The Playa Lake Depositional Model for the Three Forks Formation*

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Search and Discovery Article #51278 (2016)**
Posted August 15, 2016

*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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Abstract

The Late Devonian Three Forks Formation of the Williston Basin is an important unit in the Bakken petroleum system, with estimates suggesting more than 3.7 billion barrels of recoverable oil. We propose that this formation was deposited in a continental environment with little to no marine influence, in contrast with widespread models that invoke restricted shallow marine, coastal sabkha or tidal flat environments. Our model allows us to explore stratigraphic controls on the distribution of hypersalinity and sour gas in the basin, as well as the vertical and lateral variability of reservoir quality in terms of petrophysical and geomechanical properties. The Devonian was a predominantly warm and arid period, with the Williston Basin located in ever so more arid equatorial position and affected by periods of marine restriction and complete isolation from the ocean. This resulted in the accumulation of a complex mosaic of silt-sized dolomite and quartz, clay and evaporite lithologies and a series of bull's-eye isopach configurations. Based on stratigraphic, sedimentological, and petrographical analyses of 28 core, we conclude the Three Forks Formation was deposited in subaerial and subaqueous environments, without tidal or marine influence, that are comparable to those found in playa lake or continental sabkha environments. This isolated and dry environment was sporadically affected by large floods that covered the basin terrigenous sediment, debrite-like deposits with intraclasts, scour and erosion surfaces. Floods were followed by a drying period when the deposition of the mineral sequence dolomite-anhydrite-halite in ponds distributed across the basin surface. The drying period is recorded by subaqueous dolomites to subaerially-exposed and transported sediments with ripples, dewatering structures, scour surfaces, evaporite cemented surfaces, evaporite-removal breccias, halite pseudomorphs, cracks, etc. The vertical succession records an upward trend of increasing proportions of subaqueous facies, indicating a transition from arid to relatively less arid climatic conditions during Three Forks deposition.

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Playa Lake Depositional Model for the Three Forks Formation

Beatriz Garcia-Fresca - Research & Technology
Daniel Pinkston - Development & Production USA

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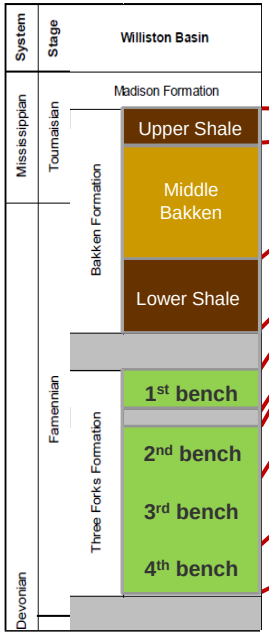
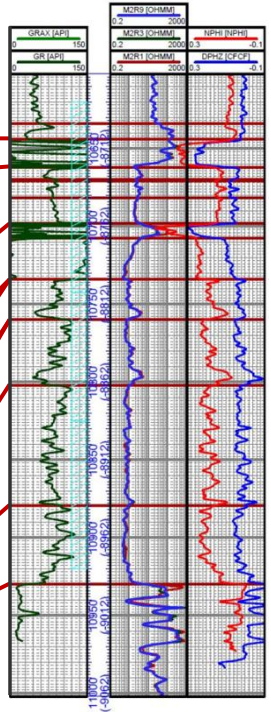
Bakken/Three Forks Petroleum System

Chronostratigraphy

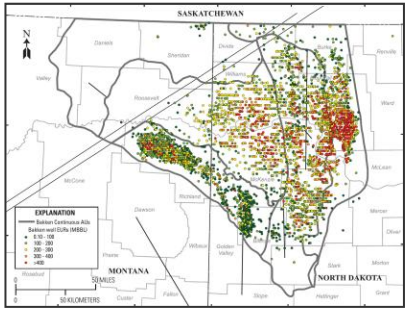


Modified from Franklin 2014

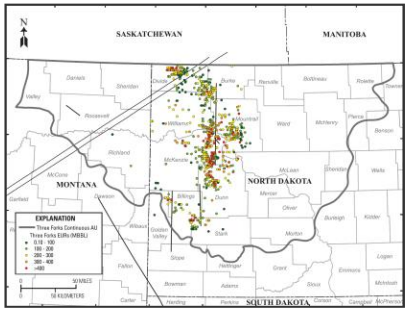
Type Logs



USGS Estim Recoverable



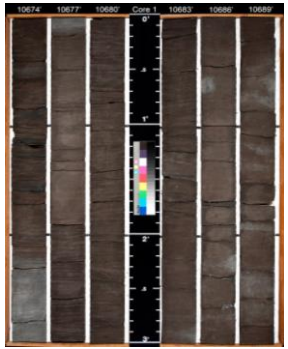
3.65 Billion BBL

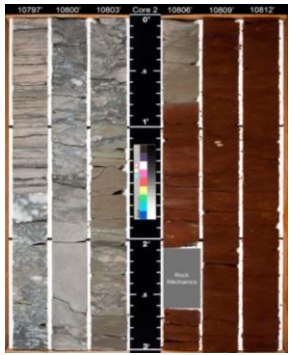


3.73 Billion BBL

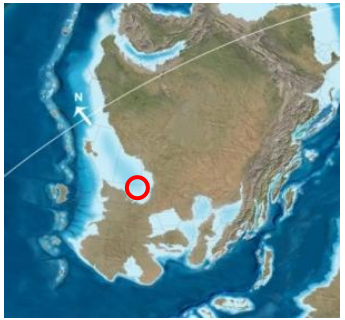
Gaswirth & Marra 2015

Core





Paleogeography



Middle Bakken

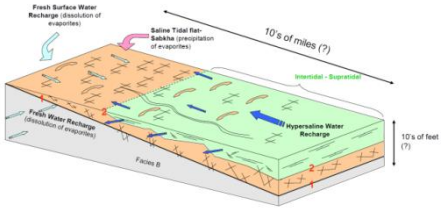
Three Forks

Modified from
http://cpgeosystems.com/nam.html

Statoil

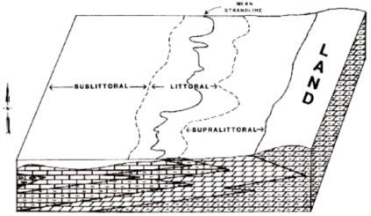
Previous interpretations

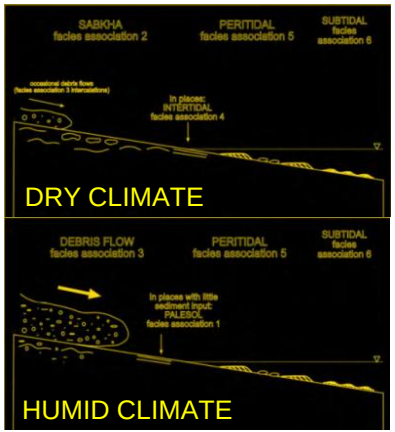
- Christopher (1961, 1963)
  - Broad, gently sloping coastal shelf
  - Arid, low relief, far from sediment sources
  - **Long exposure periods**
  - Submarine ridges acted as sediment dams
  - **Vigorous wave action** occasionally stirred the sea bottom
- Bottjer et al. (2011) as a shallowing-upward succession of tide-dominated nearshore facies ranging from subtidal sand flats to intertidal mudflats
- Egenhoff et al. (2011): intertidal, peritidal, and subtidal environments; **terrestrial paleosols**, sabkha, **subaerial gravity flows**, algal mats; controlled by sea-level changes and **climatic shifts**
- Franklin (2014, unpublished PhD) shallow shelf (schizohaline, storm-dominated or arid) and mudflats. Recognized **allogenic controls** in the stratigraphy, decreasing aridity and evidence of **fluvial inputs**; ascribed transgressive-regressive cycles to global eustatic trends



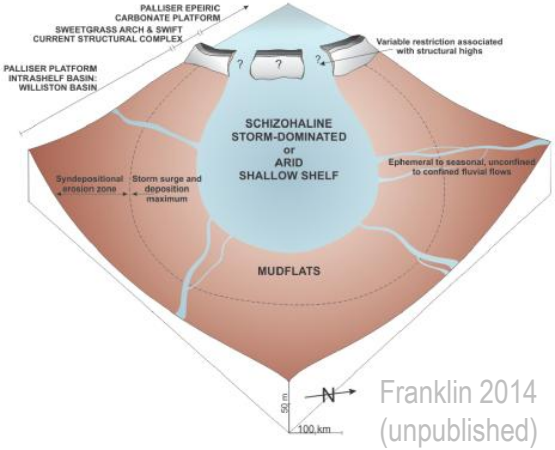
Berwick 2008 (unpublished)

Dumonceaux 1984 (unpublished)





Egenhoff et al 2011

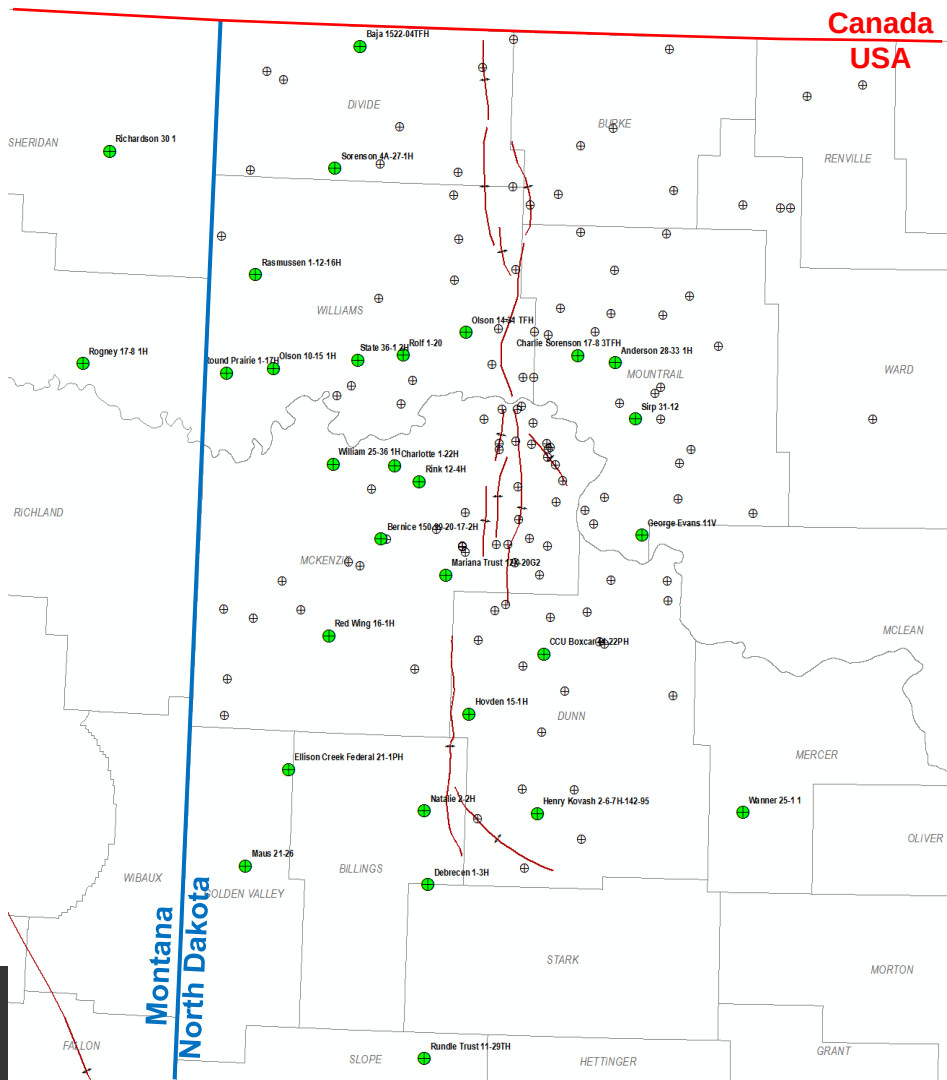


Franklin 2014 (unpublished)

Statoil

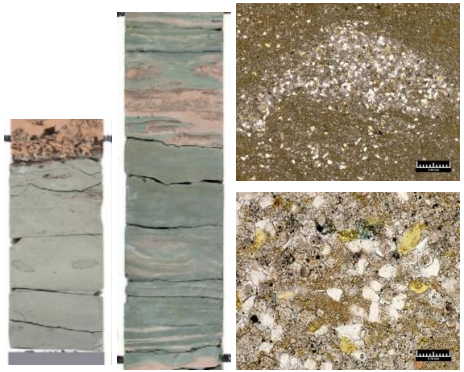
Three Forks core

- 29 core inspected in 2015
- 3500+ ft of core logged

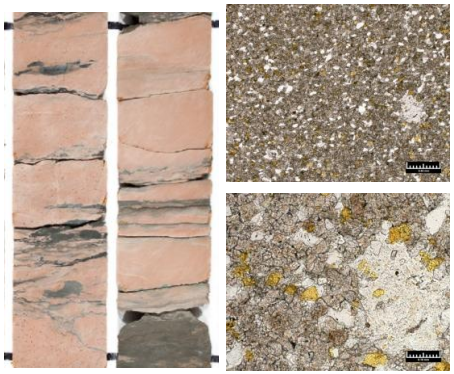


Three Forks depositional rock types

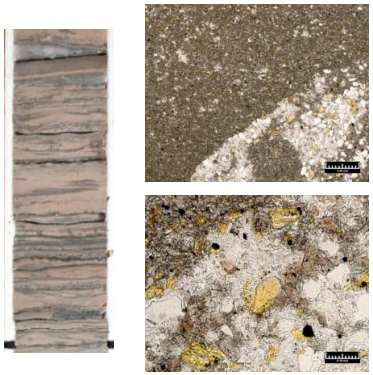
Green Mudstone



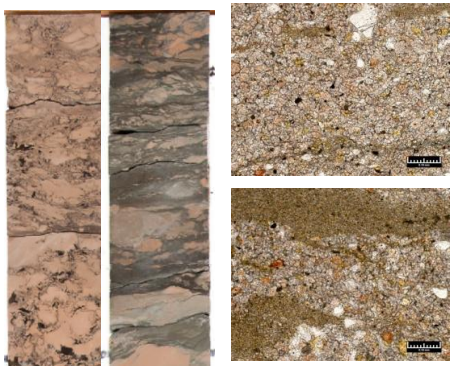
Dolostone



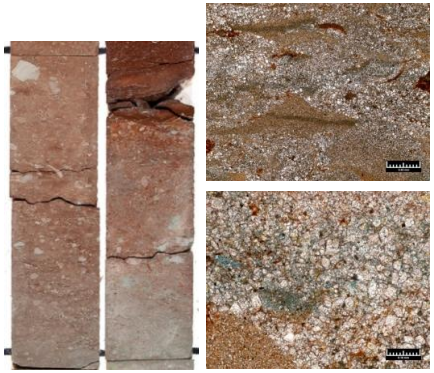
Laminated Siltstone/ Mudstone



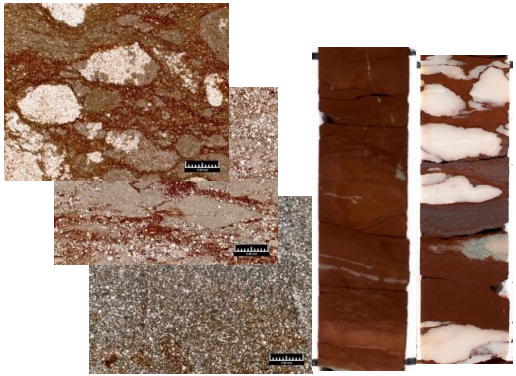
Distorted & Brecciated Dolostone



Matrix-supported Breccia



Red Mudstone



Statoil

Playa-lake depositional environment

MODERN (Hardie et al. 1978)

1. Alluvial fan
2. Sandflat
3. Mudflat
4. Ephemeral saline lake
5. Perennial saline lake
6. Dune field
7. Perennial stream floodplain
8. Ephemeral stream floodplain
9. Springs
10. Shoreline features

ANCIENT (Eugster & Hardie 1975)

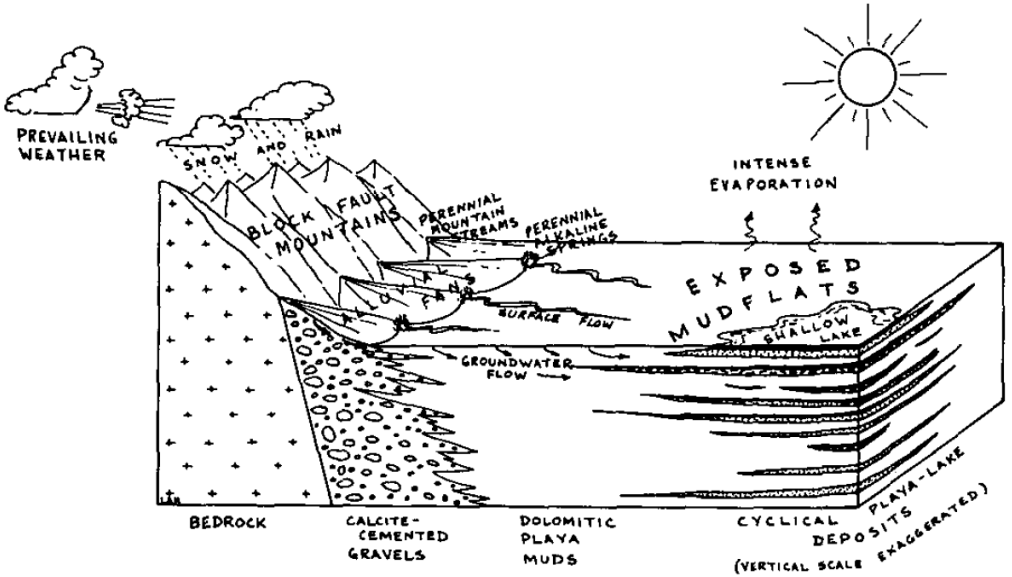


Figure 19. Schematic block-diagram showing general depositional framework envisaged for Wilkins Peak Member. Eocene Green River Fm

Statoil

Playa-lake depositional environment

Hardie et al. 1978

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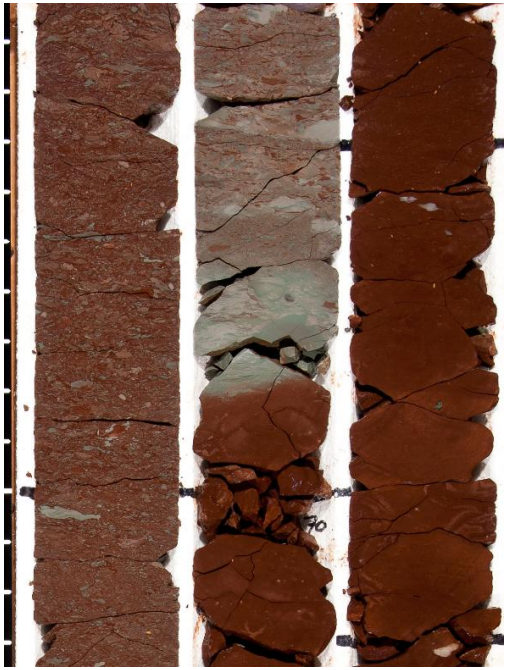

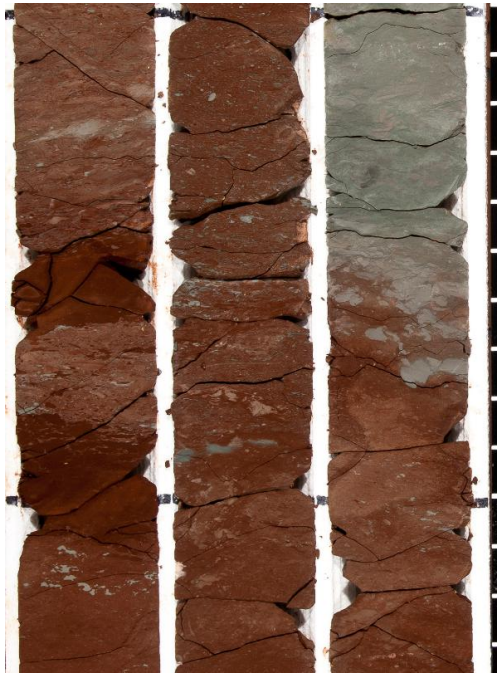

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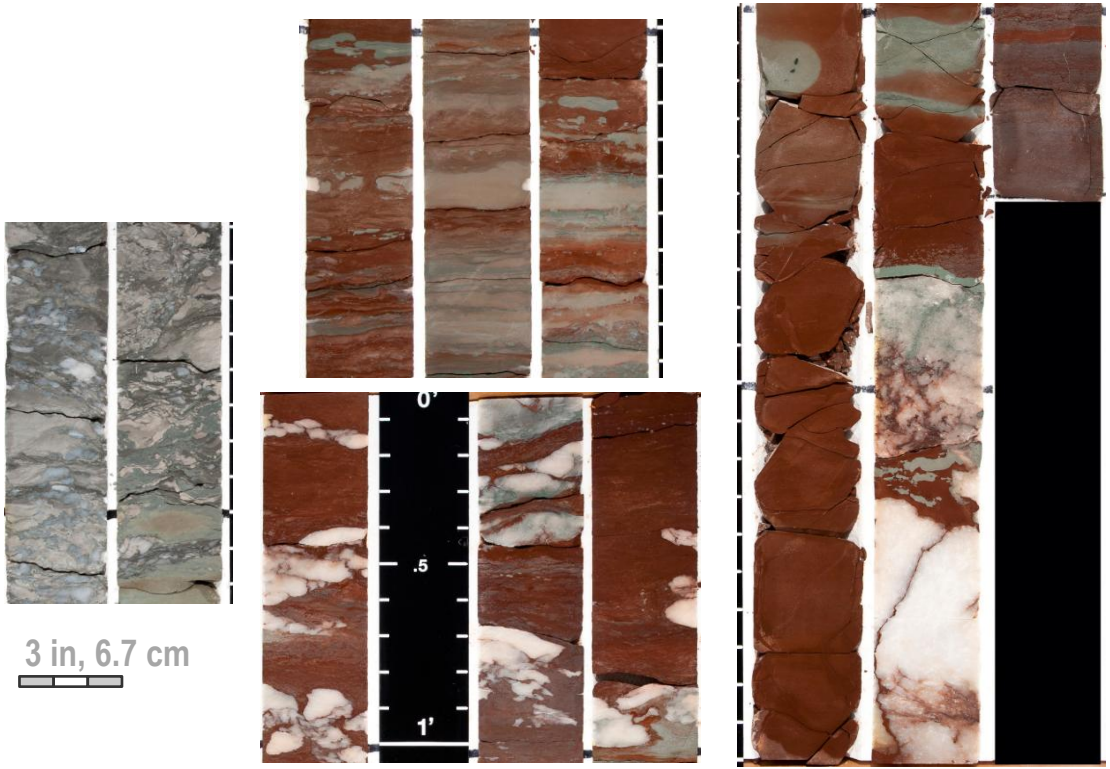

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Playa-lake depositional environment

Hardie et al. 1978

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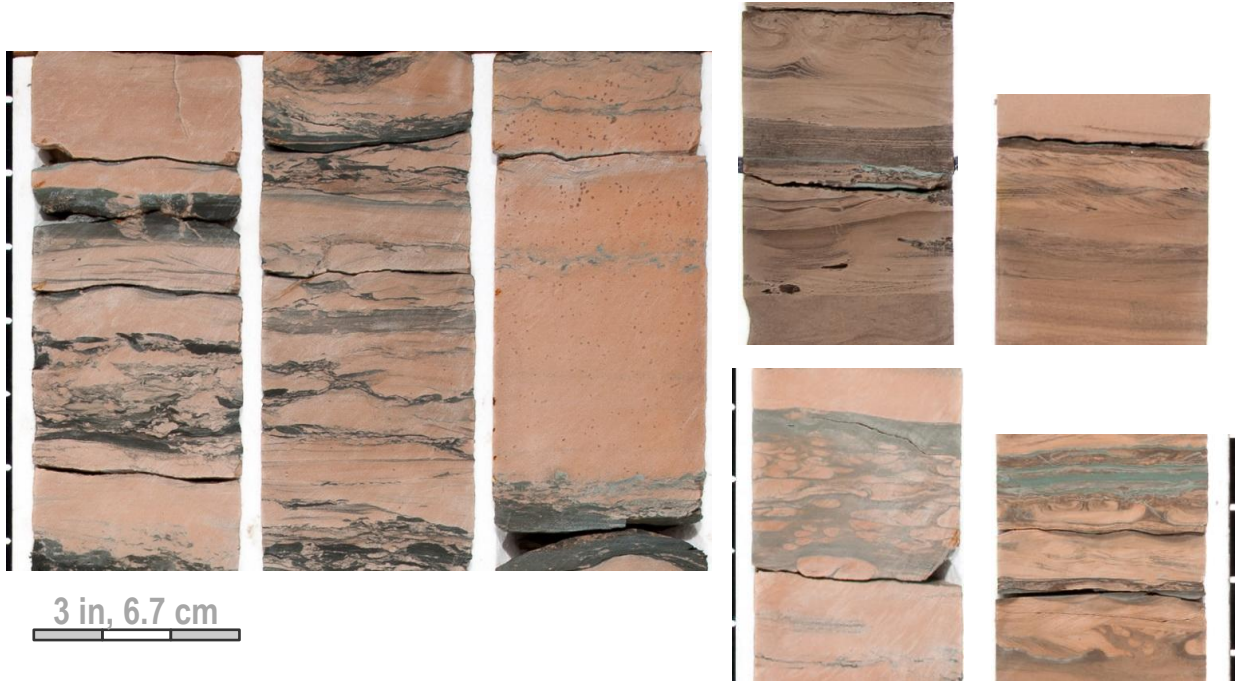

Statoil

Playa-lake depositional environment

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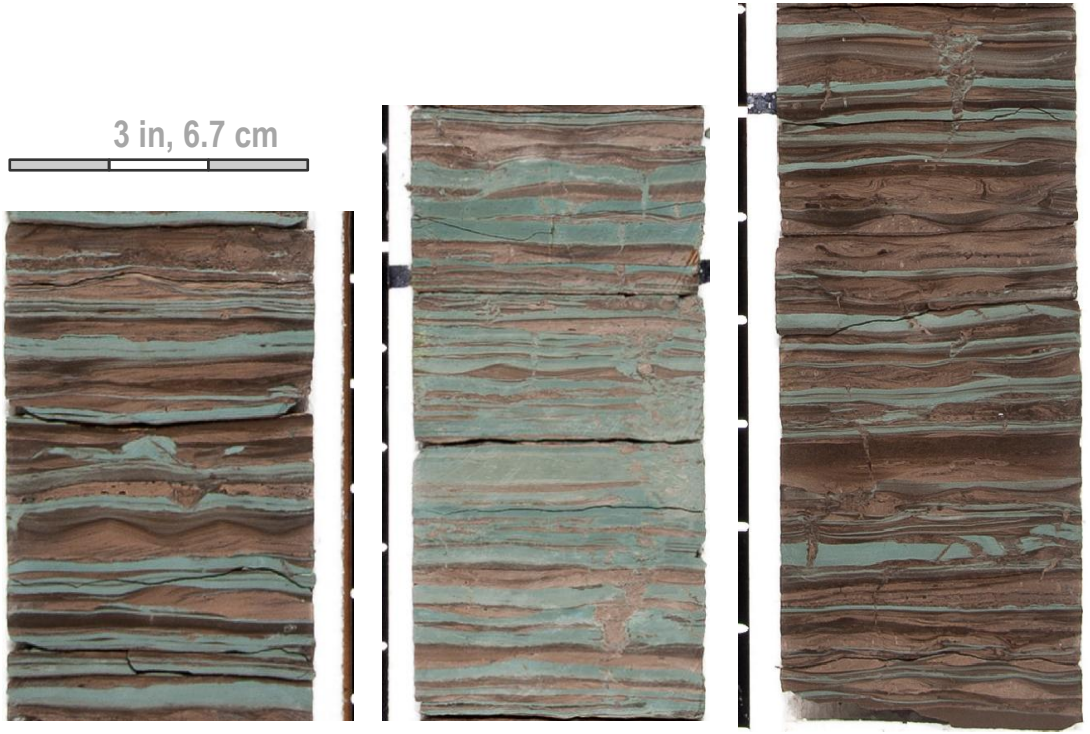

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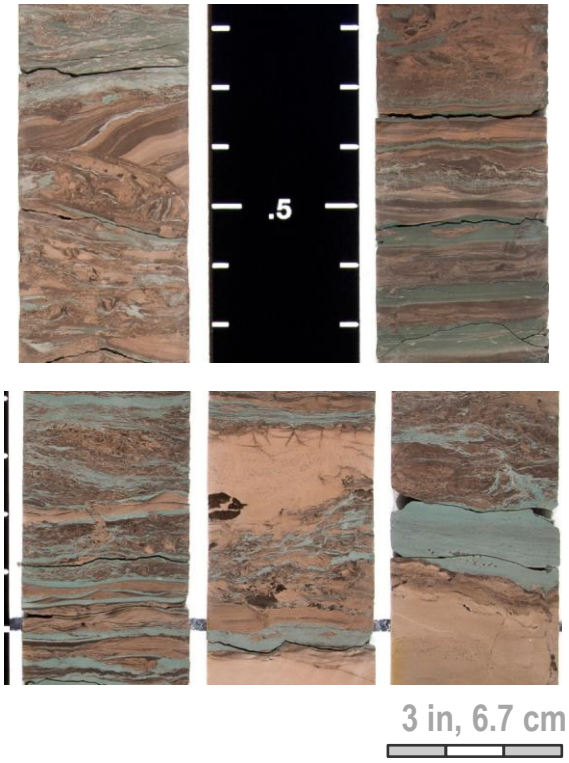
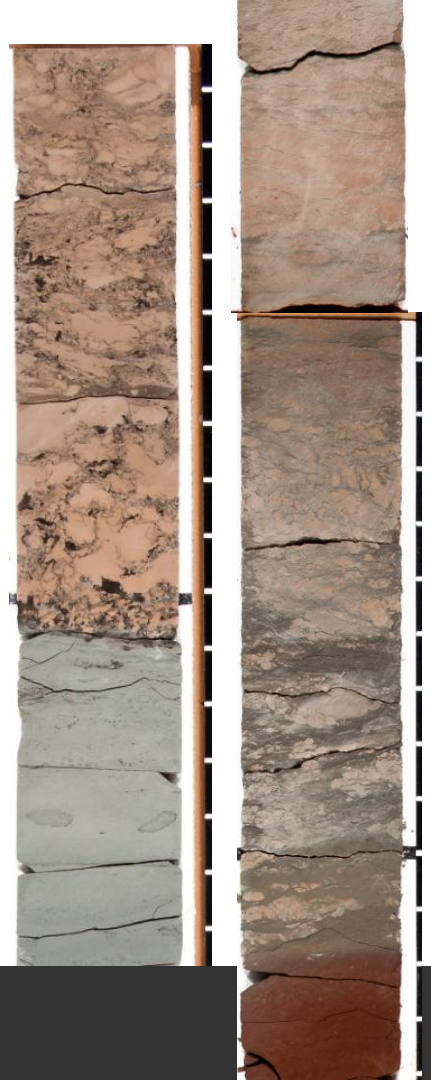
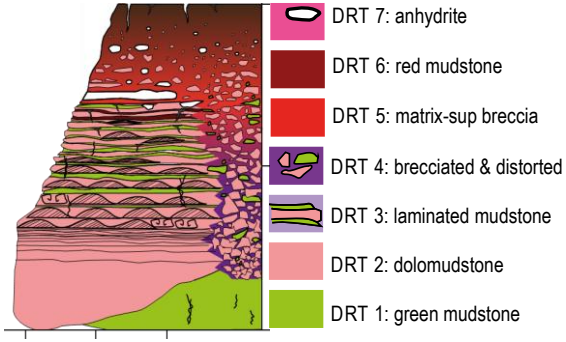
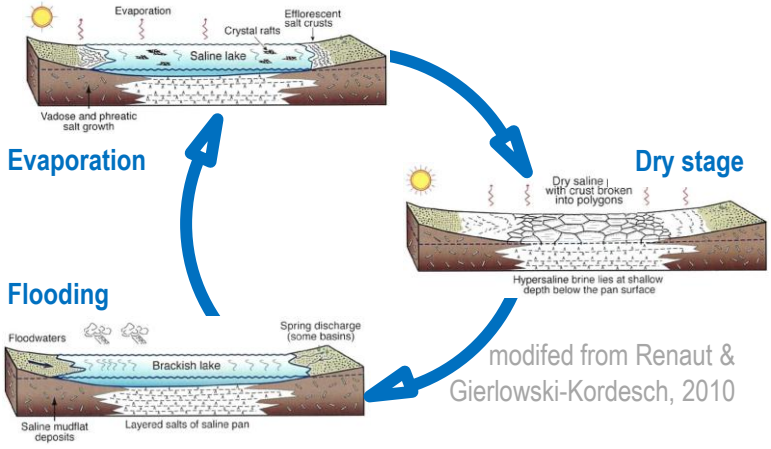


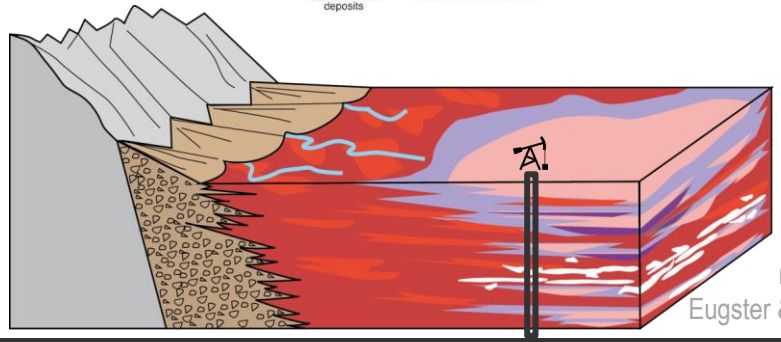


Three Forks playa-lake model

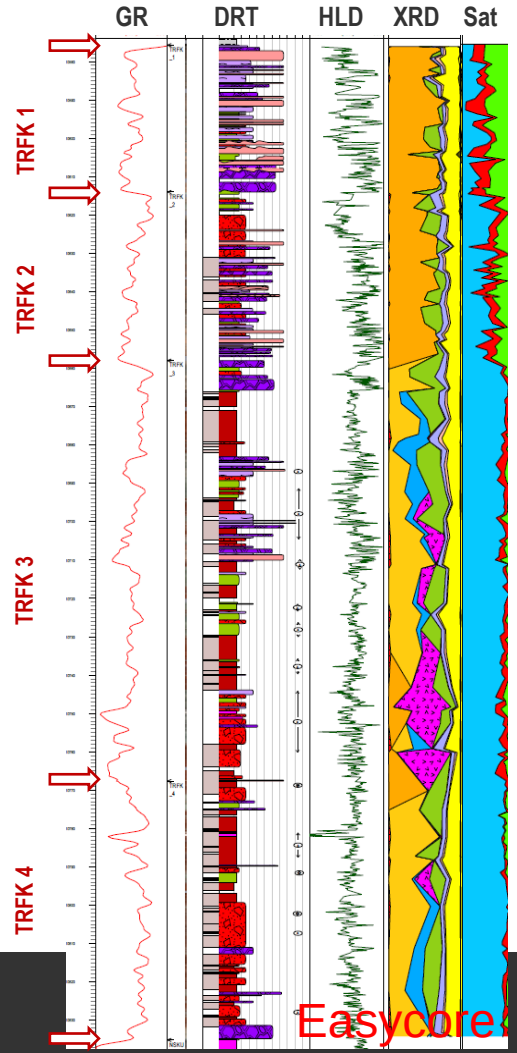




modifed from Renaut & Gierlowski-Kordesch, 2010



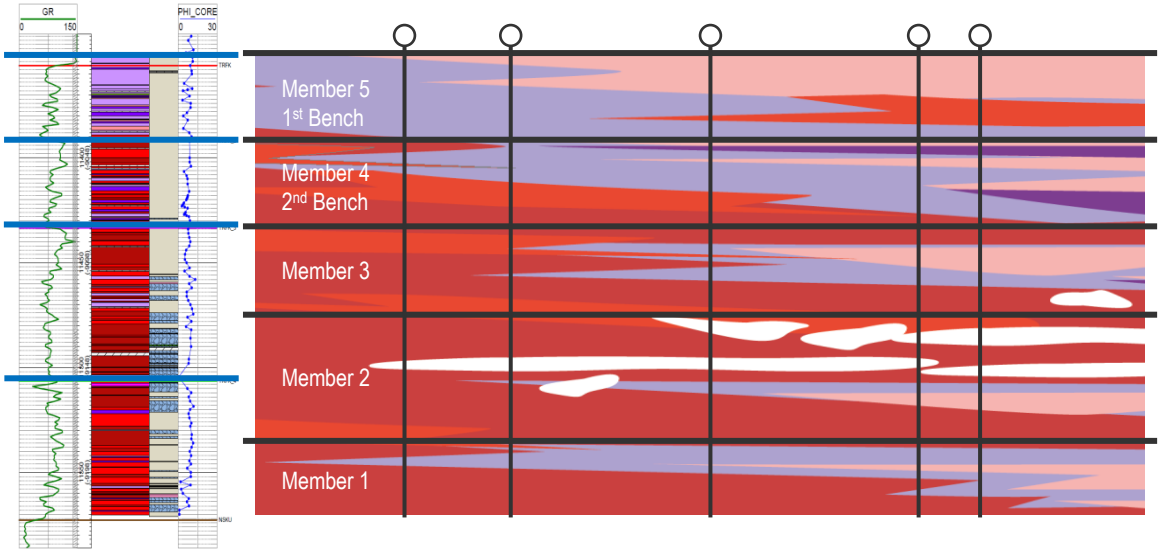
modified from Eugster & Hardie 1975



Garcia-Fresca, Pinkston & Loucks, in review

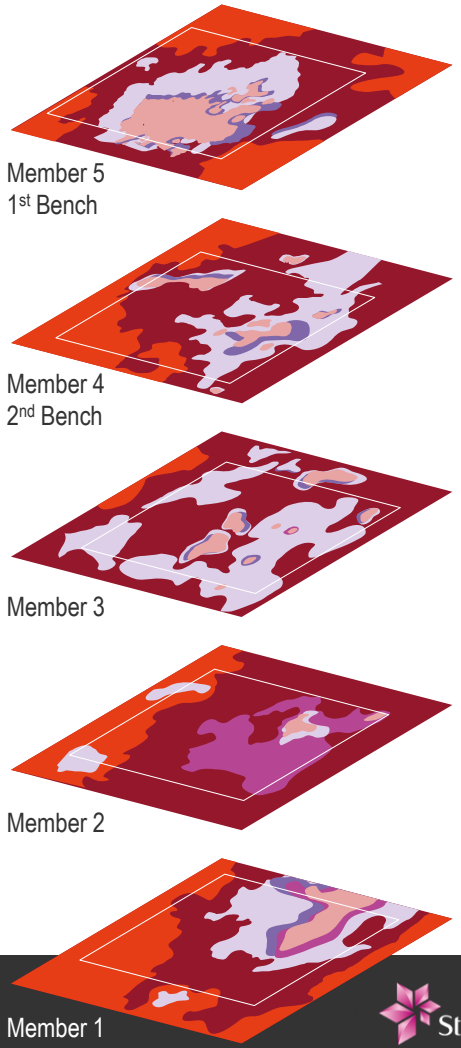
Easycore

Three Forks playa-lake model

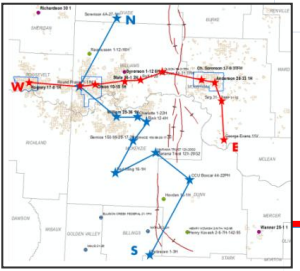


CONCEPTUAL DIAGRAMS
Inspired by Richard LeFever's isopach maps (personal communication)

Grn Mdstn	Dolo	Lmntd Slt/Mdstn
Dstrtd/Brccd Dolo	Mtrx Sprtd Brcc	Rd Intrclstc Mdstn



Statoil



N

Sorenson | Round Prairie | William | Charlotte | Rink | Bernice | Red Wing | Mariana Trust | CCU Boxcar | Debrecen

S

W

Rogney | Round Prairie | Olson | State 36 | Rolf | Olson 14 | Charlie Sorenson | Anderson | Sirp | George Evans

E

1st Bench

2nd Bench

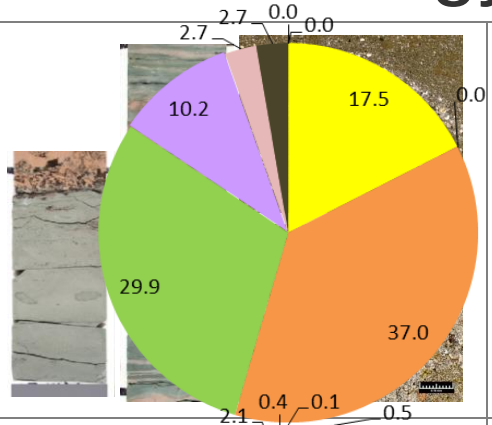
3rd Bench

4th Bench

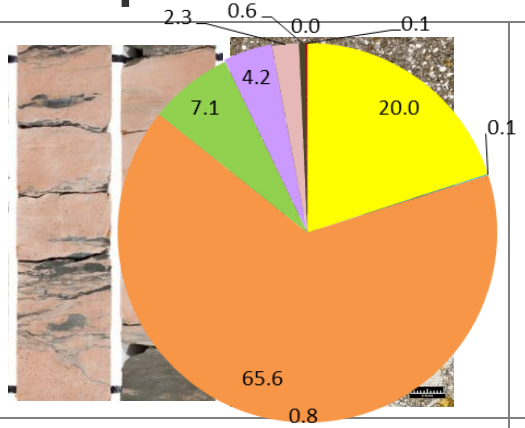
Statoil

XRD mineralogy of depositional rock types

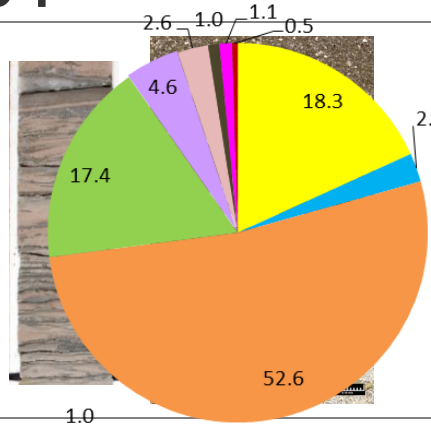
Green Mudstone



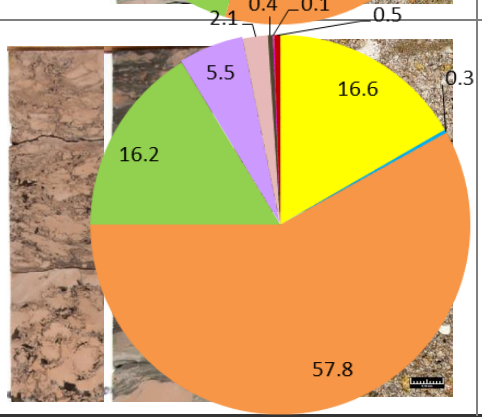
Dolostone



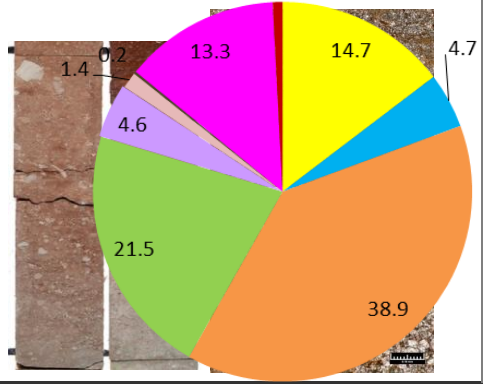
Laminated Siltstone/ Mudstone



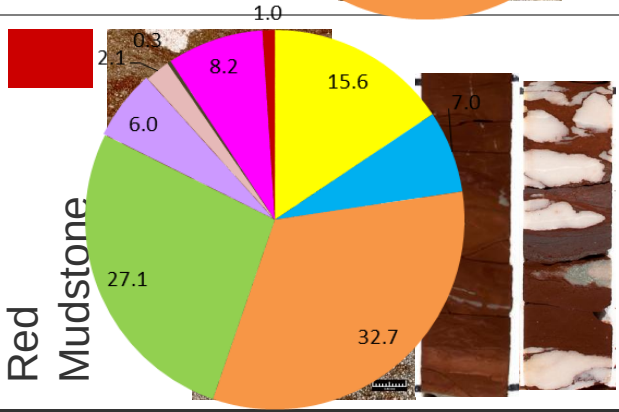
Distorted & Brecciated Dolostone



Matrix-supported Breccia



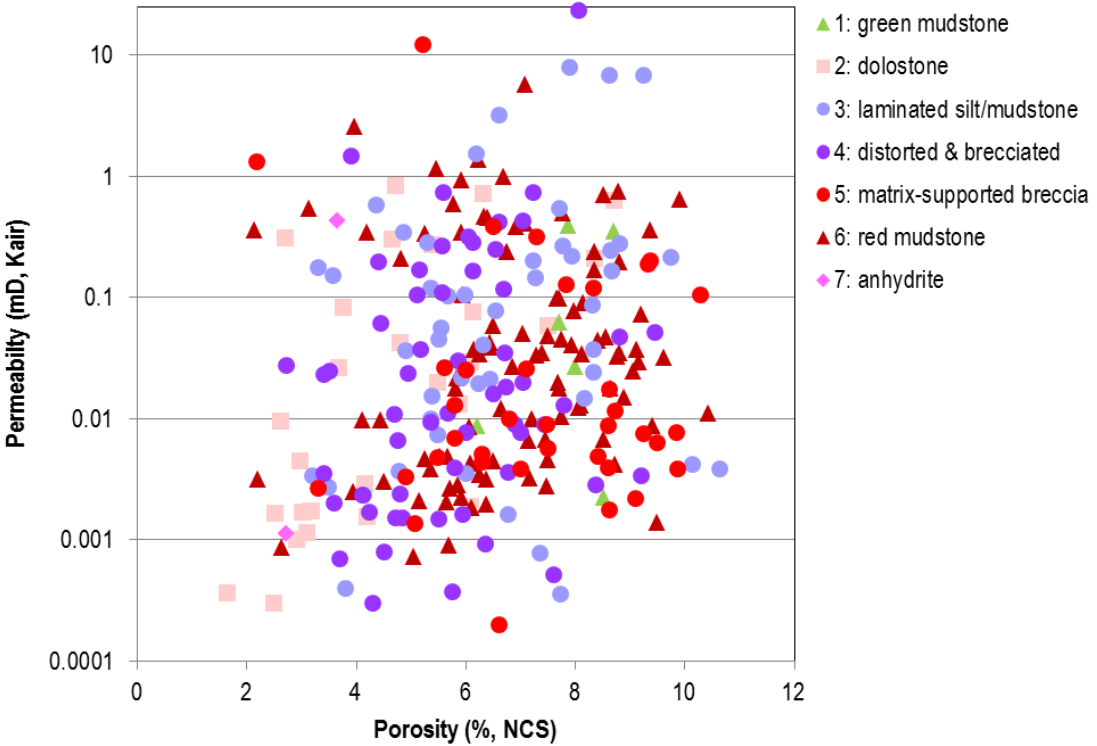
Red Mudstone

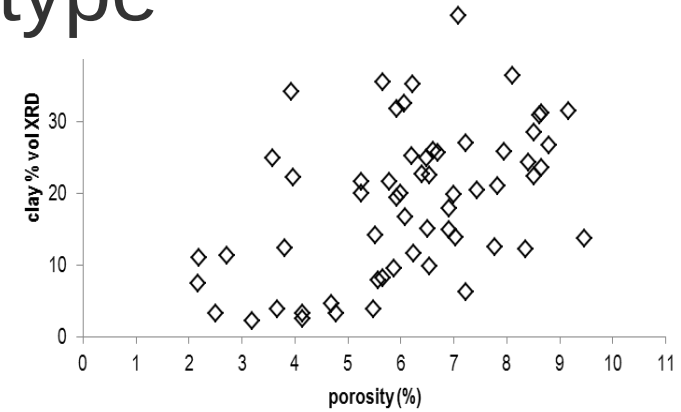


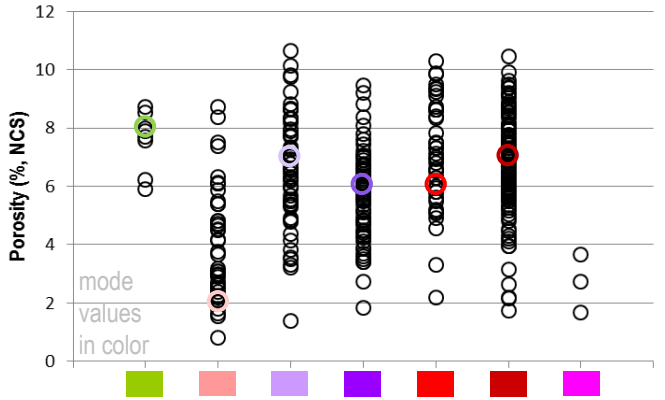
Quartz | Calcite | Dolomite | Clays | Orthoclase | Albite | Pyrite | Anhydrite | Halite

Statoil

Porosity by depositional rock type





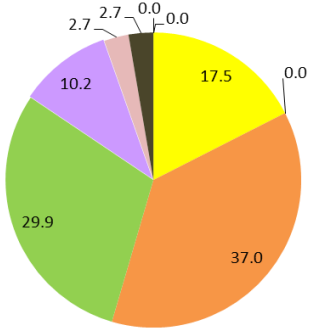


Statoil

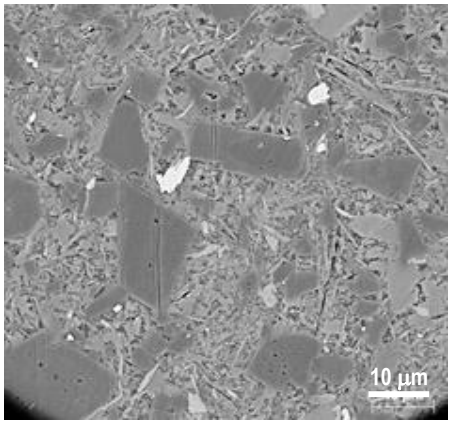
Bob Loucks, RCRL
BEG, The University of Texas

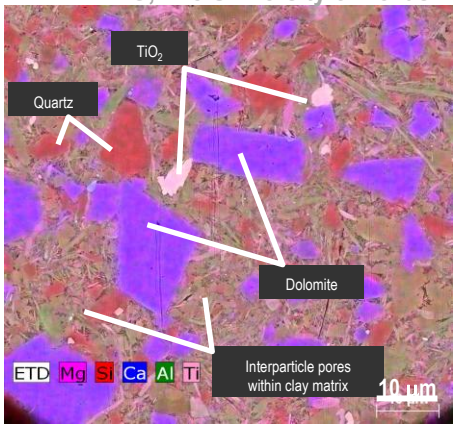
Pore system

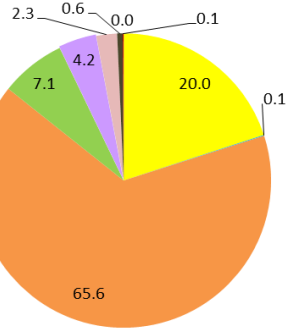
- Quartz
- Calcite
- Dolomite
- Clays
- Orthoclase
- Albite
- Pyrite
- Anhydrite
- Halite



DRT 1







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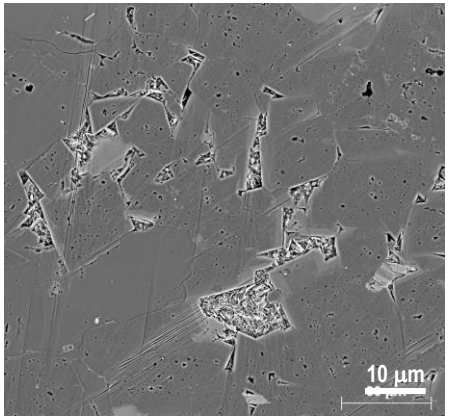
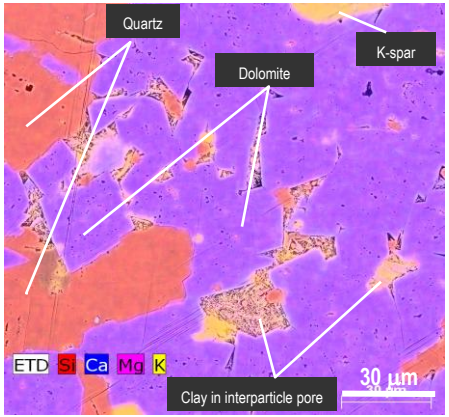
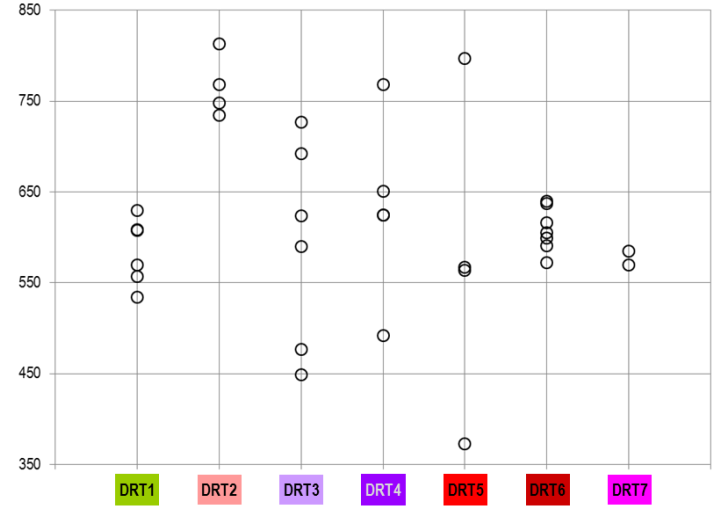


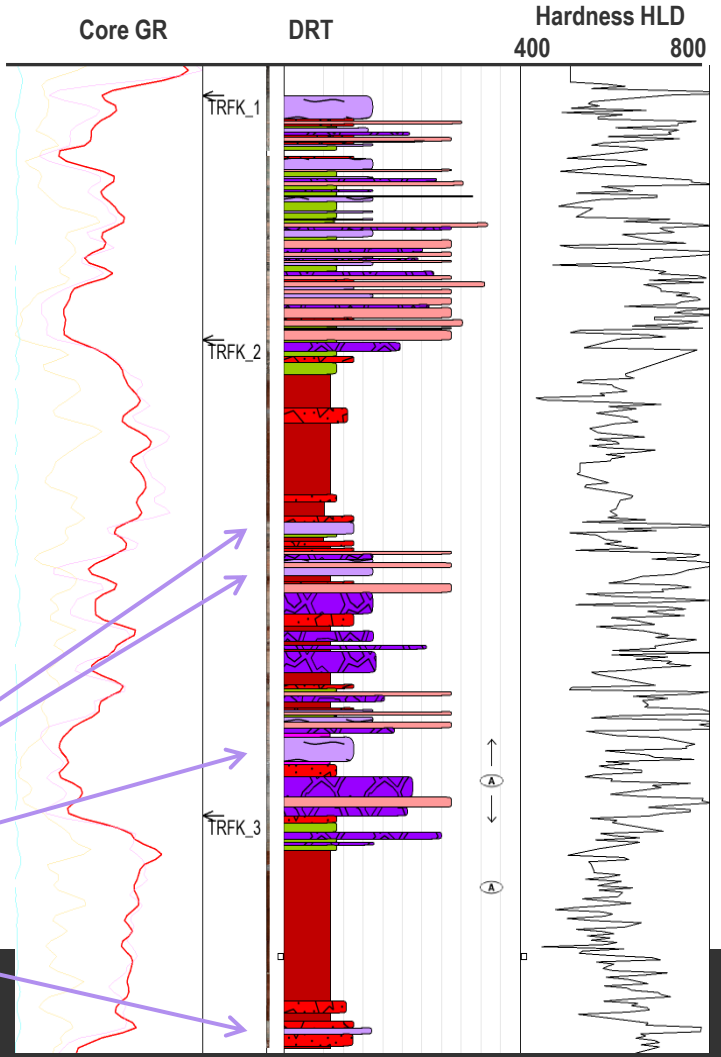


Statoil

Mechanical properties

Schmidthammer measurements by Ryan Idzior
MS The University of Texas, Austin **WED POSTER**

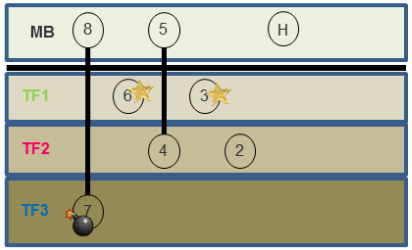


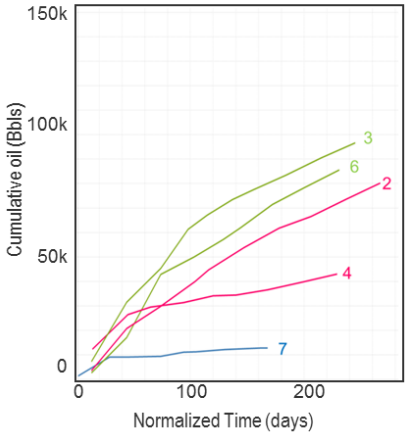


Statoil

Completion scheme and production

Pad 1



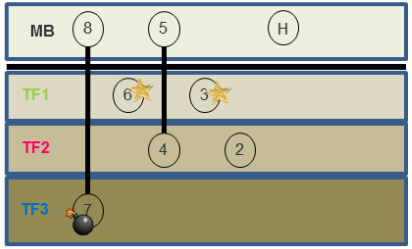


- Production generally best in 1st bench and decreases downward
- Three Forks wells completed below pressure-depleted Middle Bakken wells seem to underperform

Statoil

Completion scheme and production

Pad 1



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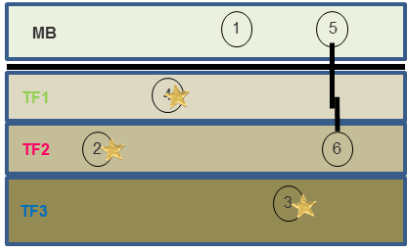
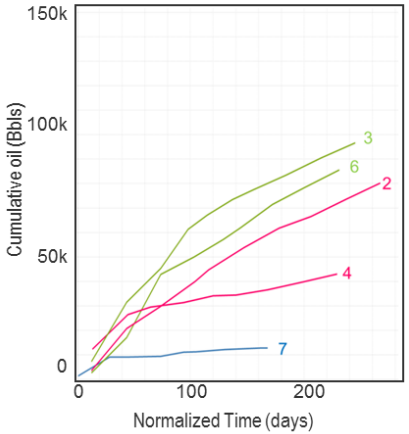
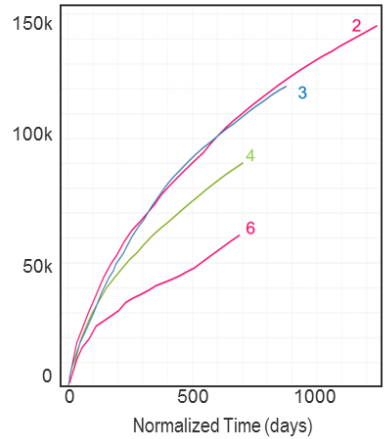




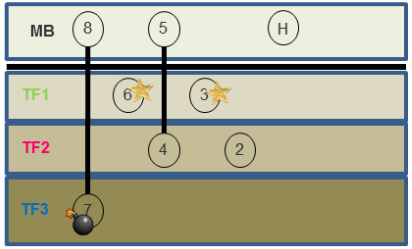


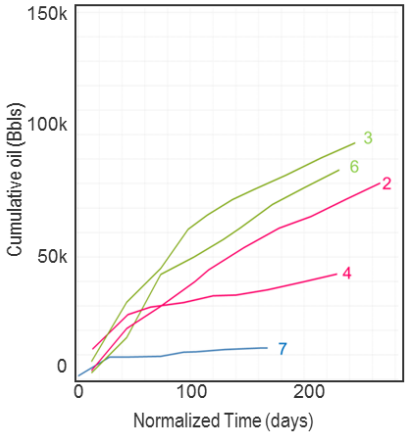
- Production generally best in 1st bench and decreases downward
- Three Forks wells completed below pressure-depleted Middle Bakken wells seem to underperform
- BUT there are exceptions to these rules

Statoil

Completion scheme and production

Pad 1





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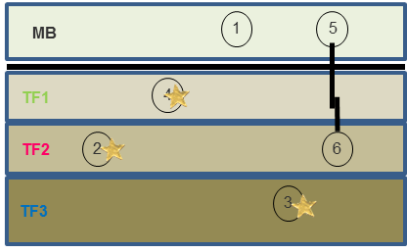

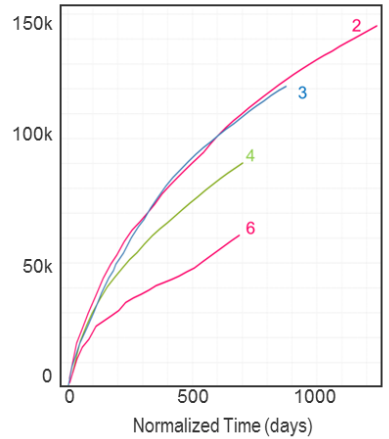

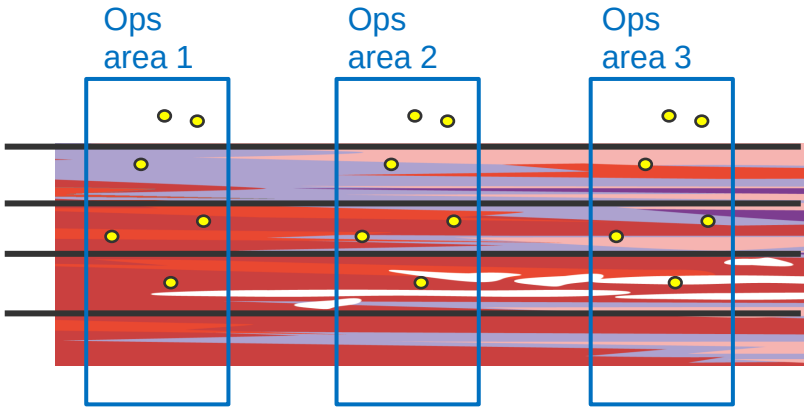

- Geological variability may play a role

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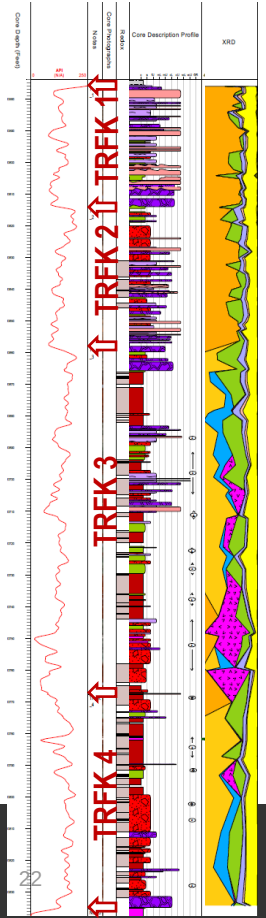
Anhydrite alteration and well souring



ANHYDRITE % vol from XRD

- Habits
  1. Massive
  2. Nodular
  3. Cement
  4. Fracture fill

DRT 7

- Evidence of alteration to calcite …and H_2S?

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Summary

- NEW DEPOSITIONAL MODEL FOR THE THREE FORKS
  - More accurate interpretation of variability of properties
  - Sound basis for geomodeling
- Many unconventional reservoirs **are not shales**
- Unconventional reservoirs require geological characterization based on core
  - Porosity, mechanical properties, S_w, etc.
- Potential impact for Three Forks development, production and HSE
  - Reduce uncertainty in OOIP
  - Optimize landing zone and completion design
  - Minimize production risks and downtime

Statoil. The Power of Possible

Playa Lake Depositional Model for the Three Forks Formation

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Many thanks to the following

Julie LeFever and staff, Wilson M. Laird Core and Sample Library

Bob Loucks, RCRL, Bureau of Economic Geology, The University of Texas at Austin

Richard LeFever, University of North Dakota

Stephan Nordeng, University of North Dakota

Sven Egenhoff, Colorado State University

Easycore

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