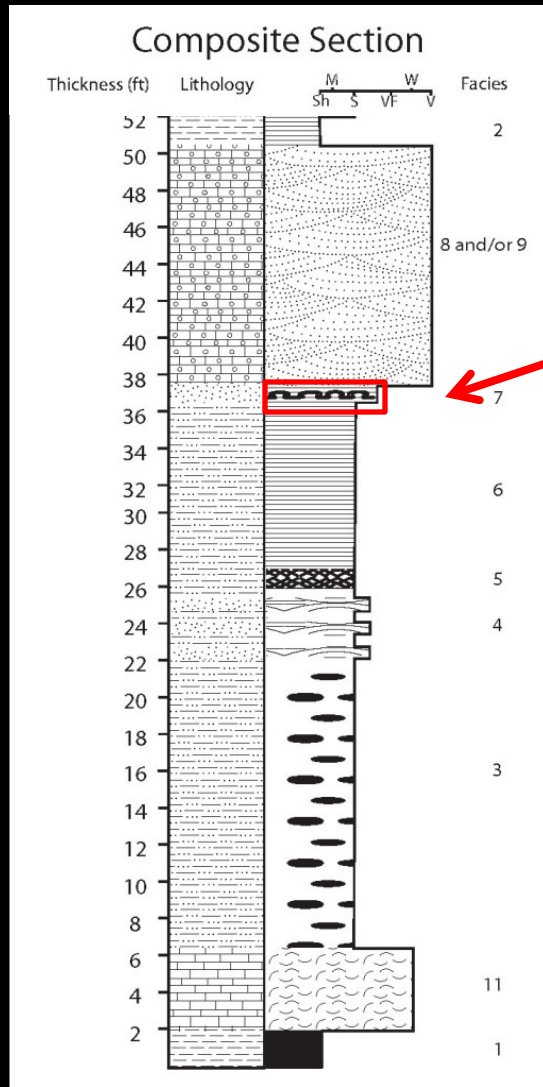
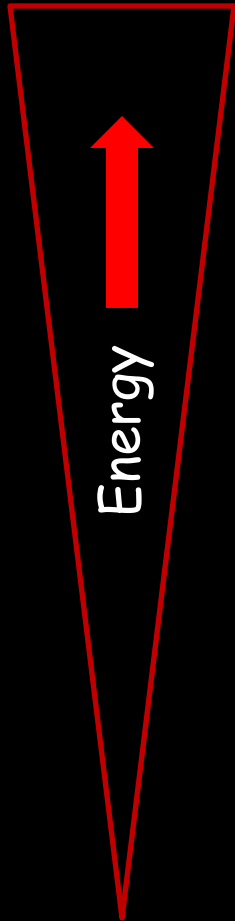




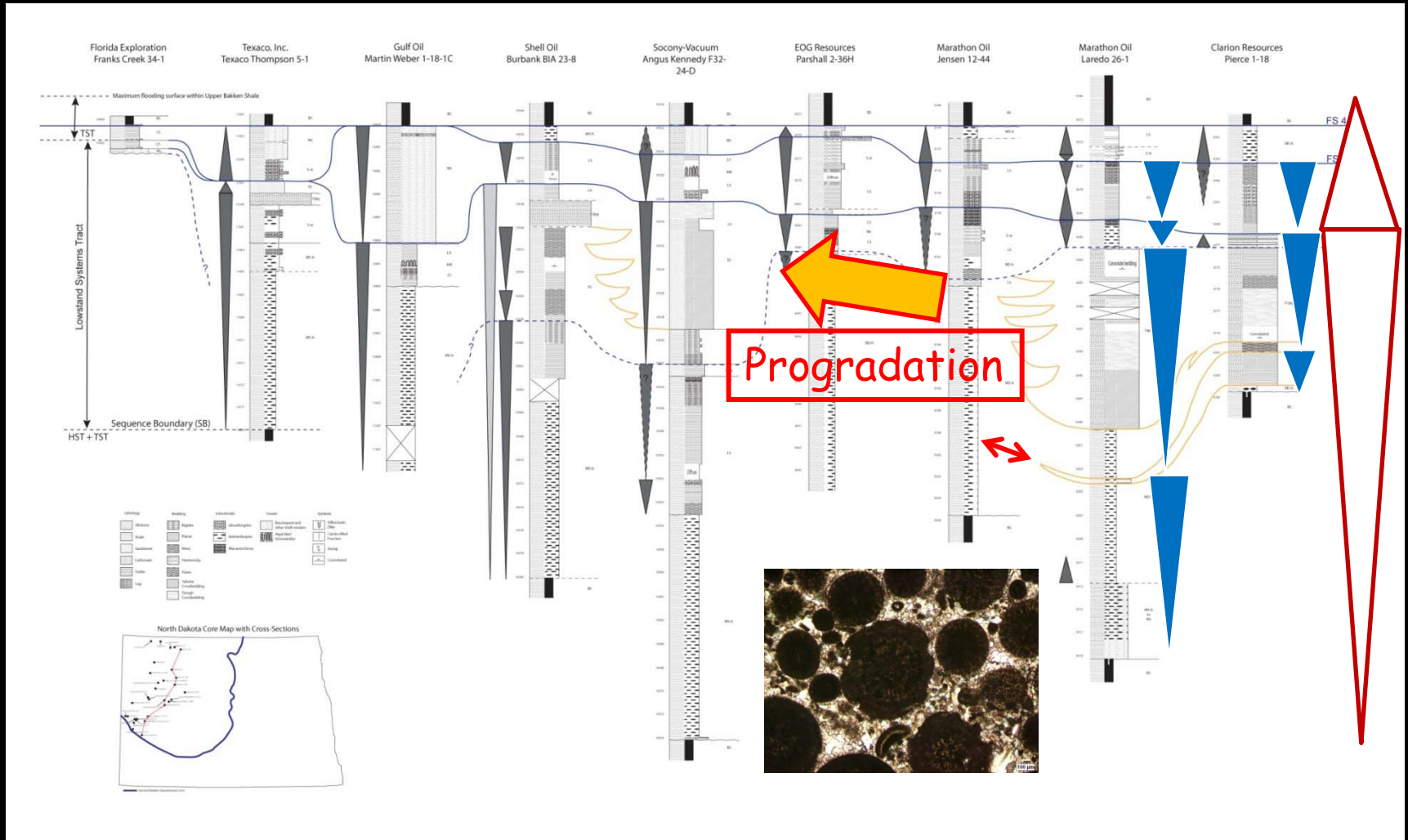
# Oolitic sandstones



# Carbonates

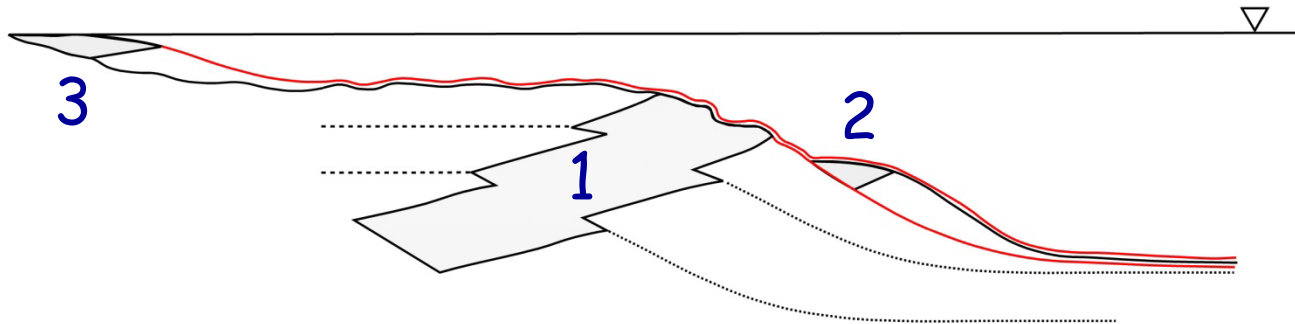


- Main "conventional" reservoir in Middle Bakken: oolites
- Small-scale facies trends - arrangement in parasequences
- Large-scale facies trend



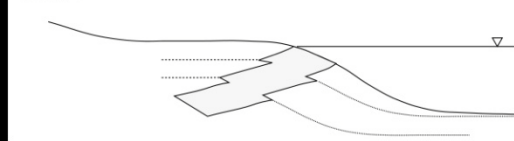
# How would facies belts move through time responding to sea-level changes?

Time 3

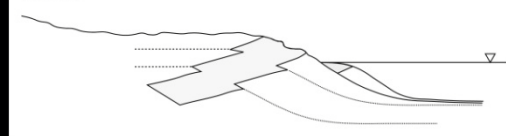


- Sea-level fall and subsequent rise
- Three oolite bodies disconnected from each other

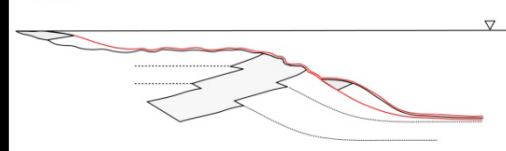
Time 1



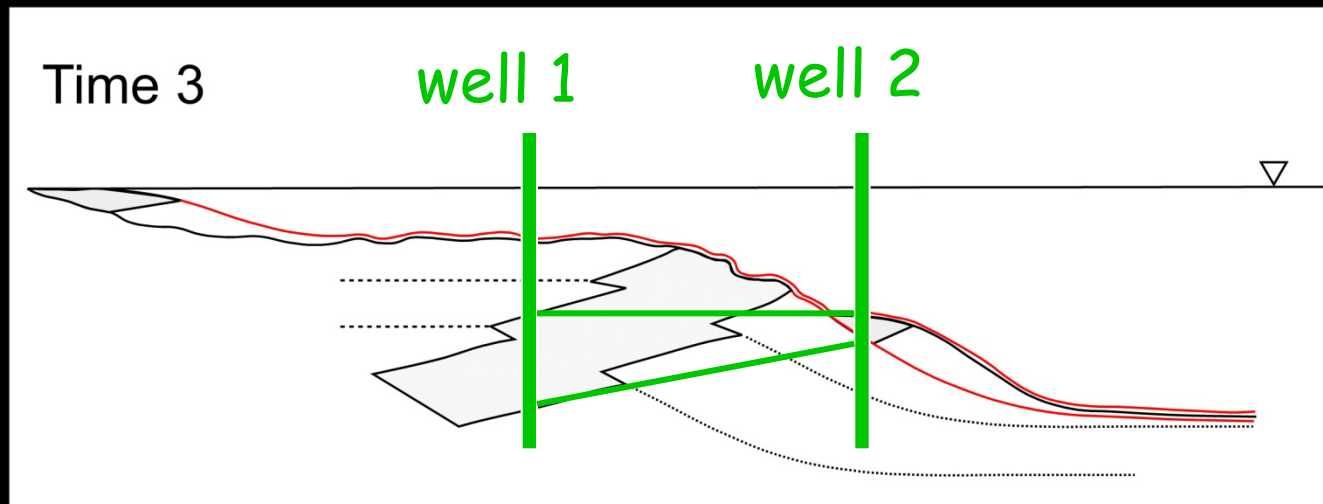
Time 2



Time 3



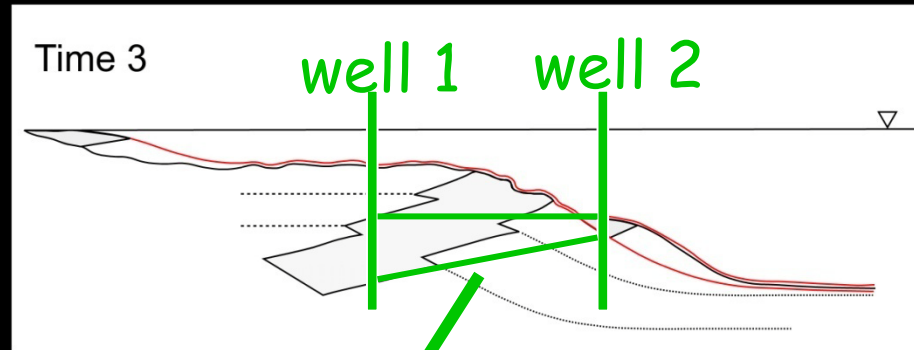
# Correlation of sand bodies ignoring timelines



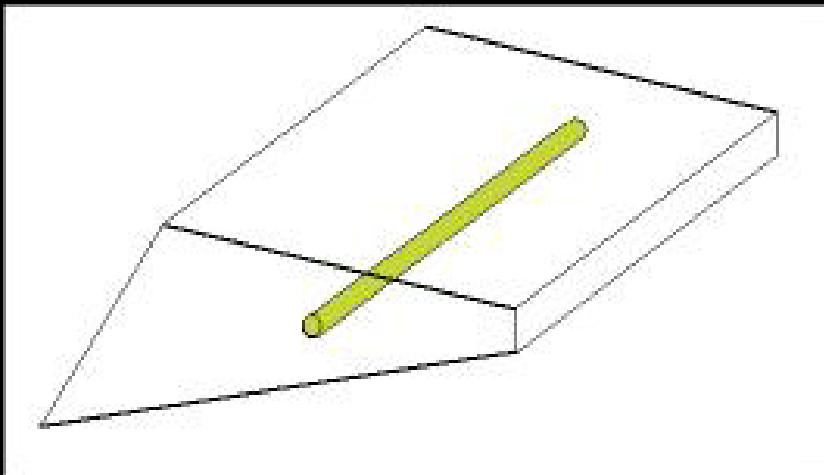
- Two wells hitting sandbodies
- Correlation using lithostratigraphy cannot predict reservoir compartmentalization
- Unsuitable approach to calculate reservoir volume



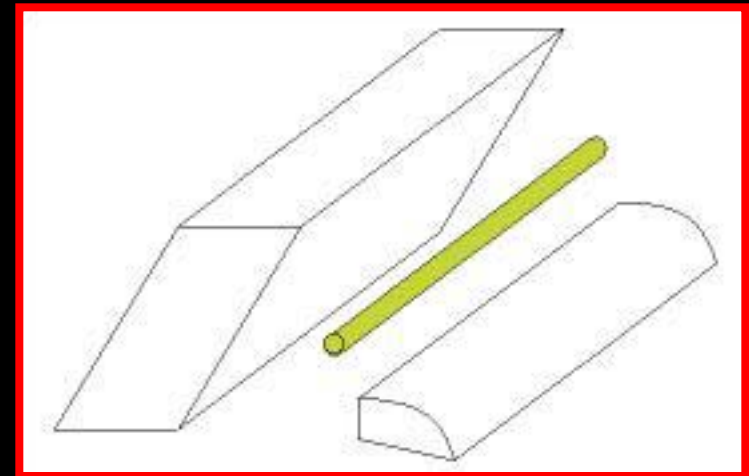
# Drilling of lateral wells based on lithostratigraphy



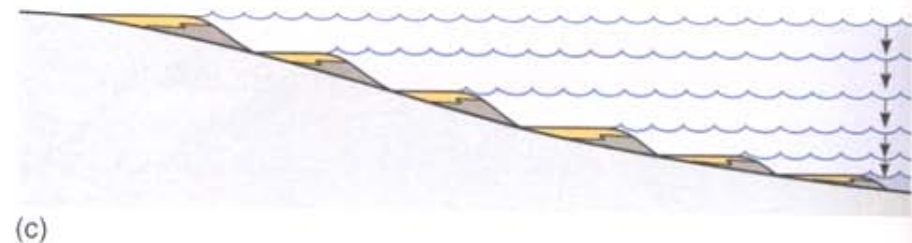
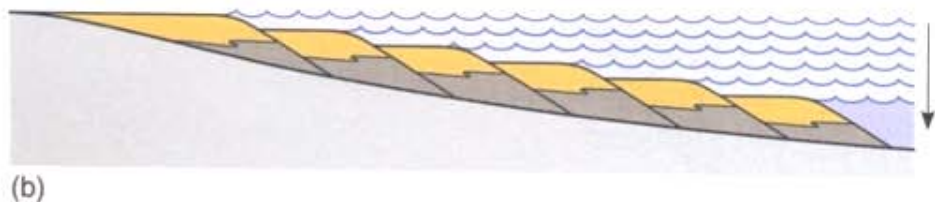
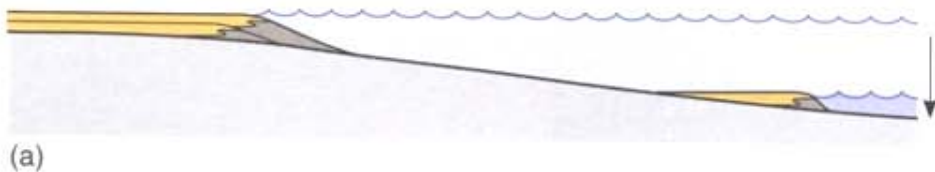
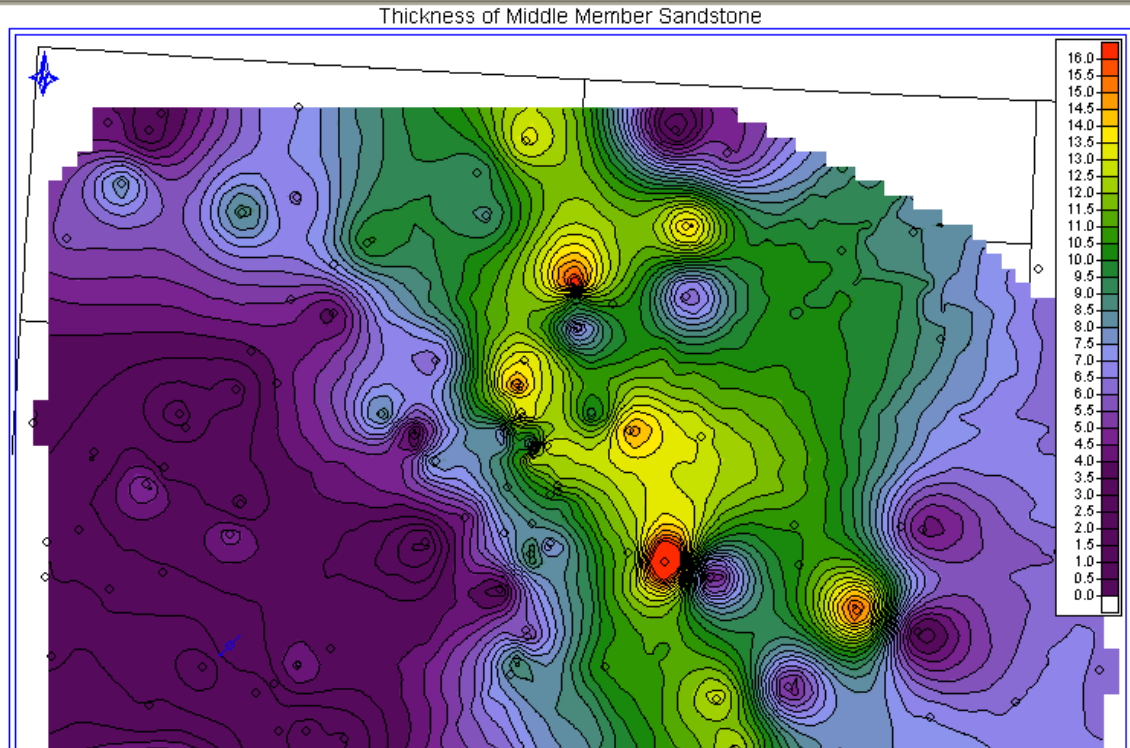
Predicted reservoir geometry



Real reservoir geometry



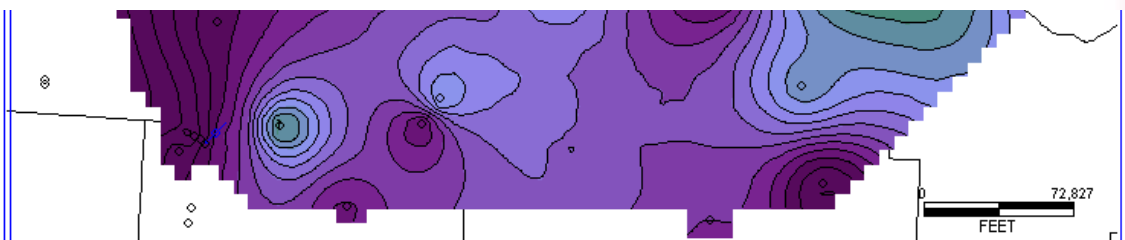
# Oolite distribution



- Cores Examined
- County Boundaries
- Well-log Coverage



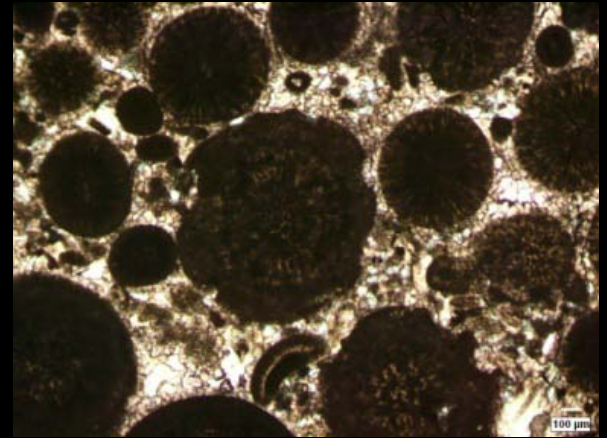
0 25 50 100 Miles





# Conclusions

- Bakken Formation not layer-cake
- Middle Bakken: 11 facies, carbonate-siliciclastic system
- Reservoir compartmentalized - 4 parasequences





Thank you!

