Mixed Siliciclastic-Carbonate System of "D" Facies in the Bakken Formation, Williston Basin*

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Abstract

The middle Bakken reservoir interval consists of six distinct facies, namely facies A-F. Facies D is the coarsest-grained, highest-energy facies in the entire Bakken Formation. Porosity varies between 1–8%. Lithologically, Facies D varies from very fine- to medium-grained calcite-cemented, quartz-rich sandstone, to ooid-rich grainstone with abundant fossil fragments. Cycles of increasing calcite and decreasing quartz and dolomite, in conjunction with massive zones alternating with zones of high-angle cross-stratification, gives Facies D a banded appearance. The Facies D is discontinuous within the Williston Basin and reaches a maximum thickness of around 5 m in North Dakota. All these features of Facies D highlight the complexity of this mixed siliciclastic-carbonate depositional setting. This study is focused on developing a depositional model for the mixed siliciclastic-carbonate system of Facies D, which will aid in improved middle Bakken reservoir characterization and proper planning of well-completion designs. Detailed core descriptions, petrographic studies, log correlations, and subsurface mapping suggest that Facies D was deposited in a middle to lower shoreface environment in a homoclinal ramp setting. Presence of oolitic grainstones and a restricted faunal assemblage indicate that it was deposited in a saline basin under arid conditions. The principal carbonate factory existed in the southern part of the basin, while the siliciclastic source was from the north. Thickened intervals of Facies D correspond to building-up of carbonate shoals that are cross-cut by intervening channels, similar to the ebb delta ooid shoals of eastern Abu Dhabi. Tidal currents and storm-generated flows within these channels distributed both siliciclastic and carbonate sediments across the basin. Seasonal variations in wind direction, as seen in the modern day Sunda Shelf in South China Sea, influenced current intensity within the channels. This resulted in cyclic deposition of alternating bands of oolitic grainstone and quartz-rich sandstone. Fast Fourier Transform analysis is applied to understand this complex interaction between tidal influence and seasonal variations in a mixed siliciclastic-carbonate depositional setting.

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06/02/2015

Key Takeaways

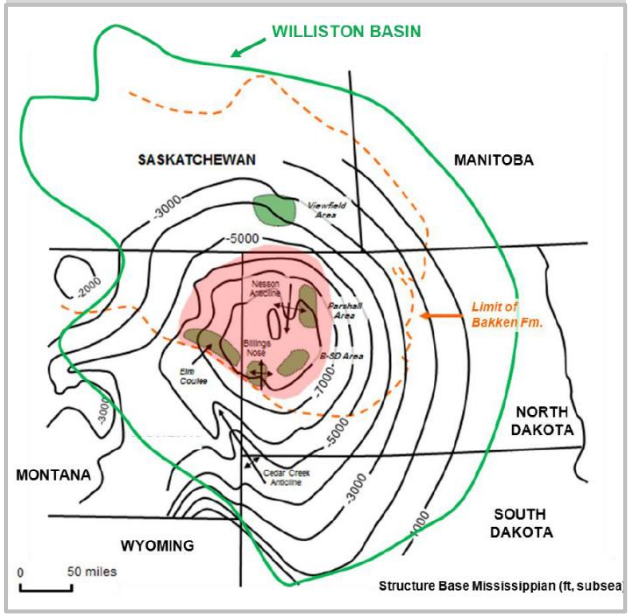
- Middle Bakken facies-D (MB-D) represents coeval sedimentation of siliciclastic and carbonate sediments in an epicontinental seaway setting.
- Tides, seasonal variation in wind direction and waves in combination helped in mixing of carbonates and siliciclastic.
- MB-D indicates a tide-influenced/dominated environment.
- Combination of different modern analogs can help in understanding ancient mixed-siliciclastic-carbonate deposits.

Outline

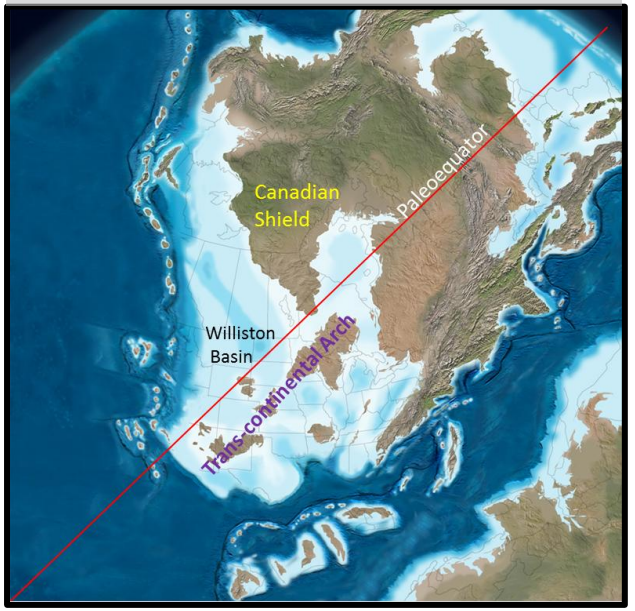
- Introduction
- Objective
- Description of facies MB-D (core study and petrography)
- Comparison with modern analogs
- Mechanism of mixing of siliciclastic and carbonate sediments
- Depositional model of facies MB-D
- Key Takeaways

Introduction

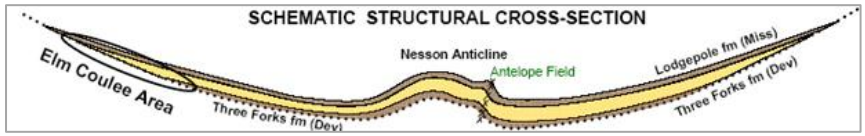
Williston Basin Map



Late Devonian Paleogeography

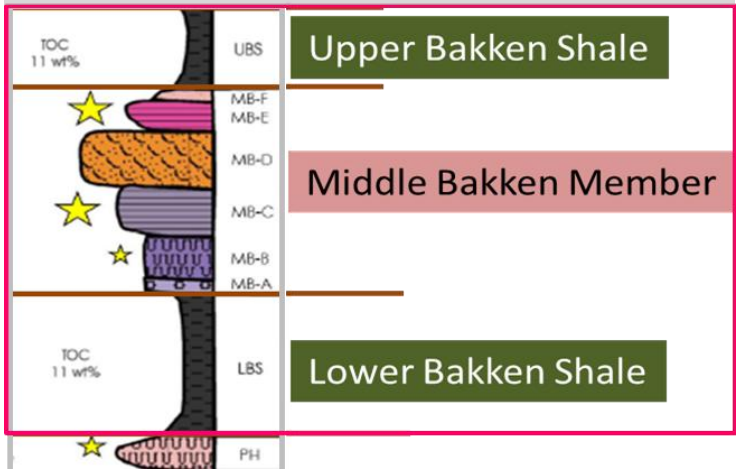


Modified from Blakey,2011

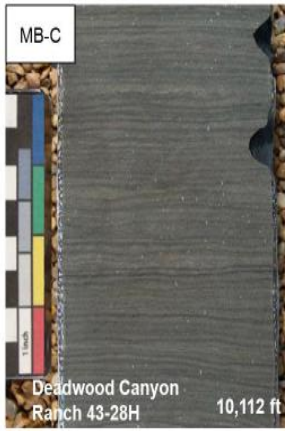


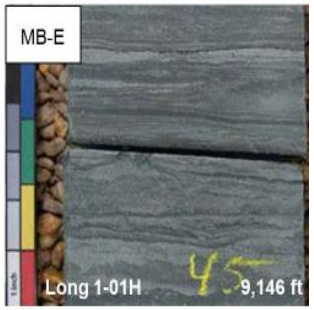
Modified from Meissner, 1978

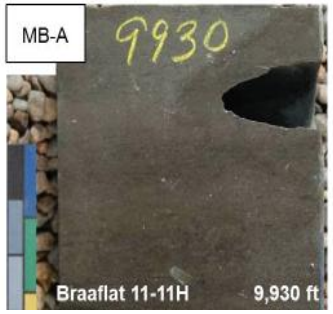
Stratigraphy

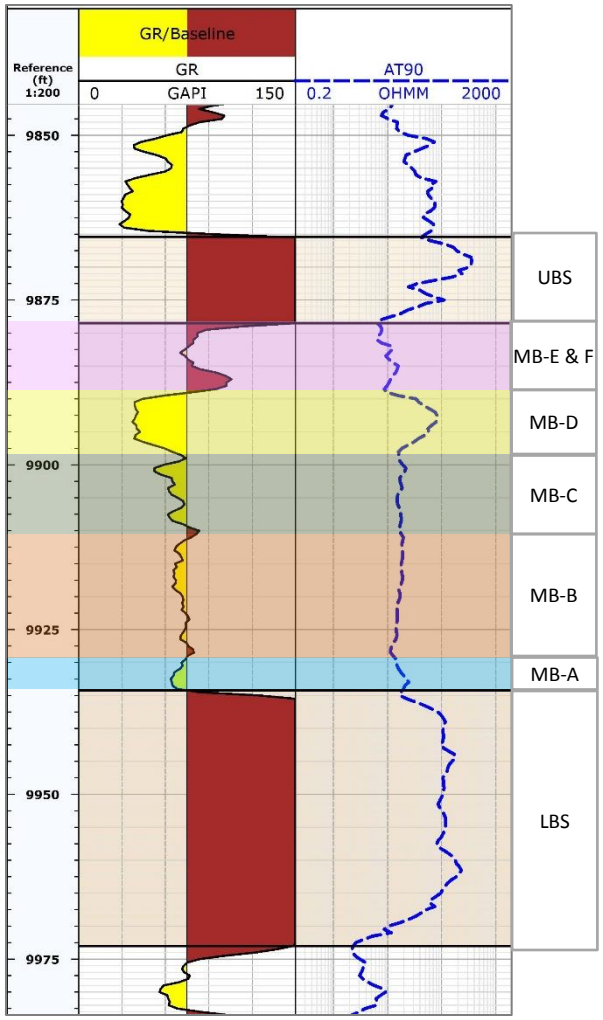


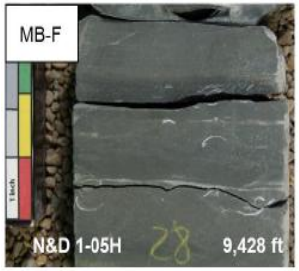
Middle Bakken Facies

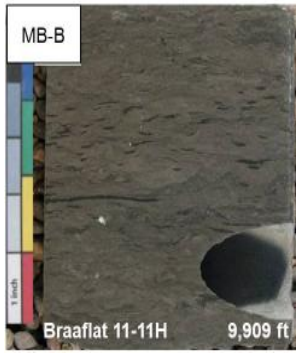










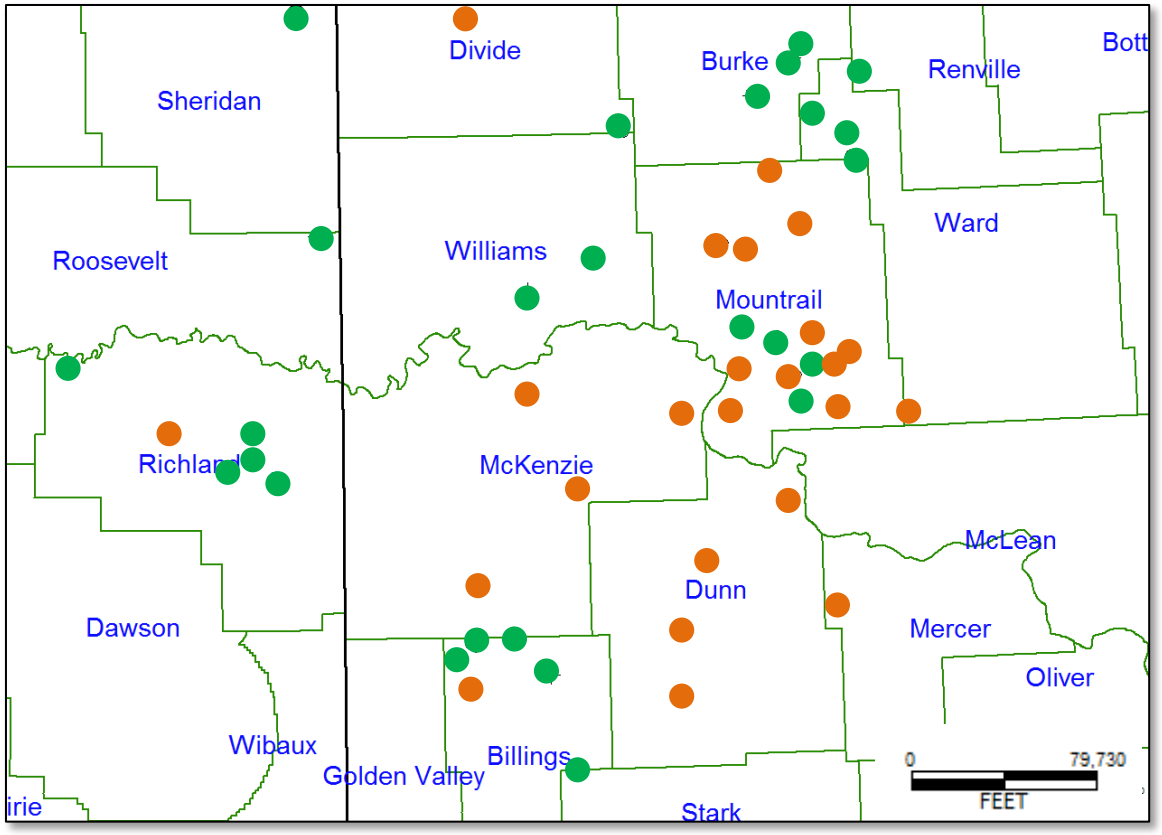


Objective

- Describe Facies-D based on core study and petrography
- Compare with possible modern analogs
- Understand the factors controlling coeval mixing of carbonate and siliciclastic sediments
- Develop the depositional model of Facies-D

Dataset

- Total 51 cores described
- 10 cores described at high resolution
- Thin section from 28 cores studied

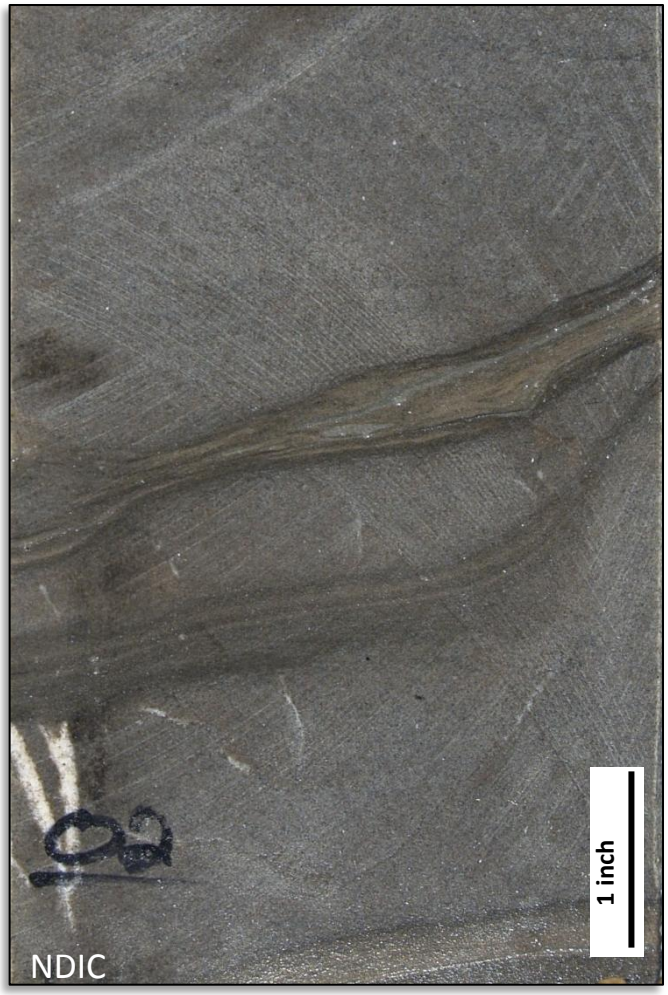


Core description

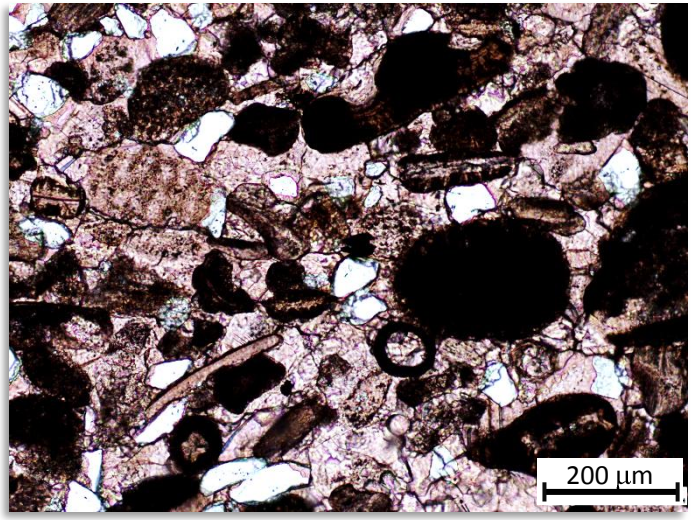
Core description & petrography

Middle Bakken Facies D-1

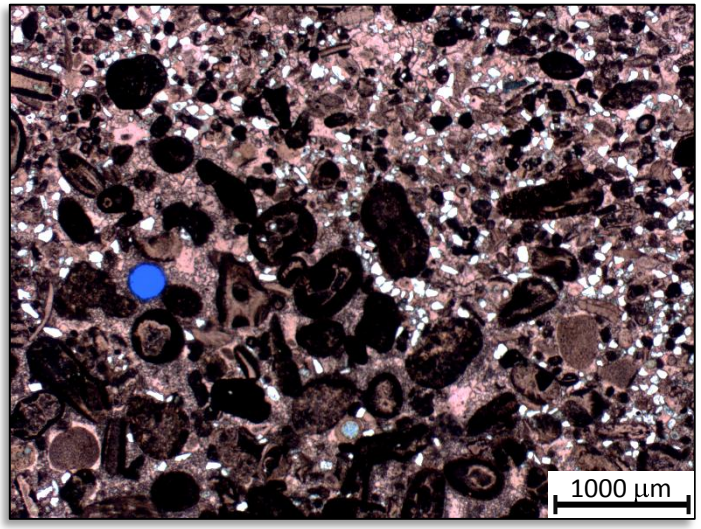
- Massive Bioclastic Pelloidal/ Oolitic Packstone to Grainstone
- Crinoids, bryozoan, bivalves present



Deadwood Canyon, 10099 ft



Deadwood Canyon, 10098 ft



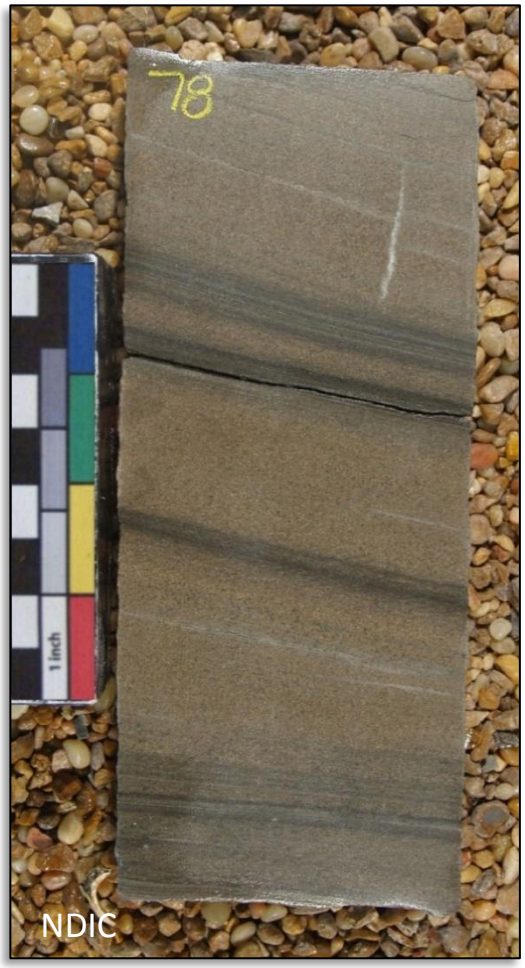
Deadwood Canyon, 10099 ft

Middle Bakken Facies D-2

- Oolitic grainstone-to- quartz-rich Sandstone
- Planar to high-angle cross-stratified layers

Rosenvold, 9293 ft

Bartleson, 10273 ft

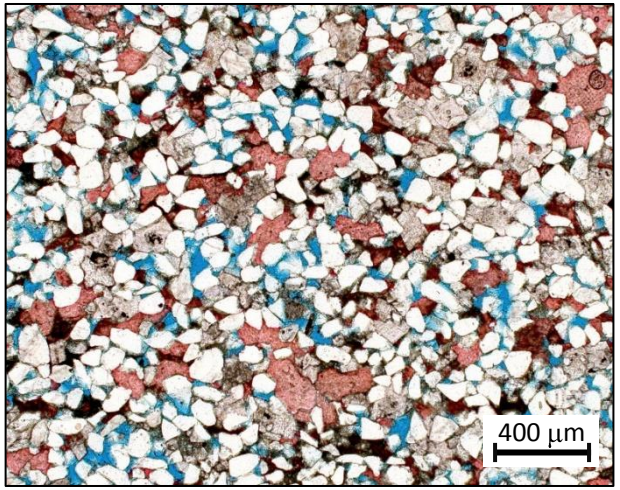


Patten, 9278 ft

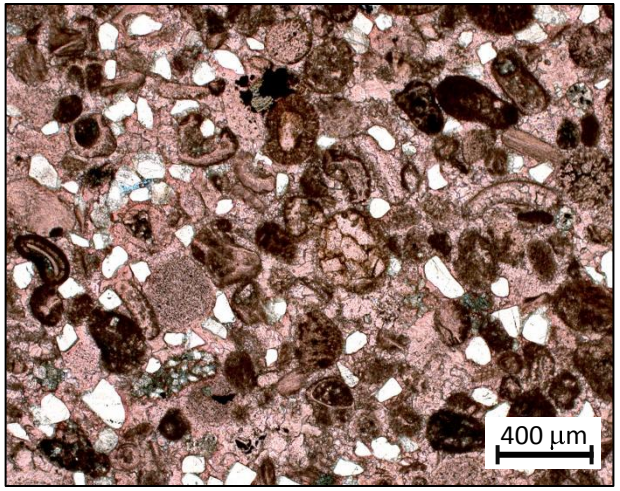
Middle Bakken Facies D-2

- Alternate carbonate-rich and quartz-rich intervals

Baja, 7915 ft



Gunnison State, 8168 ft

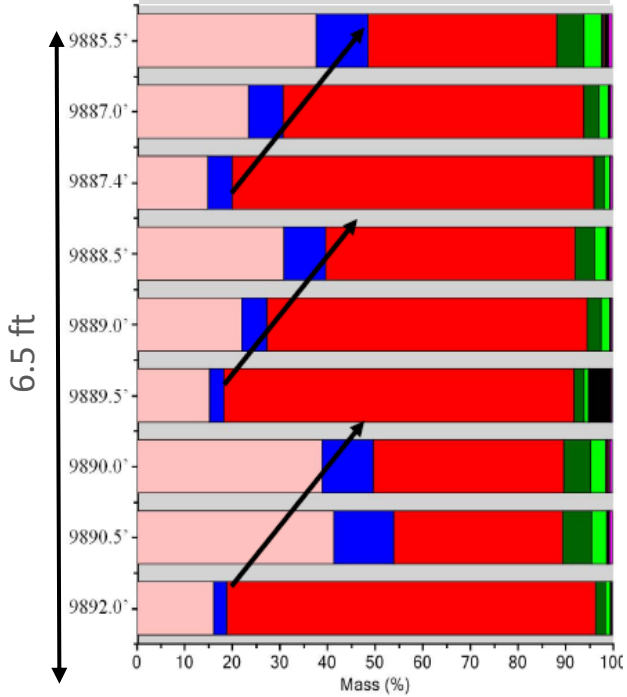


Gunnison State, 8166 ft

Carbonate-Quartz-rich Cycles

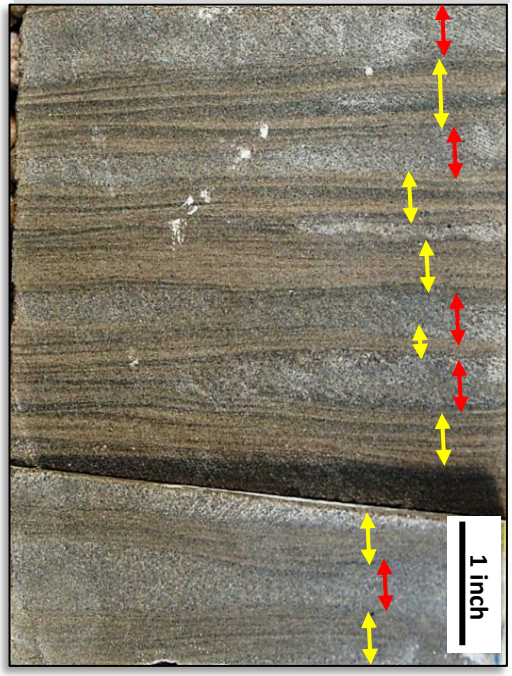
- Alternate cycles of carbonate and quartz-rich intervals

QEMSCAN Mineralogy



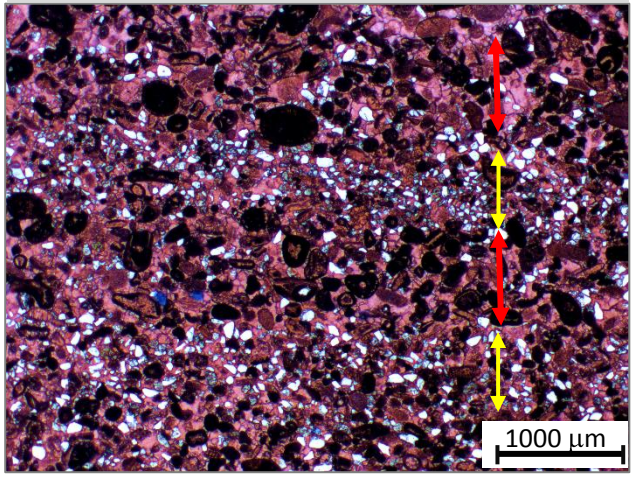
Braaflat

Core Photograph



Braaflat, 9890 ft

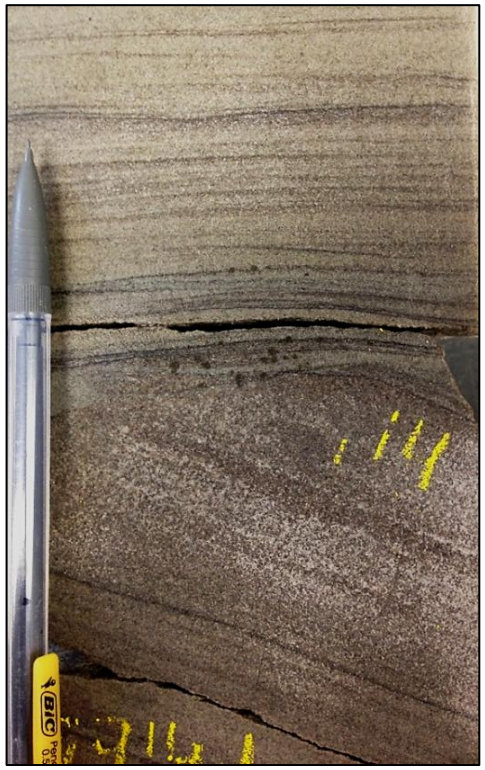
Photomicrograph



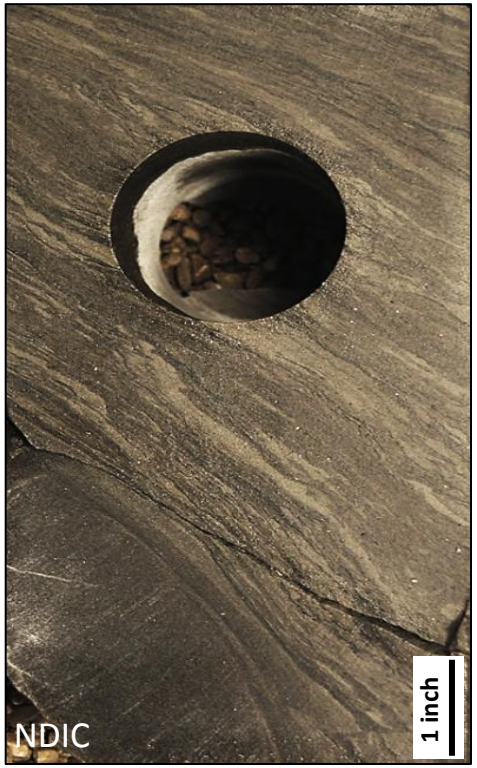
Deadwood canyon, 10098

Middle Bakken Facies D-2

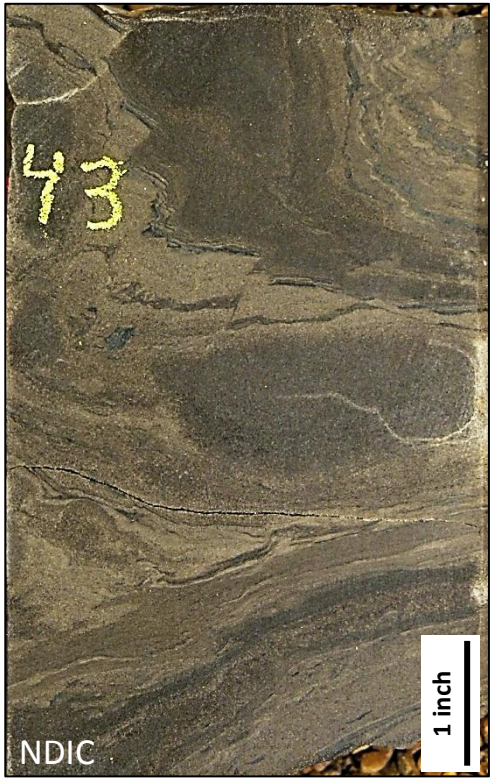
- Internal scour surface
- Soft-sediment deformation
- Microfaults



Baja ft



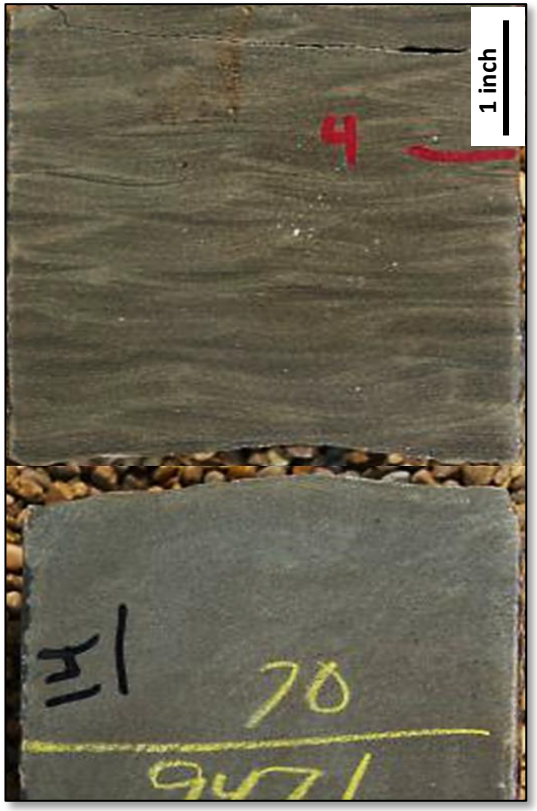
Bartleson 10242.3ft



Bartleson 1023ft

Middle Bakken Facies D-3

- Flaser-bedded, fine-grained sandstone to siltstone
- Climbing ripples, symmetrical ripples



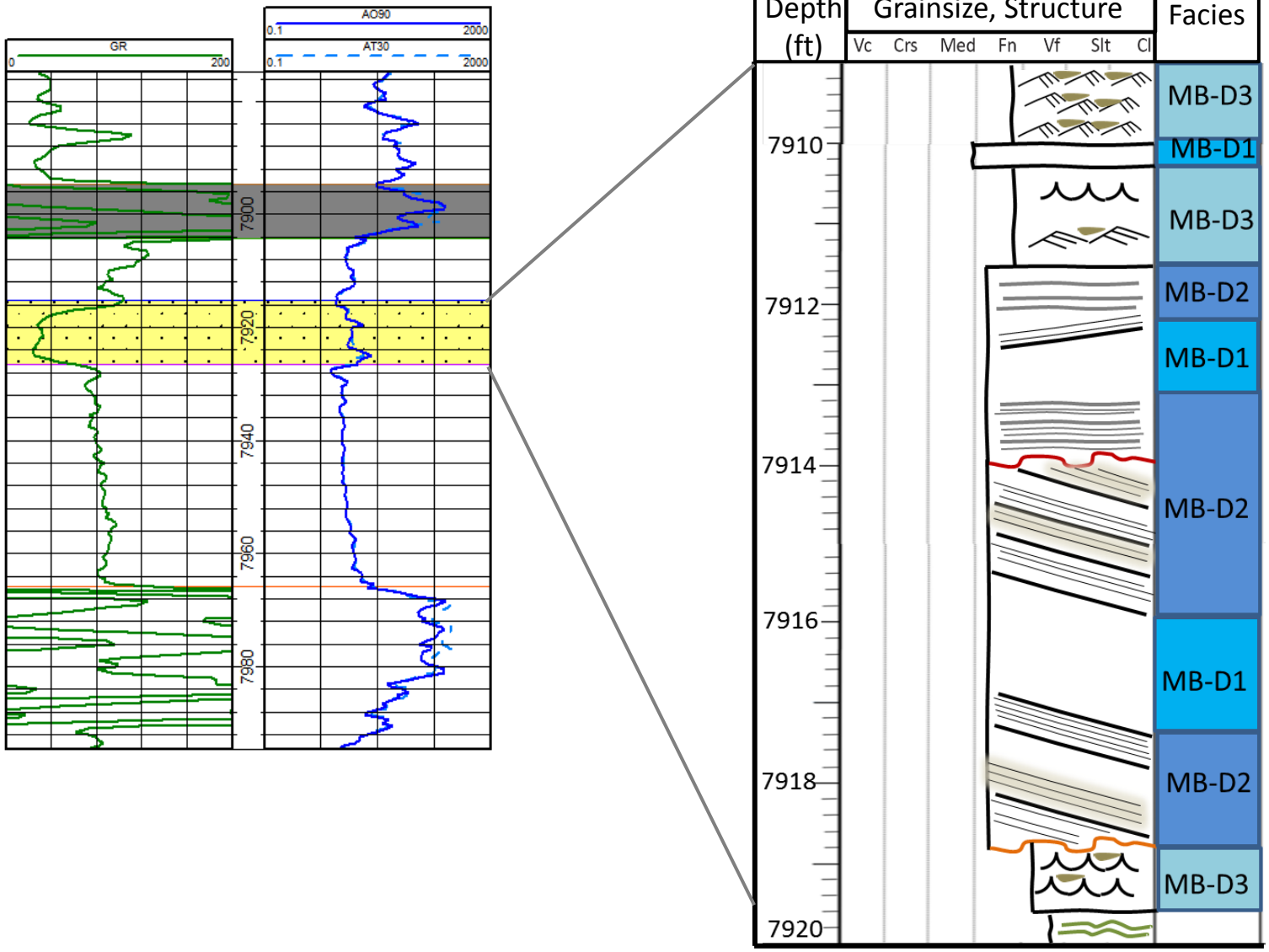
Van Hook, 9470.9 ft

Baja, 7919 ft

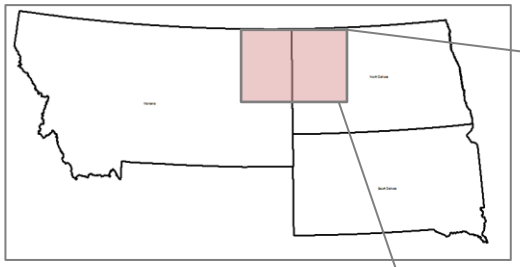
Bartleson ft, 10244.4 ft

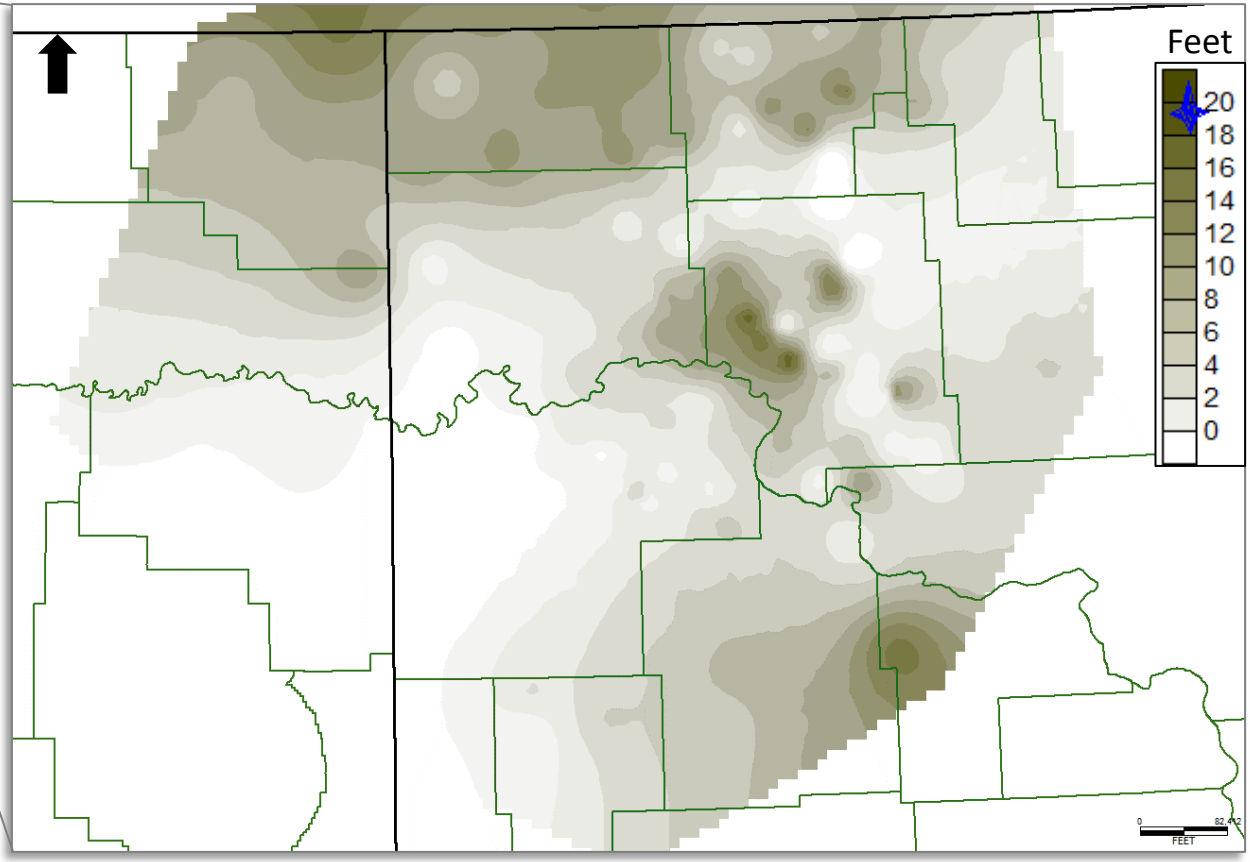
Core description

Baja



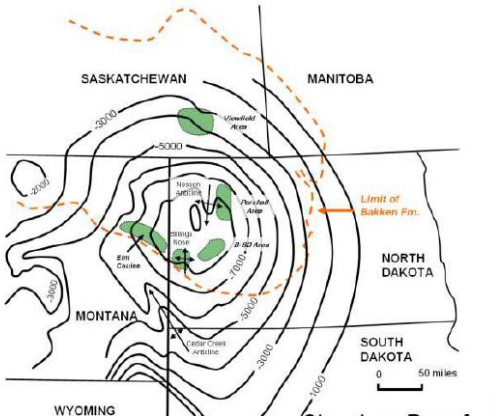
Isopach Map of MB-D



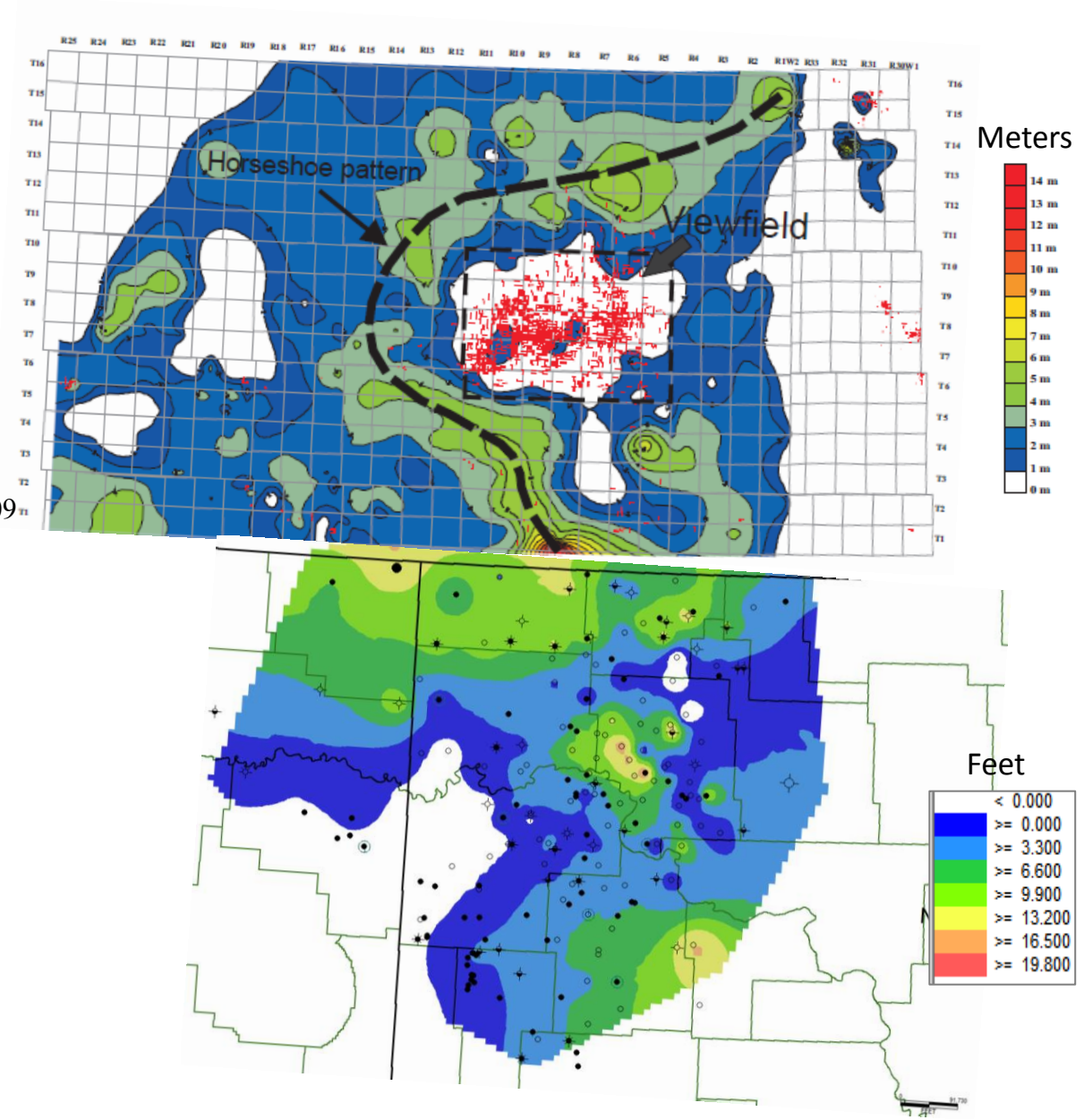


- Thickening and thinning of facies

Isopach Map of MB-D



Kohlruss and Nickel., 2009

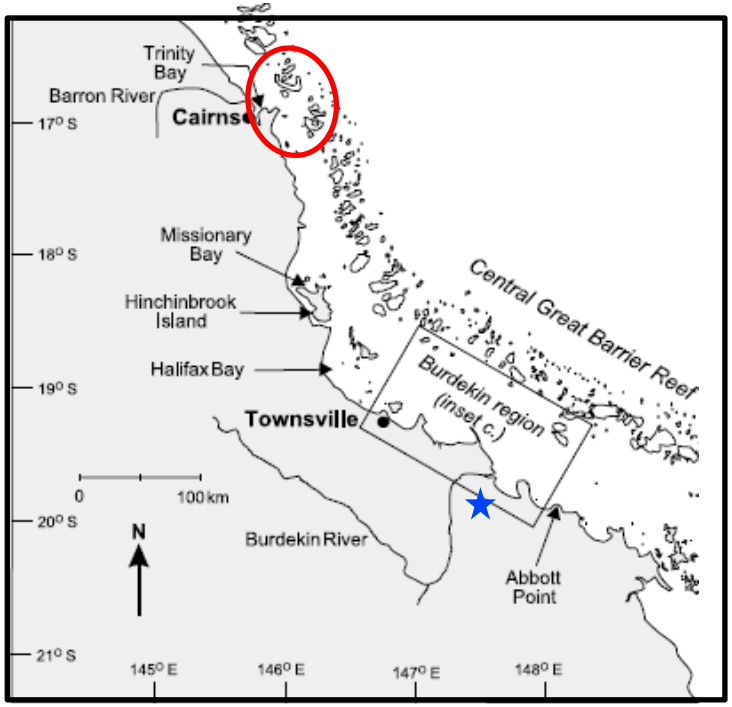


Challenges

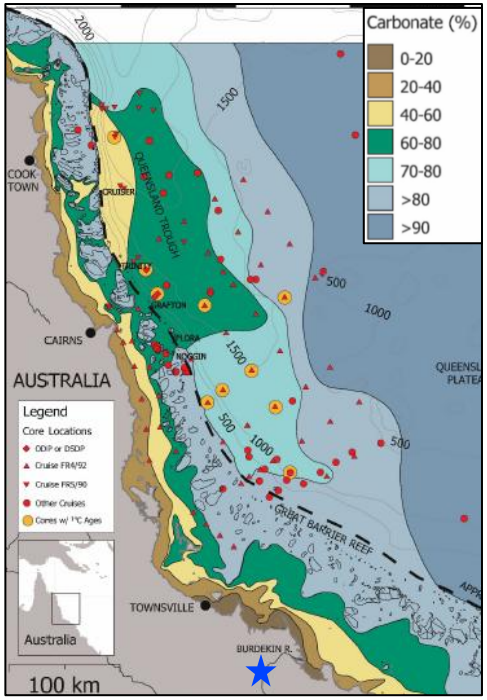
- Coeval sedimentation of carbonates and siliciclastic sediments
- Oolite deposition in homoclinal ramp/ epeiric sea setting
- Source and mode of transport of siliciclastic sediments
- Mechanism of mixing of siliciclastic-carbonate sediments

Coeval sedimentation

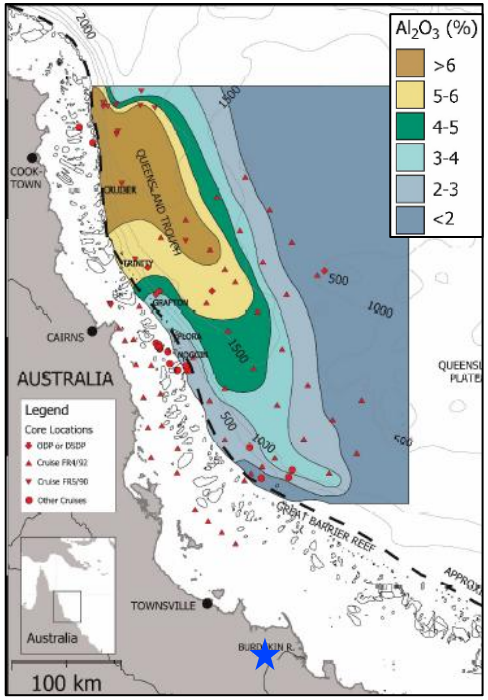
Modern Analog: Great Barrier Reef, Northeastern coast of Australia



Orpin et al., 2004



Francis et al., 2007

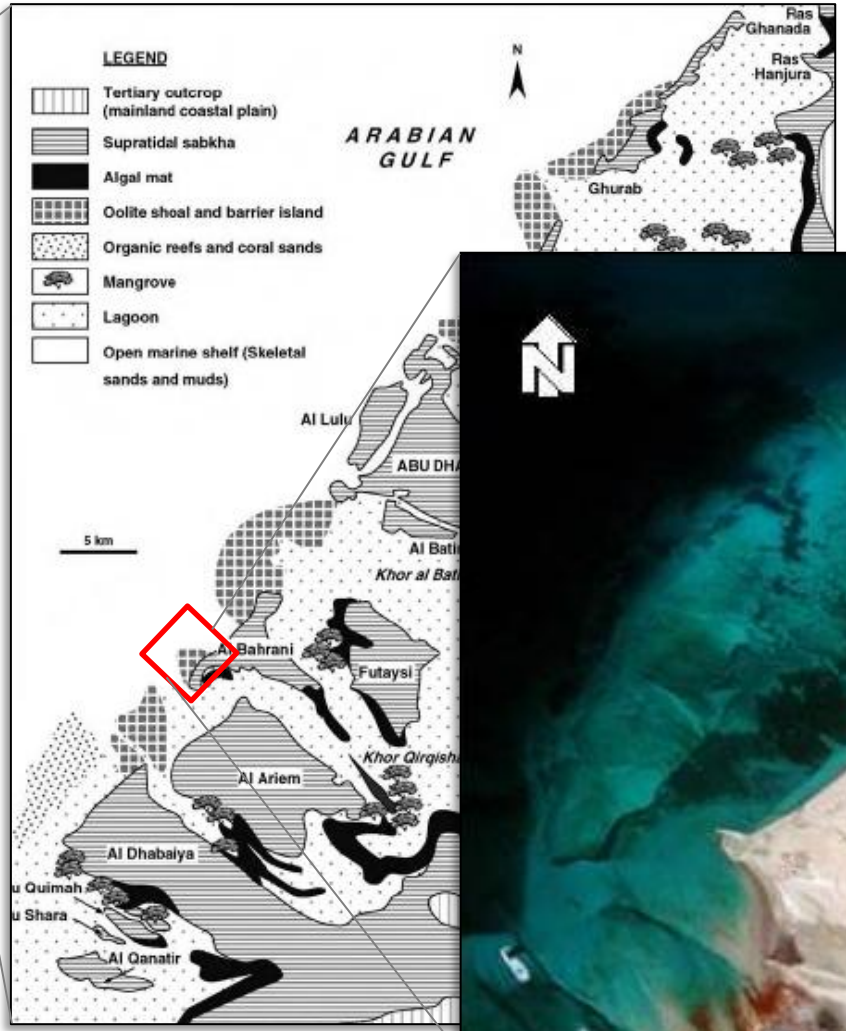


Francis et al., 2007

Siliciclastic sediment is sourced from a combination of dry tropical rivers transporting Holocene sediment to the Great Barrier Reef shelf and upper Pleistocene sediment eroded from the outer shelf and reworked to Queensland Trough.

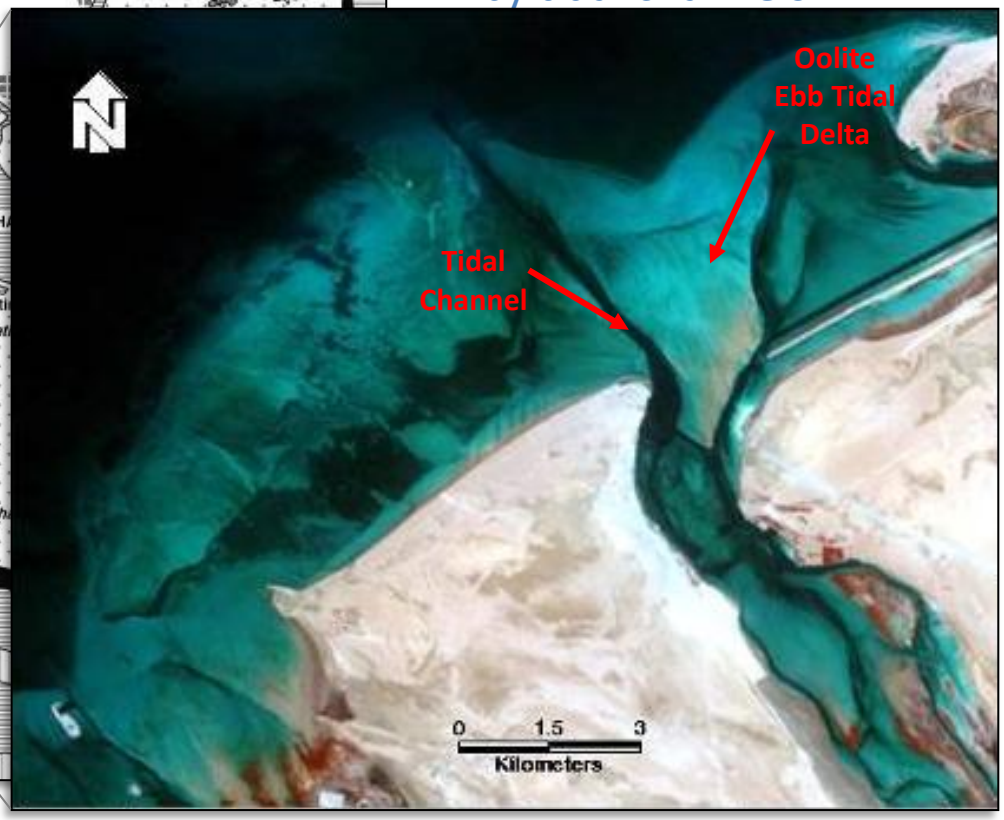
Oolite Deposits

Holocene oolites in Abu Dhabi, UAE



Alsharhan and Kendall, 2003

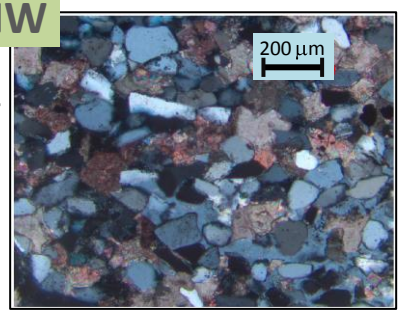
- Homoclinal ramp setting
- Oolitic tidal delta incised by tidal channels



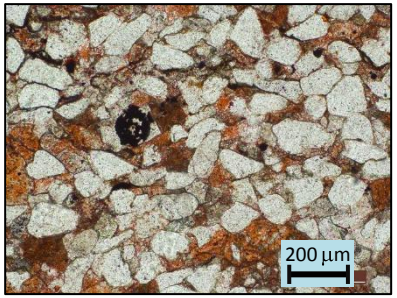
C.G.St.C Kendall (Sepmstrata)

Source of Siliciclastic Sediments

NW

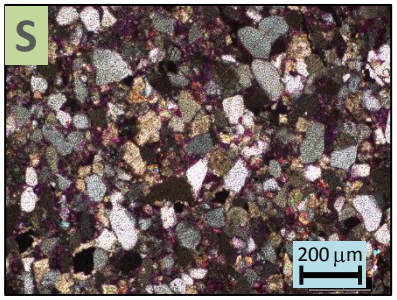


Wascana Joyce



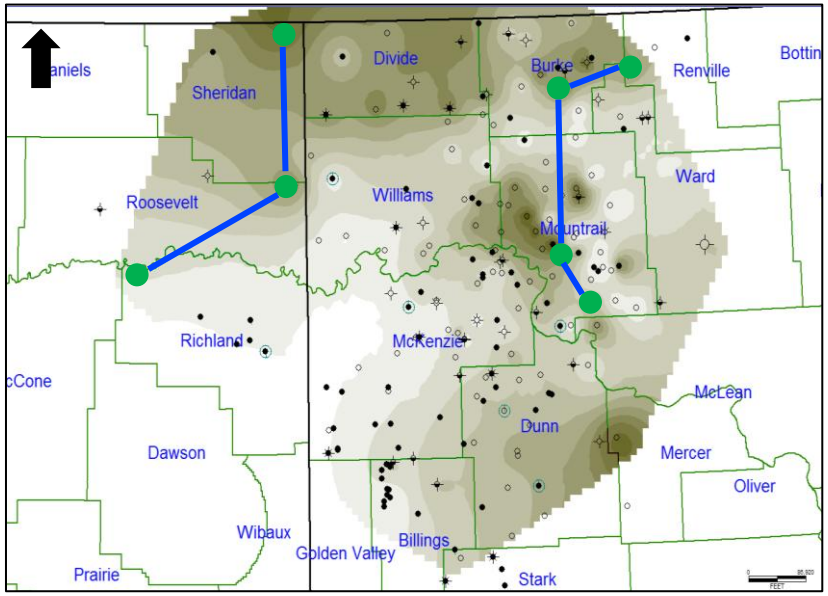
Harvey Gray

S



Jackson Rowdy

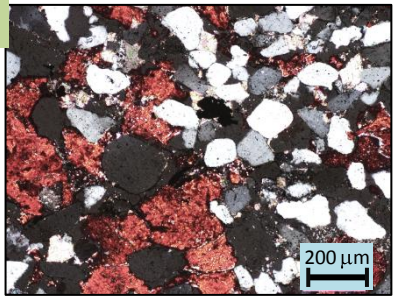
- Subangular to subrounded detrital grains
- Grain size decreases from N to S
- Siliciclastic content decreases from N to S



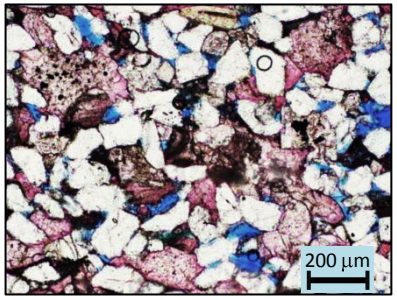
- Probable source: Canadian Shield
- Mainly fluvial-derived detrital sediments

Grain size decreases

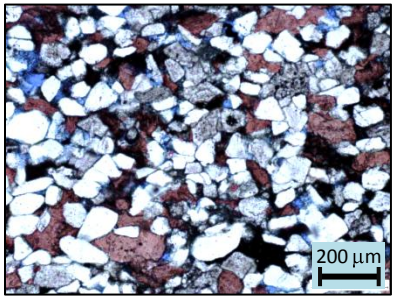
NE



Pierce

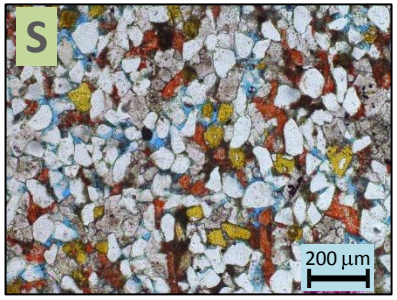


Gunnison State



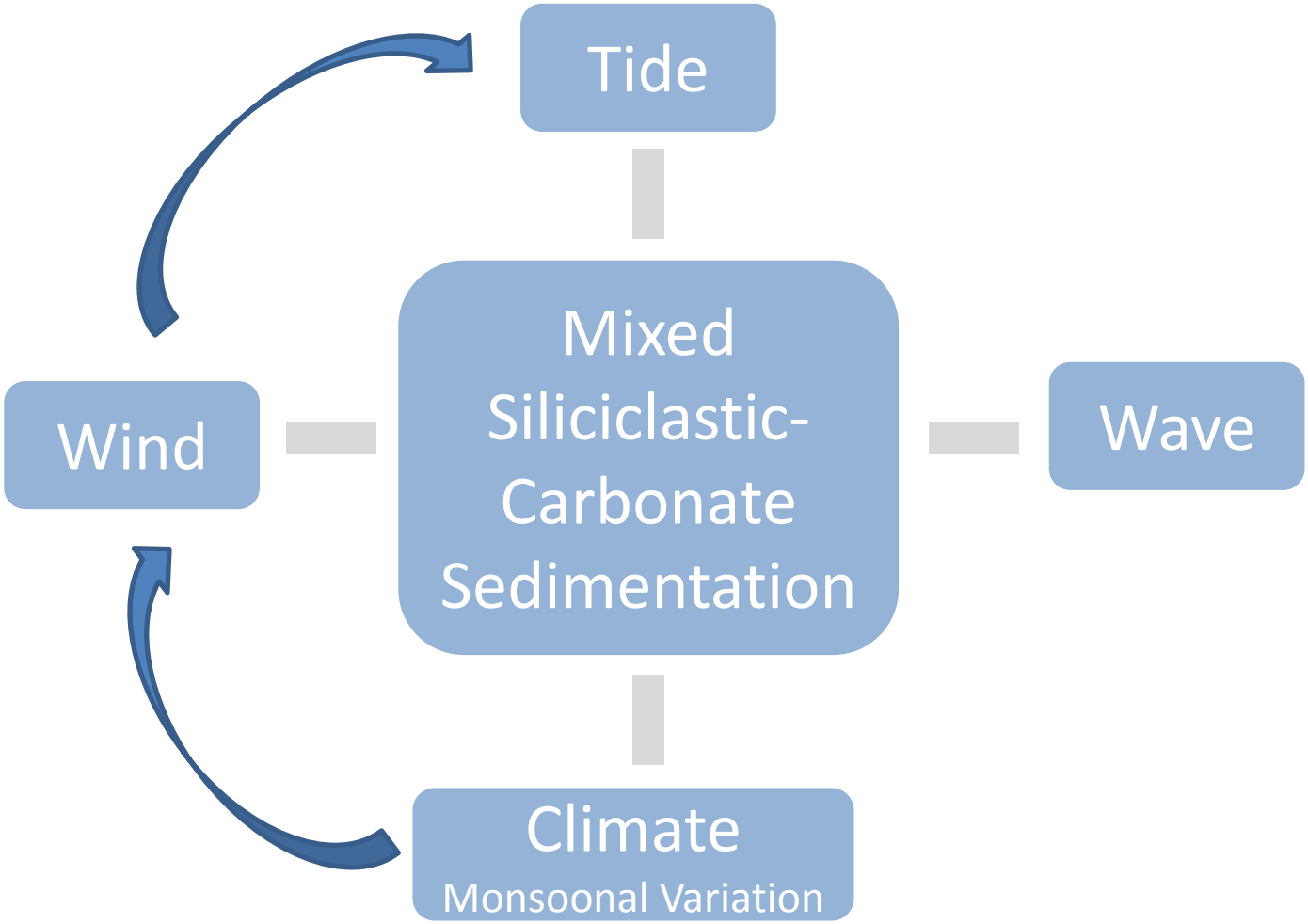
Deadwood Canyon

S

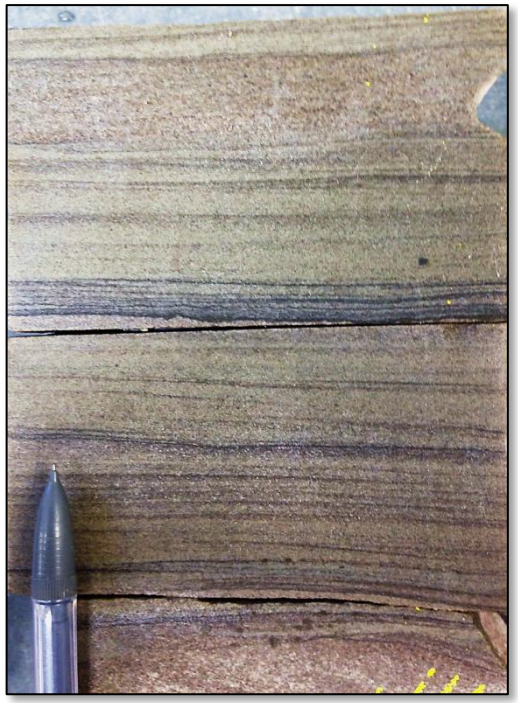


Liberty

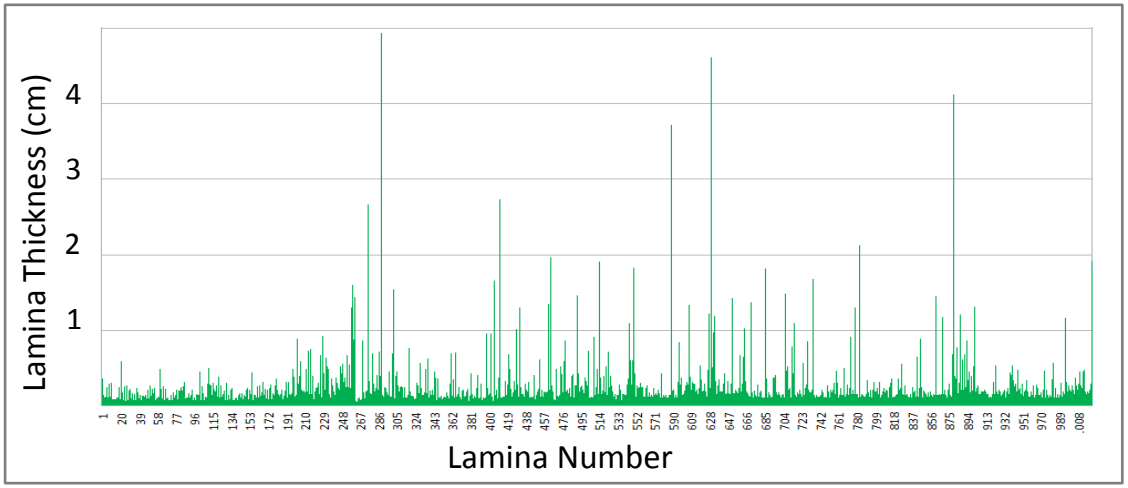
Mixing of siliciclastic-carbonate sediments

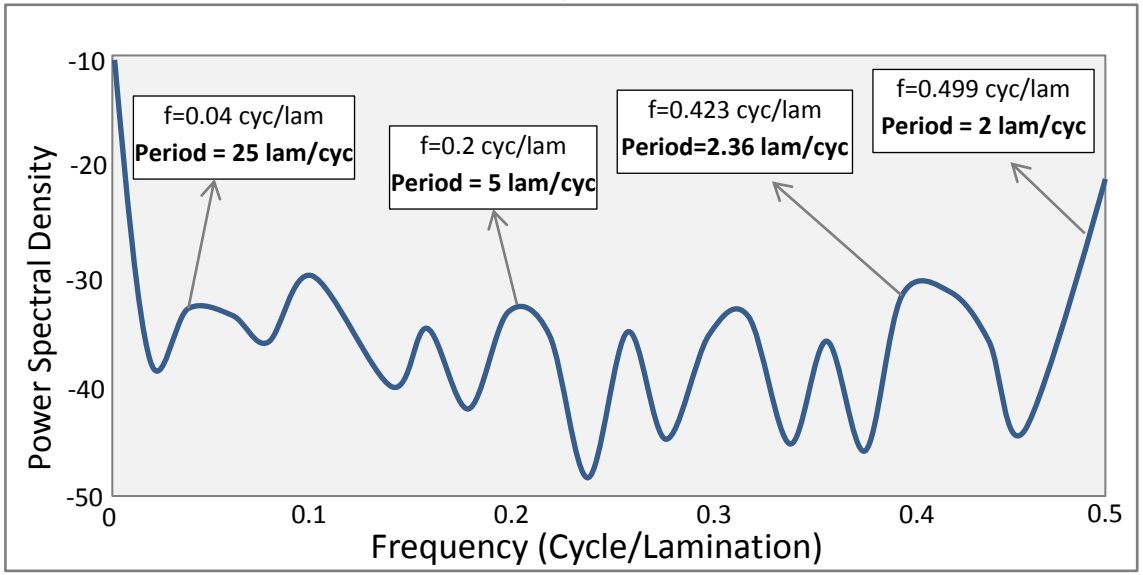


Tidal Signature: Spectral Analysis



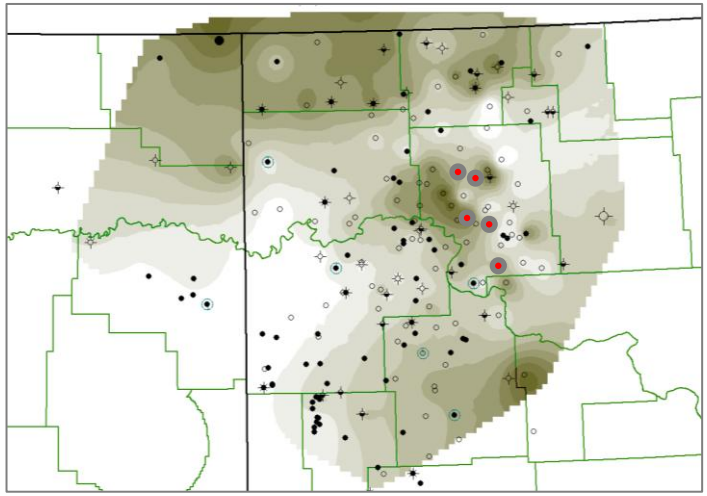
- Harmonic spectral analysis using Fast Fourier Transformation (FTT)





Period	Interpretation
2 lam/cyc	Semi-diurnal tides
2.36 lam/cyc	Mixed tides
5 lam/cycle	Meteorological
25 lam/cyc	Monthly tidal cycle

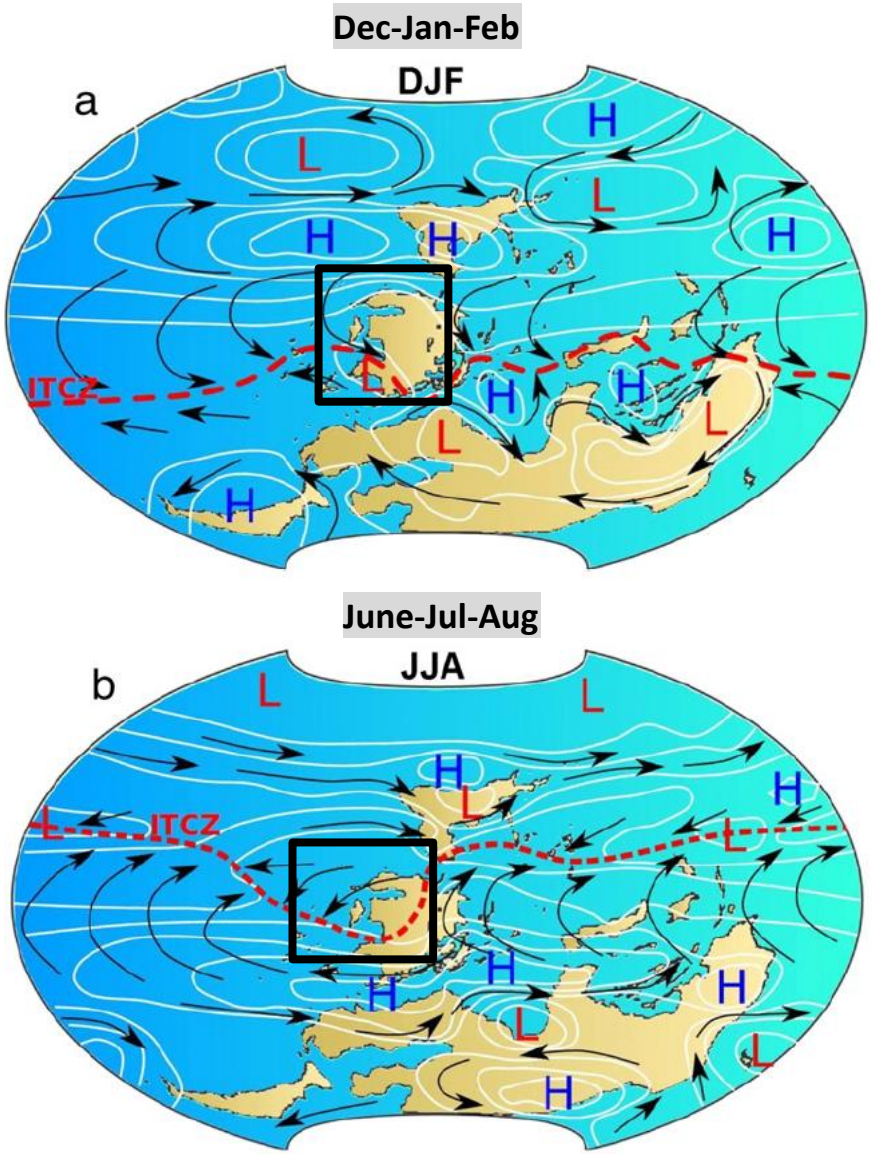
Tidal Signature: Spectral Analysis



Well Name	Semi-diurnal	Mixed	Meteorogical/ Storms		Monthly	
Braaflat	2	2.4	3.1	5	10	25
Deadwood Canyon	2	2.8	3.6	5 to 7	10	16.7
Liberty	2.1	2.9	3.3	4.5 to 7	12.5	16.7
Ross	2	2.3	3.3	4.5 to 6	12.5	25
Nelson Farms	2	2.8	4.5	5 to 7	12.5	

- Tidal-influenced/dominated environment
- Tidal periodicity ranging from a semidiurnal to mixed tidal system and synodically driven tidal forces.

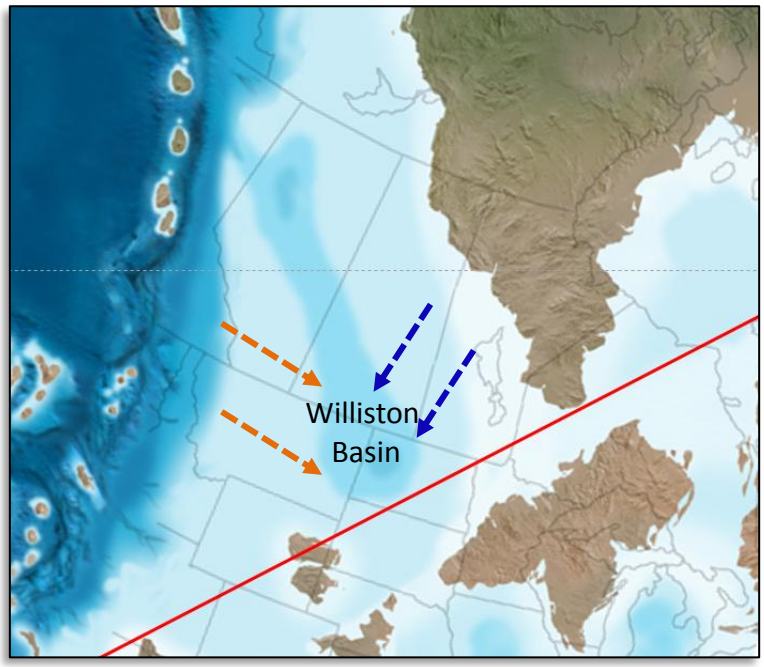
Late Devonian Paleoclimate



ITCZ: inter-Tropical Convergence zone

Vleeschouwer et al., 2014

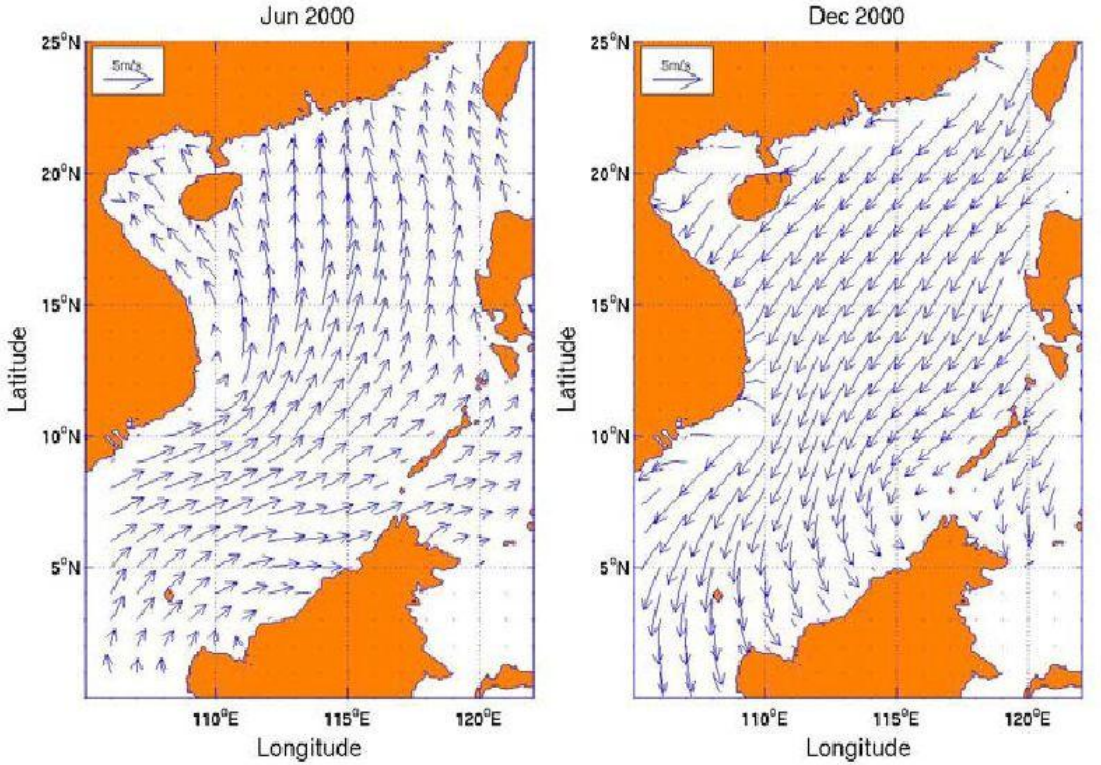
- Tropical to Arid climate
- Seasonal variation in wind direction



Modified from Blakey,2011

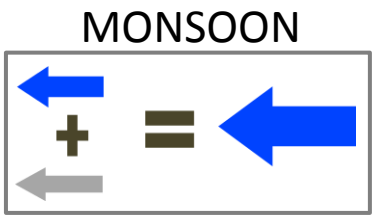
Modern Analog: Sunda Shelf

Synoptic-scale wind patterns during summer and winter monsoon seasons

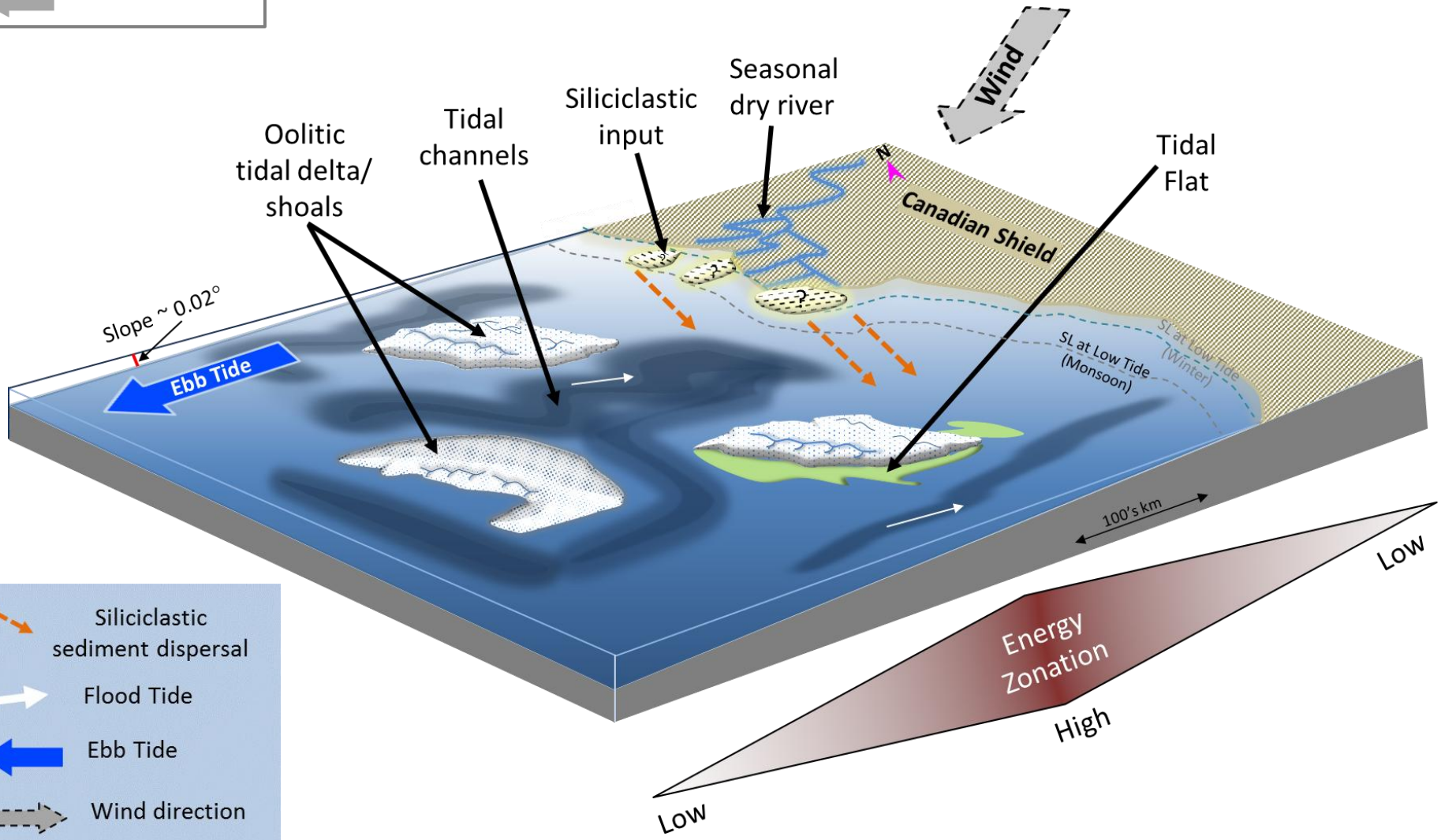


(Chu et al., 2003)

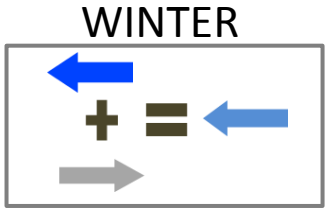
Depositional Model of Facies MB-D



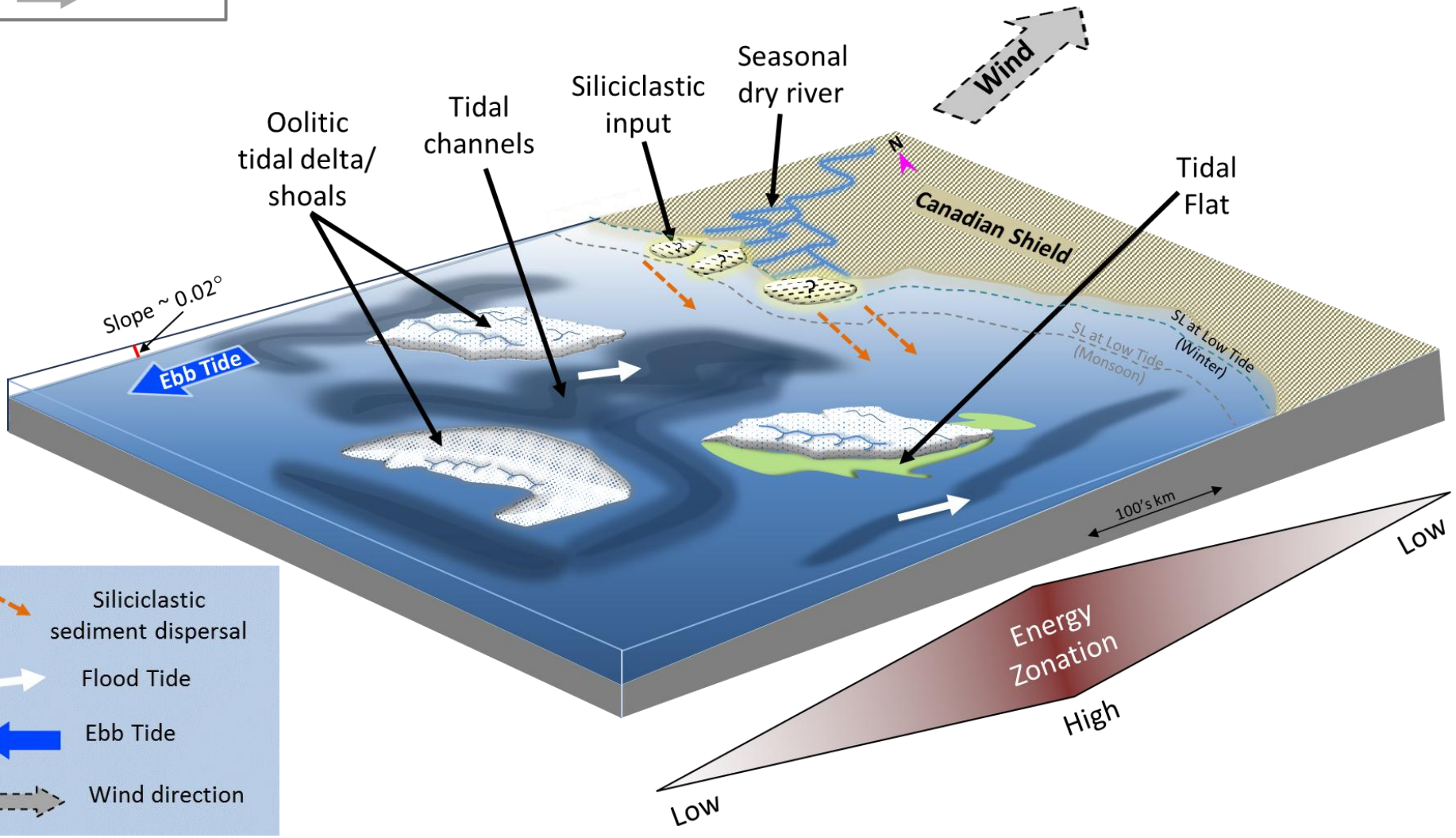
- Dominant ebb tidal direction is in phase with wind direction.



Depositional Model of Facies MB-D



- Dominant ebb tidal direction is out of phase with wind direction.



Key Takeaways

- Middle Bakken facies represents coeval sedimentation of siliciclastic and carbonate sediments in an epicontinental seaway setting.
- Tides, seasonal variation in wind direction and waves in combination helped in mixing of carbonates and siliciclastic.
- MB-D indicates a tide-influenced/dominated environment.
- Combination of different modern analogs can help in understanding ancient mixed-siliciclastic-carbonate deposits.

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Chevron

White Eagle Exploration

Statoil

Husky Energy

WPX Energy

Anschutz Exploration Corporation

EOG Resources

Newfield

The Energy of enerPLUS

Oasis

Schlumberger

Abraxas Petroleum Corporation

PlatteRiver Associates Inc.

XTO Energy

Samson

MJ Systems

IHS

Mike Johnson & Associates