Microbially Influenced Waulsortian Mound Reservoirs in the Lower Mississippian (Tournasian) Lodgepole Formation, Dickinson Field Complex, Williston Basin, North Dakota, USA*

William A. Morgan[1], Raymond W. Mitchell III[2], Mark A. Sheedlo[2], Susan L. Wygant[2], and Wayne M. Ahr[3]

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[1]Morgan Geoscience Consulting LLC, Madison, Wisconsin, United States (wamorgan24@gmail.com)
[2]ConocoPhillips, Houston, TX, USA
[3]Texas A&M University, College Station, Texas, United States

Abstract

Waulsortian mounds in the Lodgepole Formation of the Williston basin and Montana trough occur in both outcrop and the subsurface. They are Type 1 buildups consisting mainly of fenestrate bryozoan cementstones and peloidal muds. Skeletal wackestones, packstones, and grainstones are common as interbeds. Other skeletal components include crinoids, ostracods, forams, and sponge spicules. Centimeter-scale stromatactis vugs that may contribute significantly to total reservoir porosity are characteristic of the mounds. The stromatactis cavities have radiaxial calcite linings (commonly on fenestrate bryozoan sheets), geopetal peloids, cavity-dwelling microfossils that are absent from coeval, level-bottom beds, and internally resedimented peloids of multiple origins. The microbial signature within the mounds consists of small peloids that commonly form a clotted texture and are endemic, in contrast to larger peloids found locally within the mounds and in coeval, off-mound sediments. Dickinson mounds exhibit normal Mississippian carbon isotopic signatures and mound fossils exhibit high species richness and moderate dominance and are not chemoautotrophic. The mounds appear to have grown below wave base, and neither shallowing-upward trends nor evidence of subaerial exposure have been recognized in the mound succession. At Dickinson, the Lodgepole Formation ranges upwards of 300 m thick and the mounds are located within the oldest of two to three 3rd-order (2+ My each) Lodgepole sequences that form part of the transgressive phase of the 16 My Madison Group 2nd-order sequence. The Dickinson mounds appear to have nucleated on a subtle paleohigh situated some 80 km basinward of the toe-of-slope (TOS), unlike mounds elsewhere that typically grew within a few kms of the TOS. Individual Dickinson mounds are typically 100 m thick. As inferred from seismic data, the smallest mounds, which are 800 m in diameter, coalesced to form circular and loaf-shaped complexes as large as 2300 m by 7500 m. Porosity within the mounds is dominated by fractures and diagenetically enhanced depositional porosity that includes stromatactis vugs and interparticle porosity in grainstones. Fractures appear to have formed both syn- and postdepositionally. Average porosity in the mounds is 5%, and reservoir permeability ranges from approximately 200 to 2000 md. Waulsortian mounds and closely associated facies in the Dickinson field complex had approximately 104 MMBOOIP at the time of discovery in 1993.

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[1] Morgan Geoscience Consulting LLC
[2] ConocoPhillips (Retired)
[3] Texas A&M University (Deceased)

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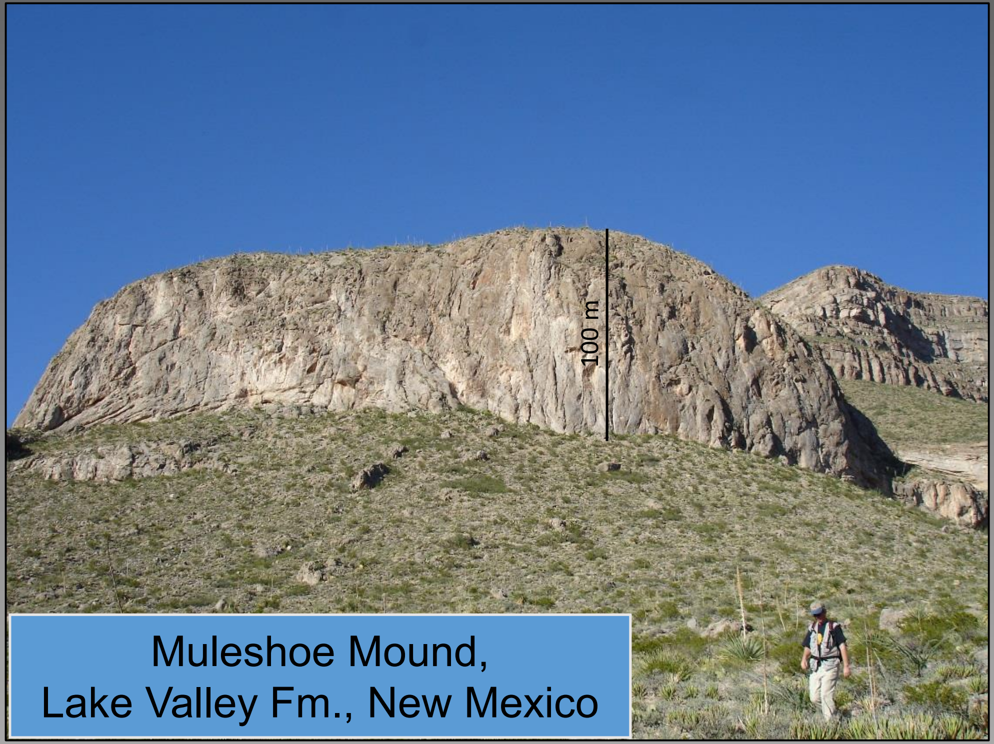


Muleshoe Mound,
Lake Valley Fm., New Mexico

"RESEARCH ON WAULSORTIAN FACIES OF THE SACRAMENTO MOUNTAINS, NEW MEXICO
or
CONFESSIONS OF A SUITOR OF LADY WAULSORT OF THE SACRAMENTOS"
Lloyd C. Pray

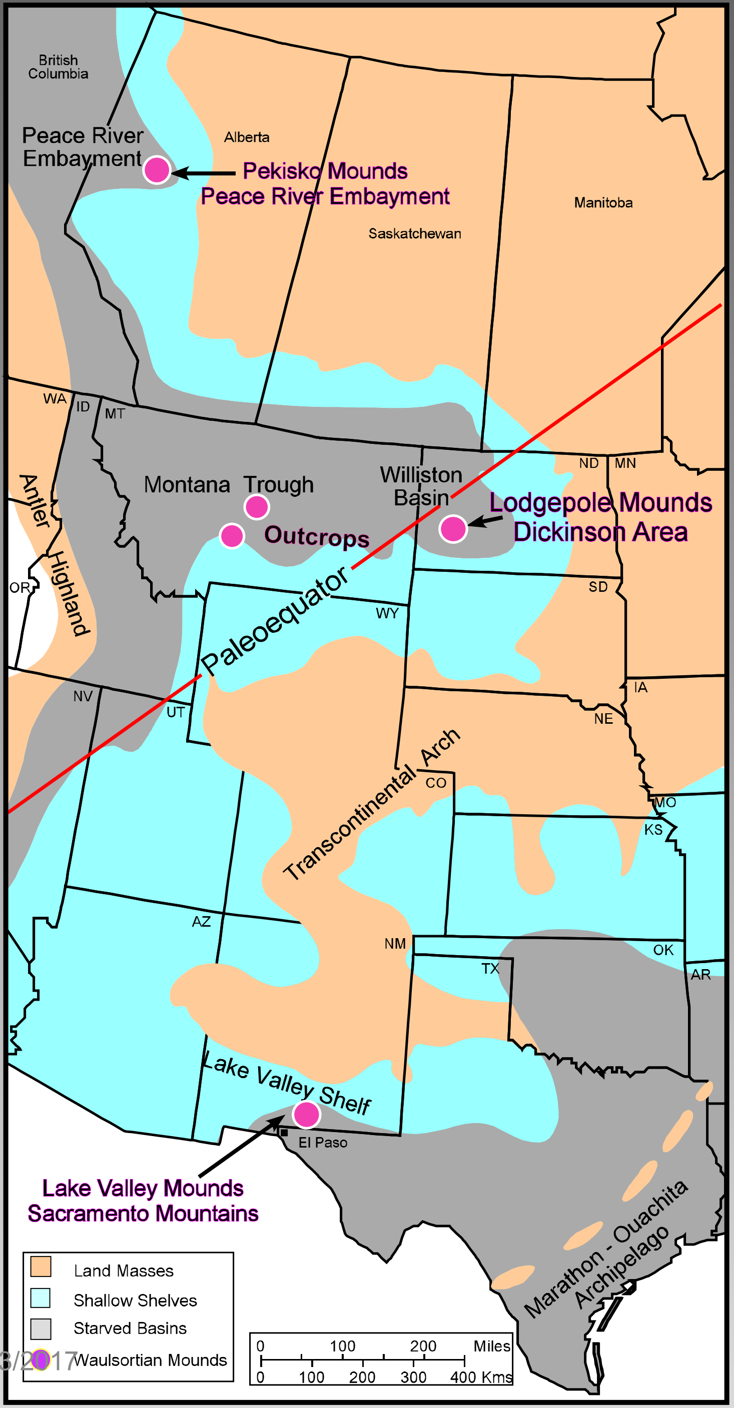
1982 Symposium on the Paleoenvironmental Setting and Distribution of the Waulsortian Facies
El Paso, Texas 1982

Outline

- Data Set
- Regional Setting
  - Paleogeography
  - Stratigraphy
  - Lodgepole ramp system
- Dickinson Mound Area
  - Mound facies and depositional model
  - Seismic identification
  - Why mounds nucleated in this area
  - Hydrocarbon production
- Conclusions

Data Employed

- Cores (903 ft total) and thin sections from 10 Wells in Dickinson area
- Thin sections of cuttings from 19 wells
- 21 basin-scale cross sections utilizing well logs from 370 wells
- 2D and 3D seismic data
- Outcrop studies in Montana, including gamma-ray logging of outcrops (Univ. of Oklahoma), to correlate outcrops to the subsurface

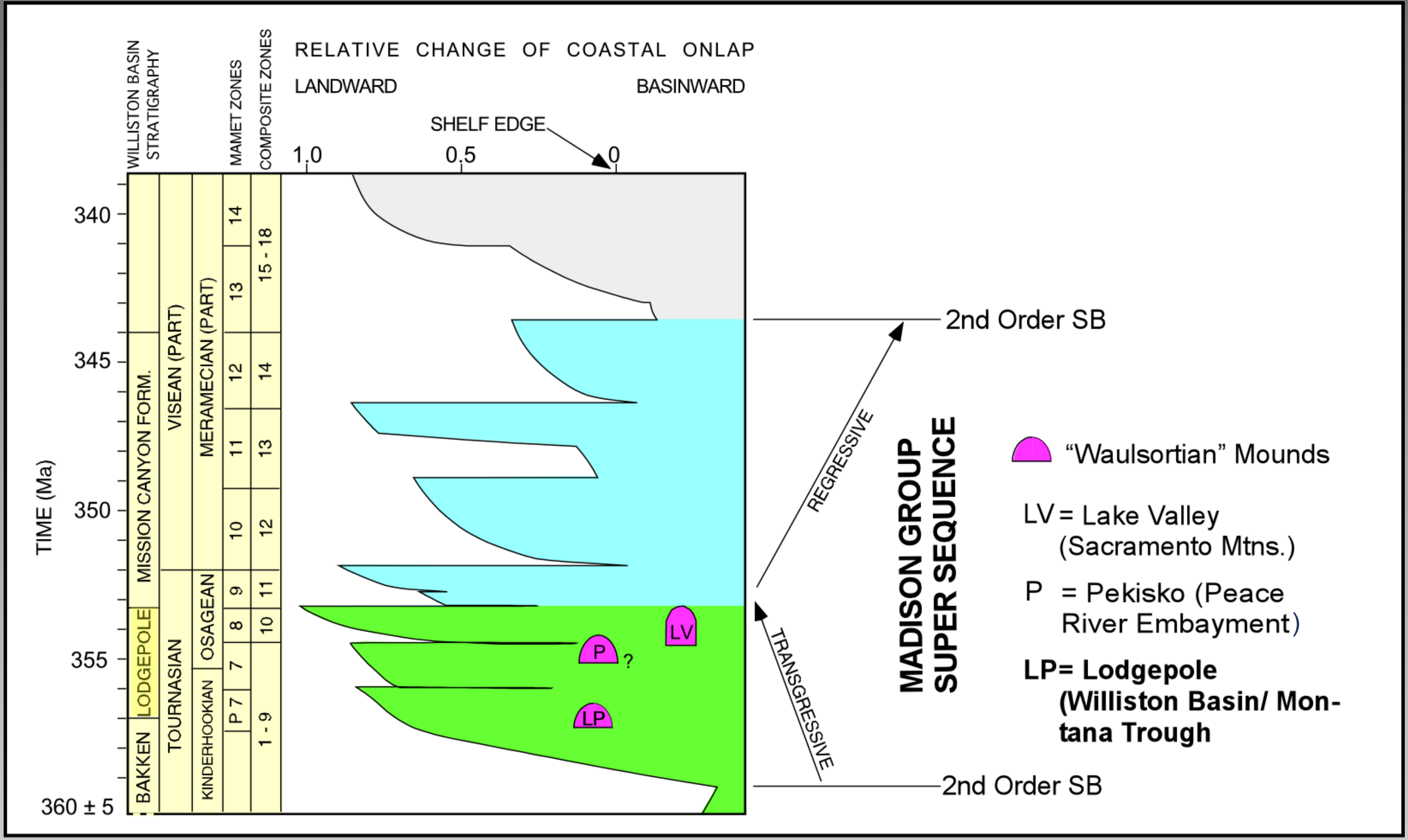


Early Mississippian Paleogeography

- Waulsortian style mounds common in early Mississippian Tournasian (Kinderhookian-Osagean)
- Typically located within few km of toe of slope
  - Unlike Dickinson mounds which are ~ 80 km (50 mi) basinward of toe-of-slope
- Pekisko and Lake Valley mounds initiated on paleo-topographic highs (Davies, 1989; Jeffrey and Stanton, 1996) – what about the Dickinson mounds?

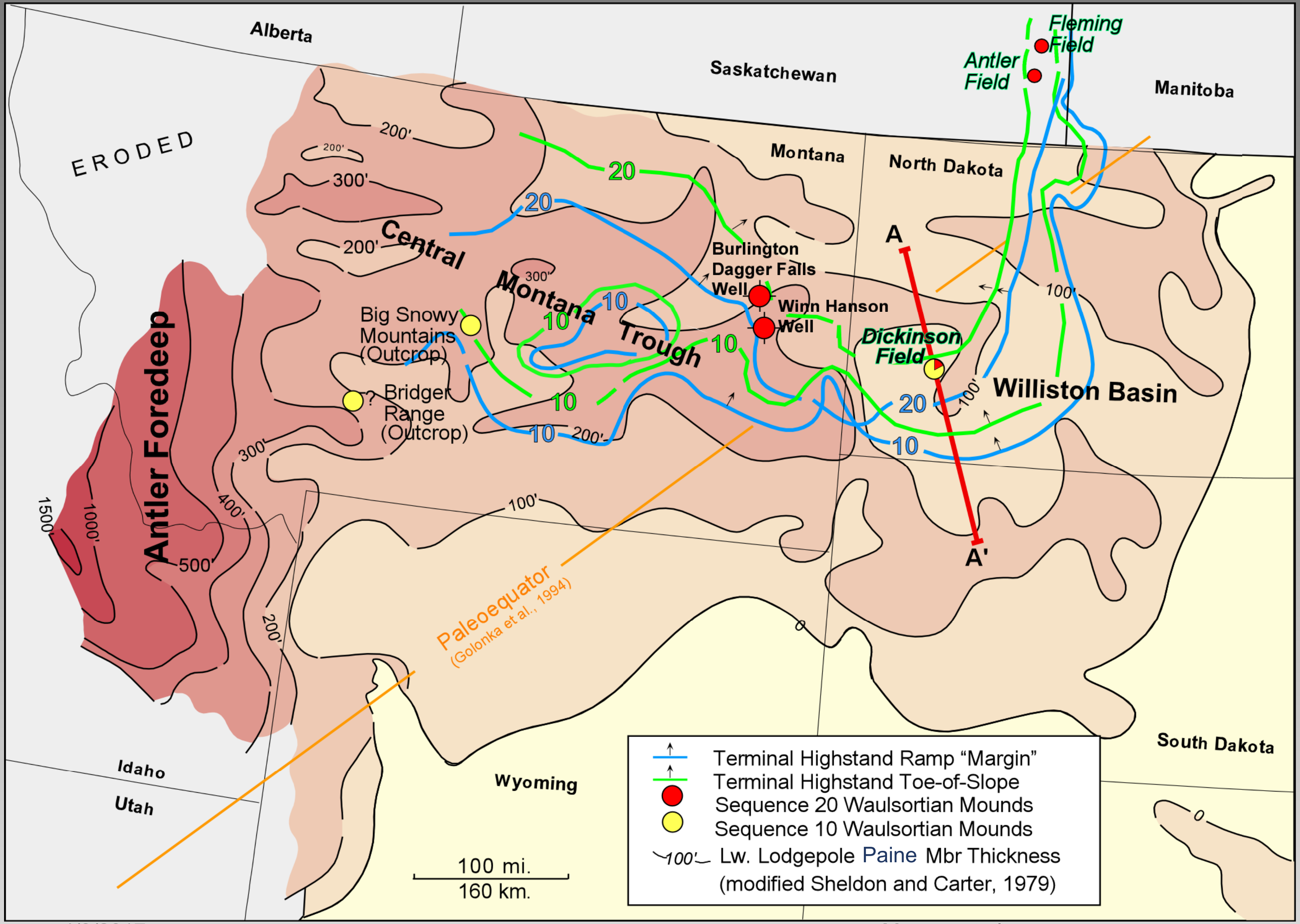
Compiled from Sheldon and Carter (1979), Davies et al. (1988), Byrd (1989), Golonka (1994), and Morgan et al.(1999).

Madison Group Coastal Onlap



Coastal Onlap-Offlap Curve for the Mississippian Madison Group Supersequence of Ross and Ross (1987); modified from Reid and Dorobek (1993).

Thickness of Lower Lodgepole Paine Member (Coeval with Waulsortian Mounds)



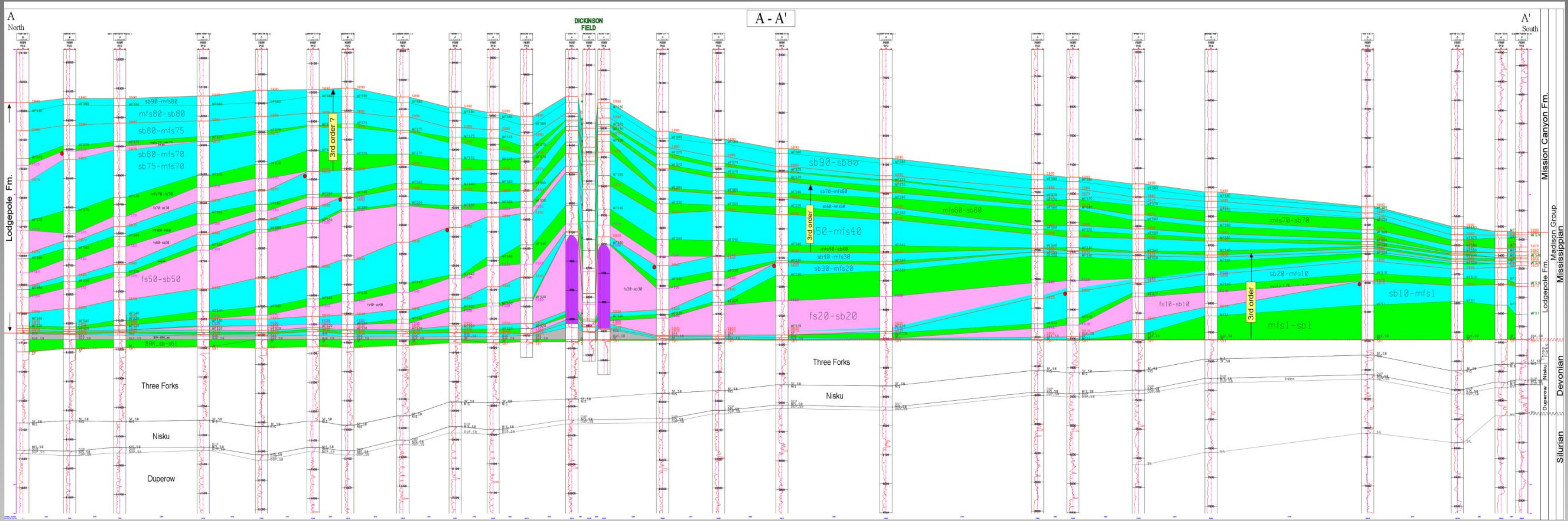
- Paine Member consists of deeper water argillaceous mudstone to skeletal wackestone
- Gradual basin-ward thickening reflects gently dipping ramp system
- Mounds initiate within 2 lower 4th order sequences (cycles)

Gamma-Ray Log Cross Section A-A’

Dickinson Field

NW

SE



200 ft

20 mi

- Three 3rd order sequences
- Ten 4th order cycles (400 Ky)
- Ramp angle <0.05° along eastern margin

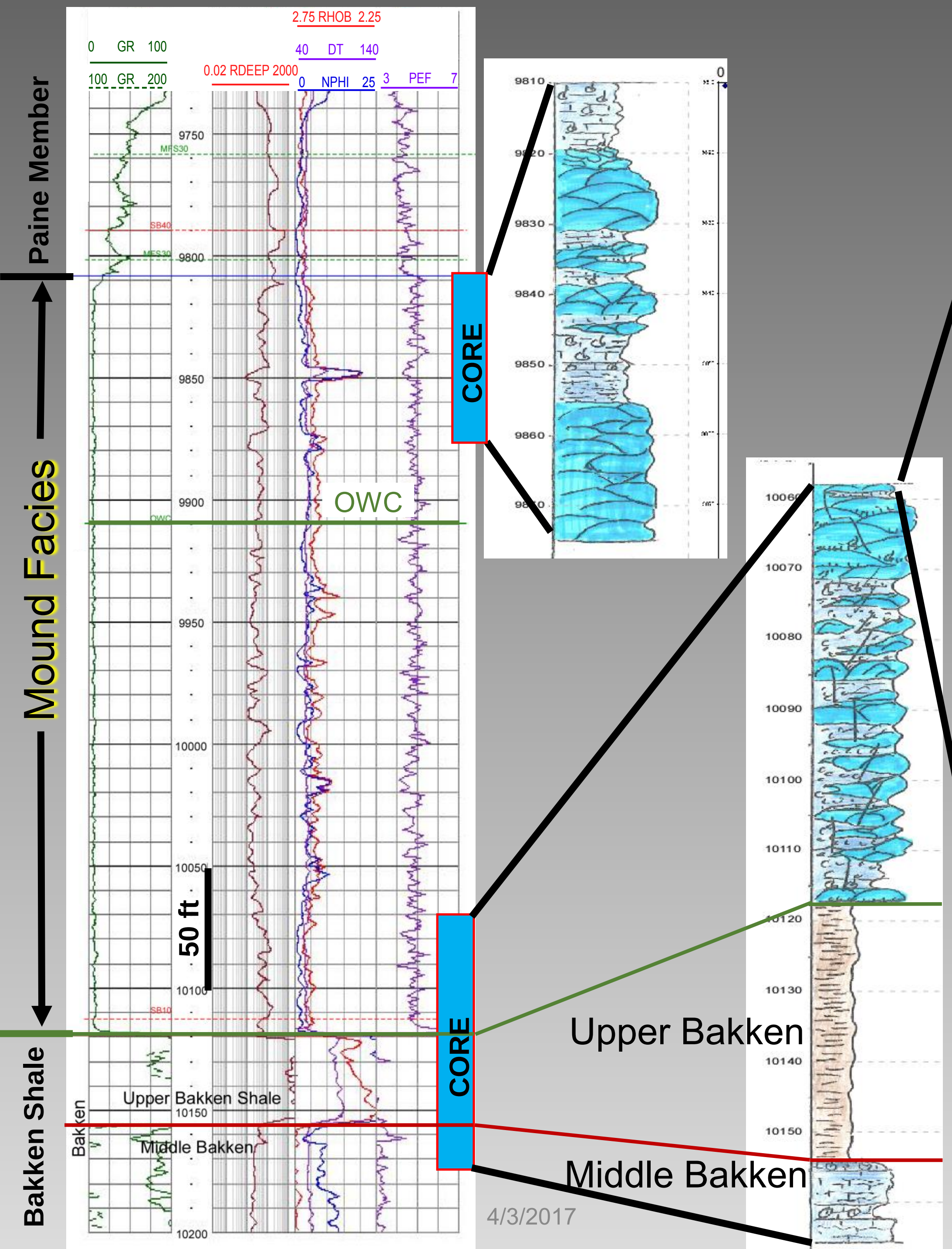
4th Order

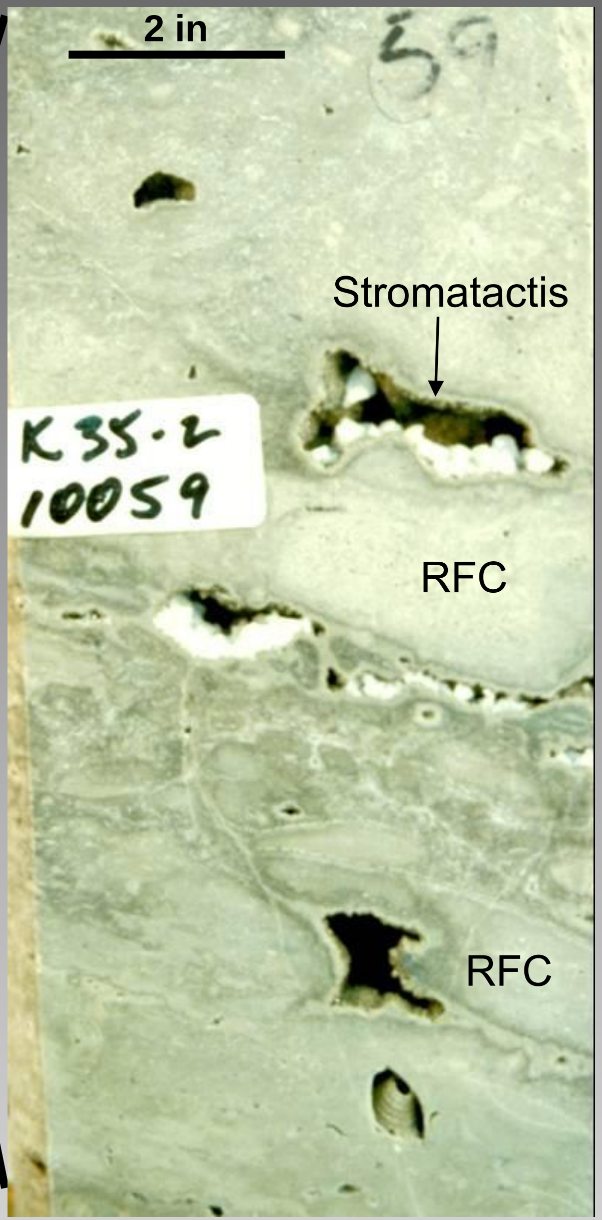
- Highstand Systems Tract
- Transgressive Systems Tract
- Lowstand Systems Tract
- Waulsortian Mounds

Datum = Base of Bakken Shale

Facies and Fabrics (Karsky 35-2 Well)

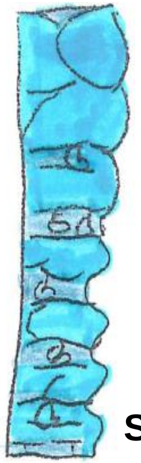
- Boundstones interbedded with peloidal/skeletal grainstones
- Diverse biota (fenestrate bryozoans, crinoids, rugose corals, ostracods, brachiopods, molluscs, forams)
- Large, laminar constructional voids with early marine cements (“stromatactis”)





RFC = Radiaxial Fibrous Calcite Cement

Mound “Cycle”



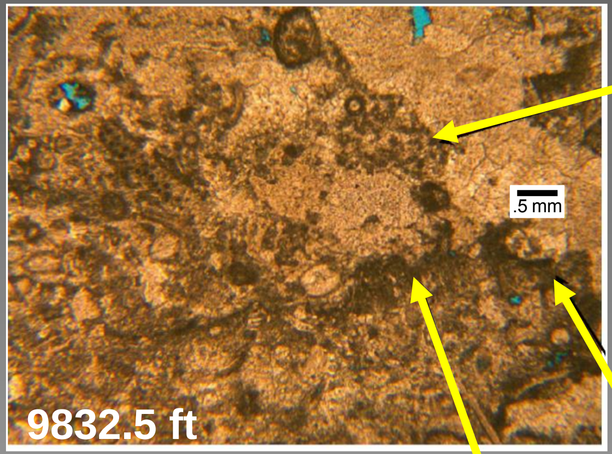
Thicker Beds: Microbially Mediated Muds, Cementstone with Stromatactis

Alternating Mudstone, Cementstone, Skeletal Packstones-Grainstones

Skeletal Pack-Grainstone Base

Microbial Fabrics Karsky 35-2 Well

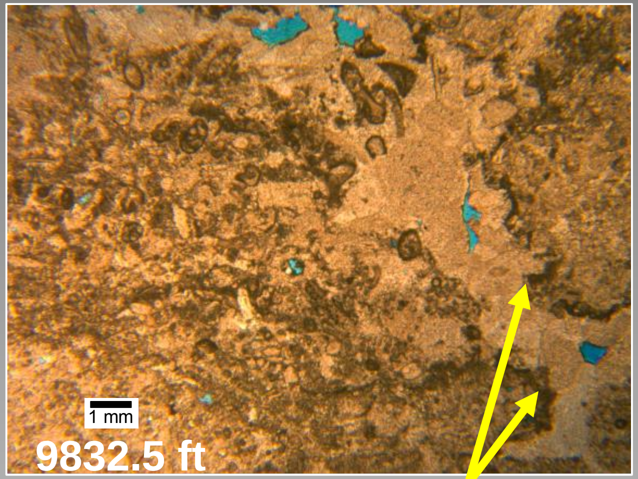
- Clotted micrite patches associated with (bounding) constructional voids, distinct from skeletal-fragment, peloidal grainy layers.
- Denser micrite commonly at edges of clotted micrite patches
- Faint traces of filaments in some clotted micrite patches
- Microbial fabrics do not occur in inter-mound facies



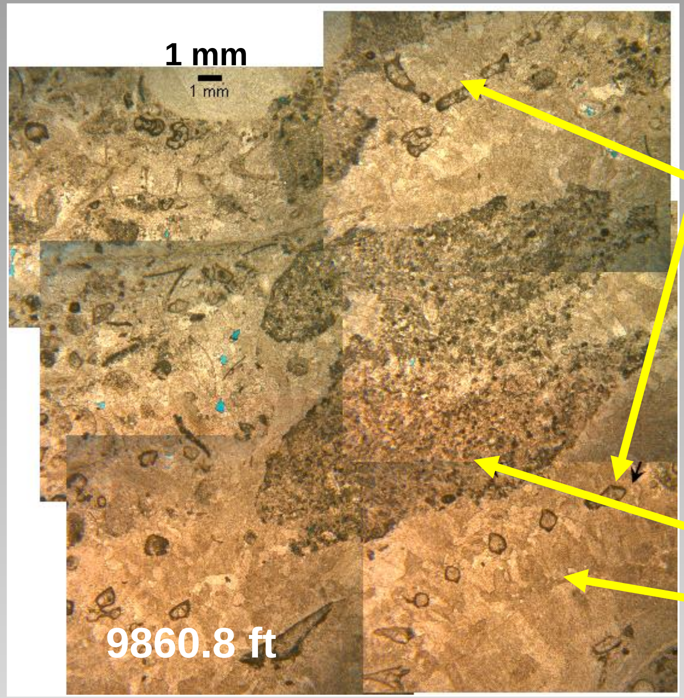
Micritic Clots

Dense micrite lining pore

Filaments?



Dense micrite lining pore



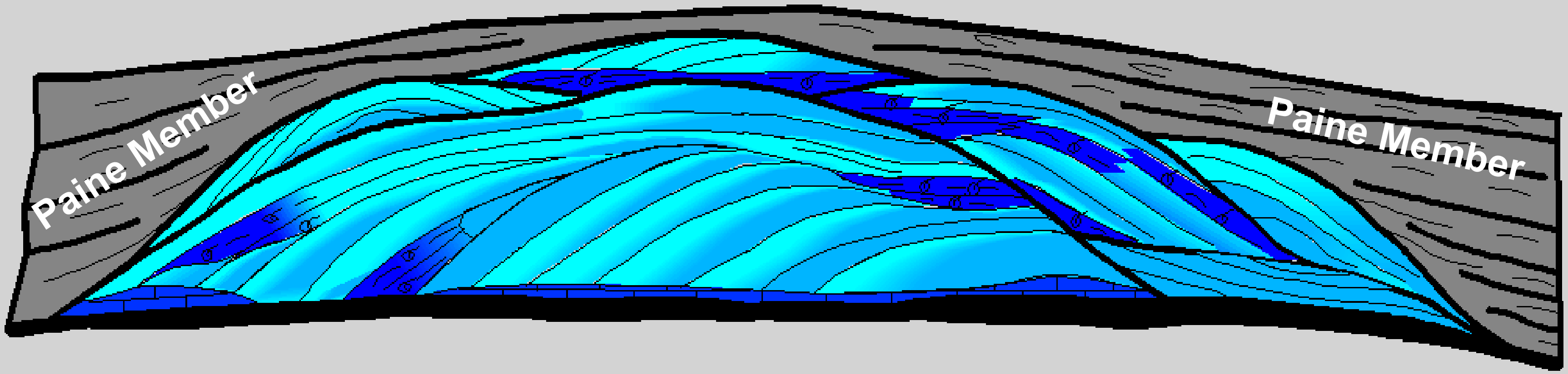
Cryptobiont fenestrate bryozoans

Clotted microbial mass with fine-grained peloids

Radiaxial fibrous calcite cement

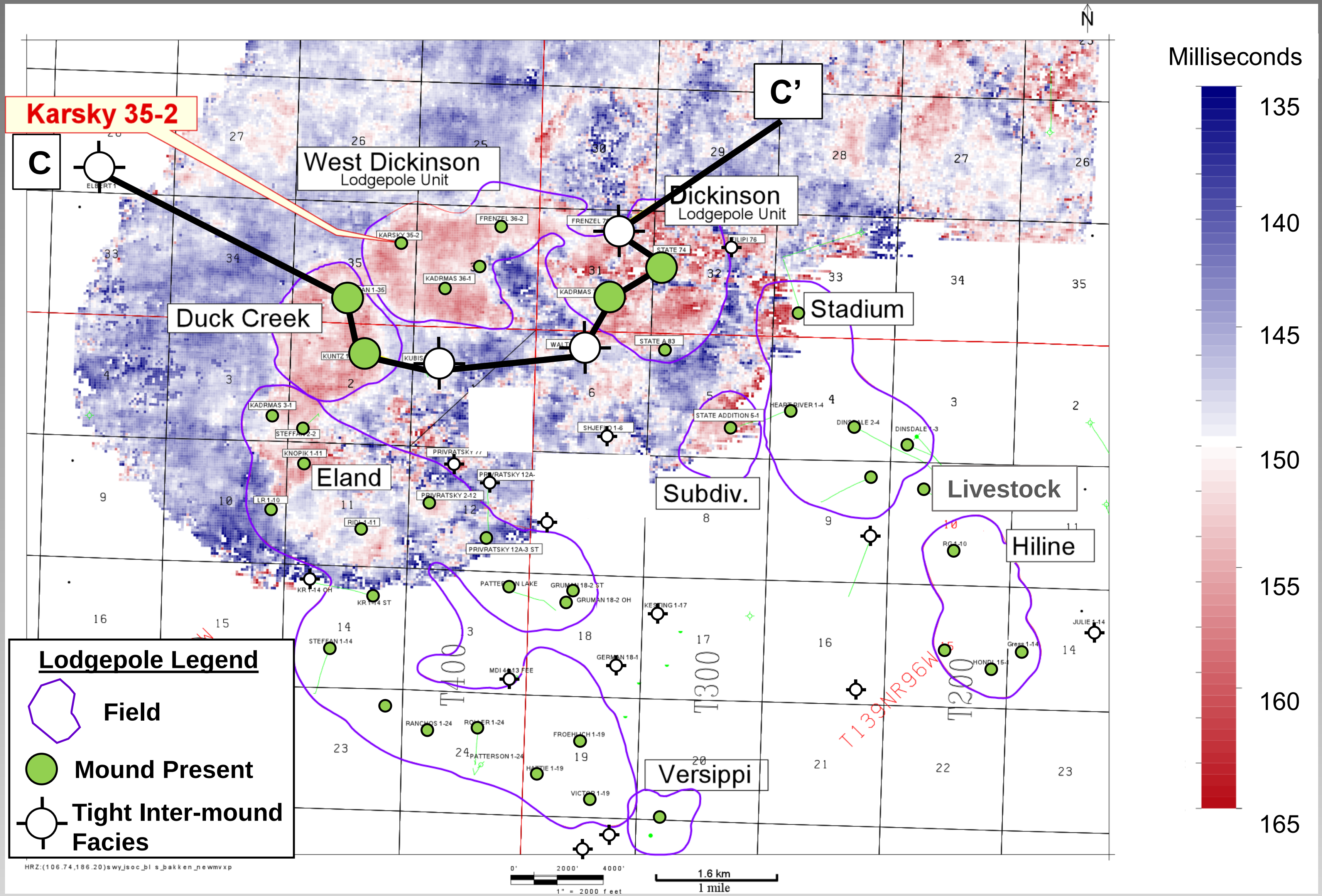
Thin-section photomicrographs (plane light)

Lodgepole Mounds – Depositional Model



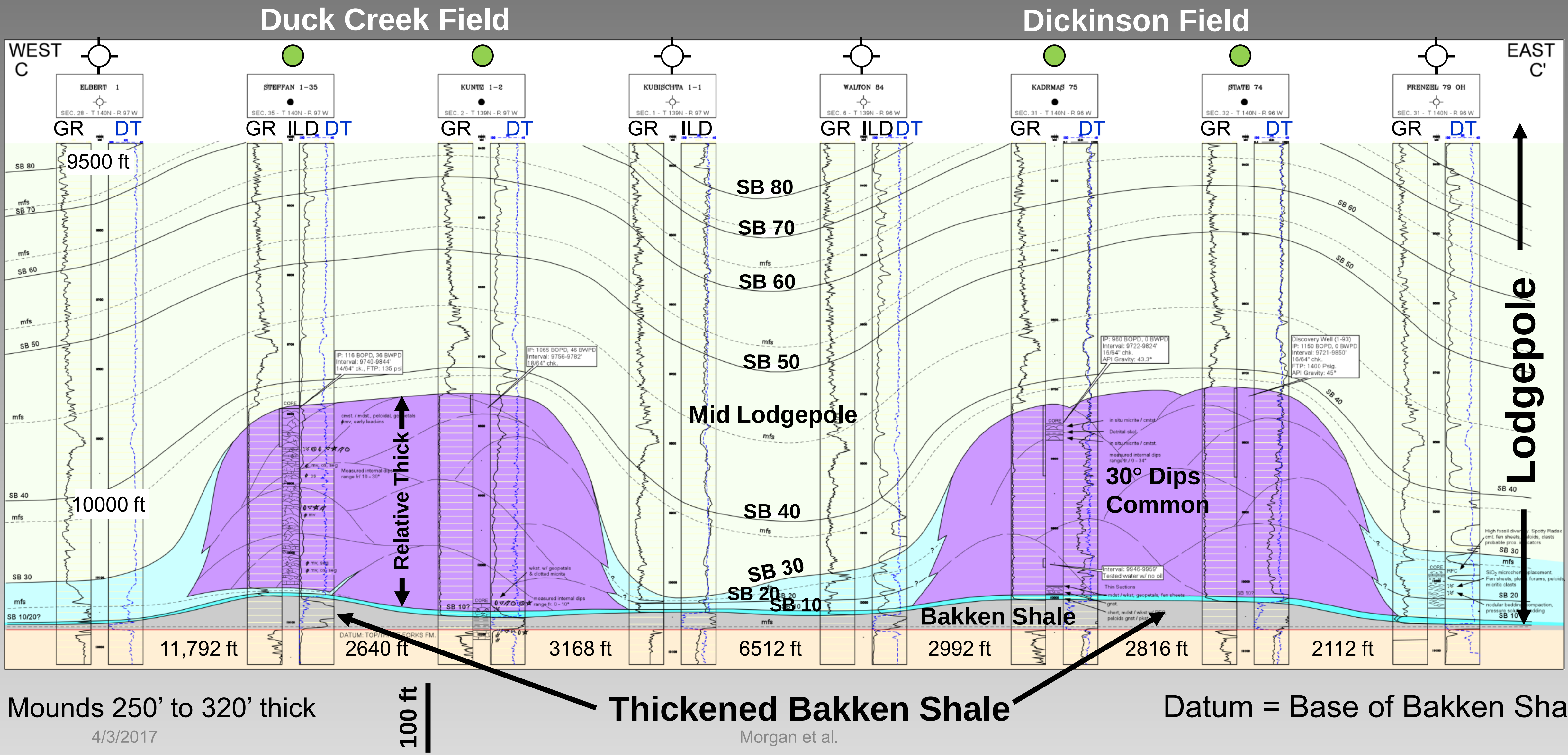
(modified from Young et al., 1998)

Base Charles Salt (Miss) to Top Bakken (Dev.) Time Interval



- ➢Time interval map shows mound locations as 10-30 ms "thicks" (red)
- ➢Higher sedimentation rate within mounds and less compactable compared to overlying and coeval Lodgepole succession

Schematic Cross-Section C-C' Showing Thickened Bakken Shale Underlying Dickinson Mounds

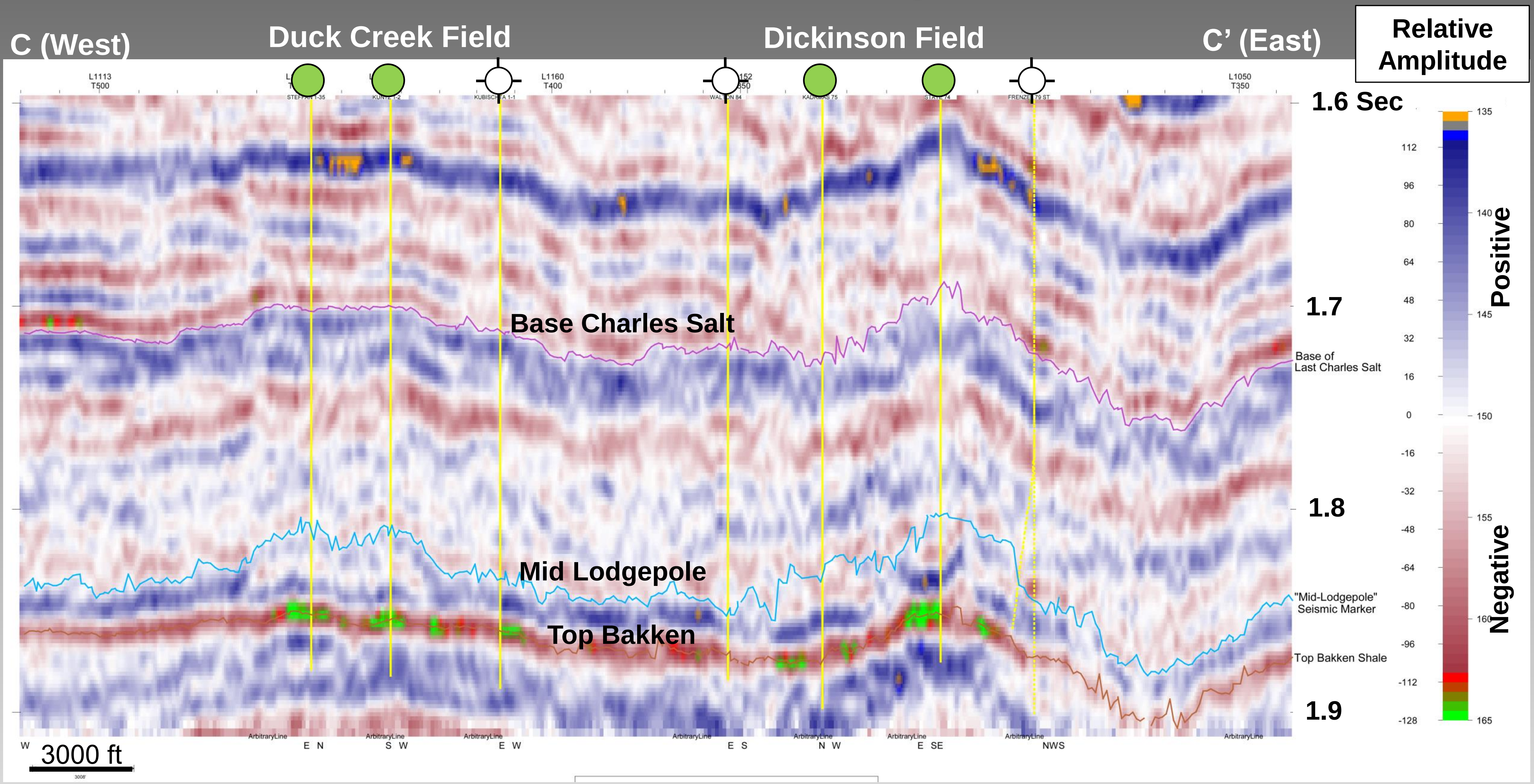


Mounds 250' to 320' thick

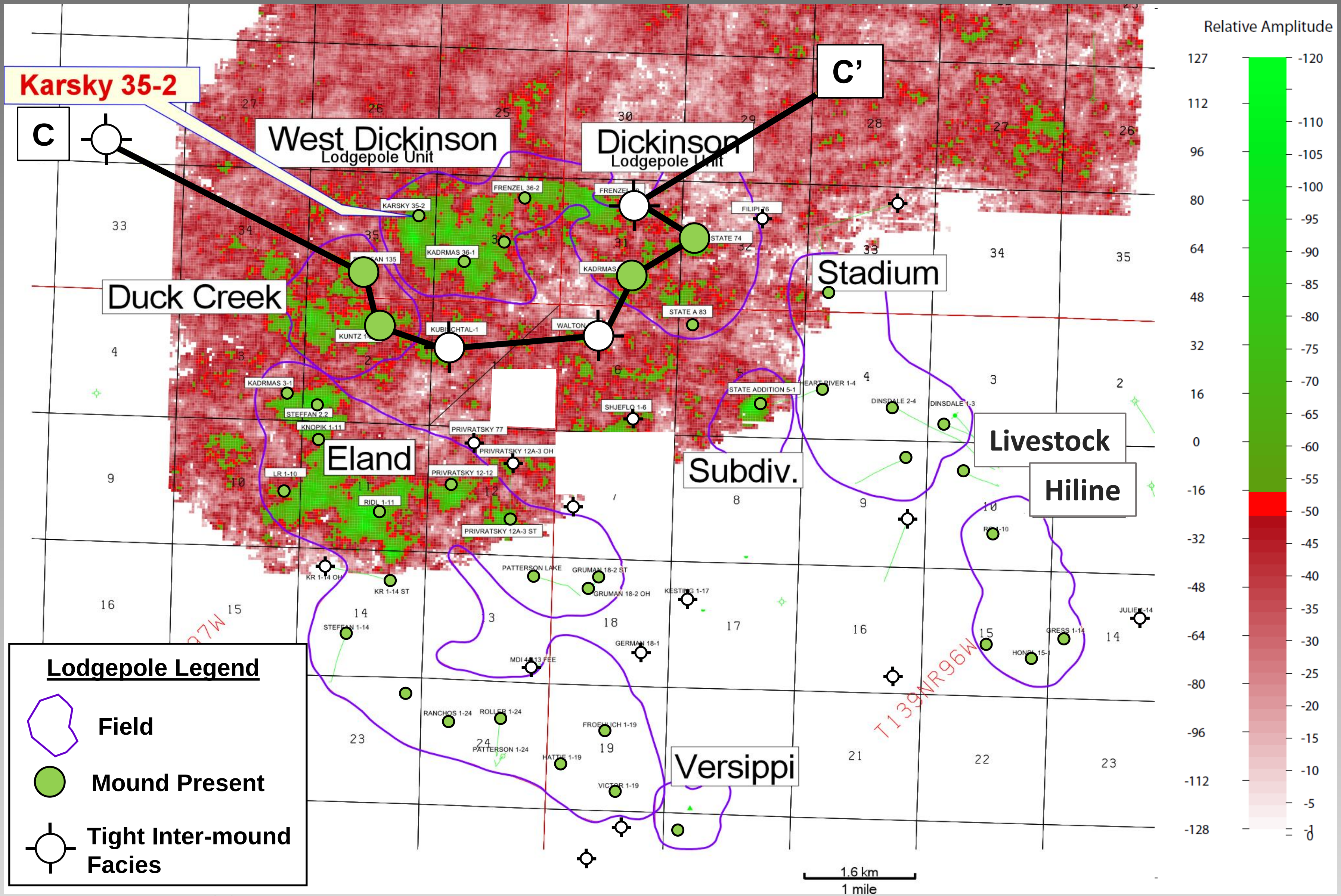
Datum = Base of Bakken Shale

Morgan et al.

Relative Amplitude Seismic Line Along Line of Cross Section



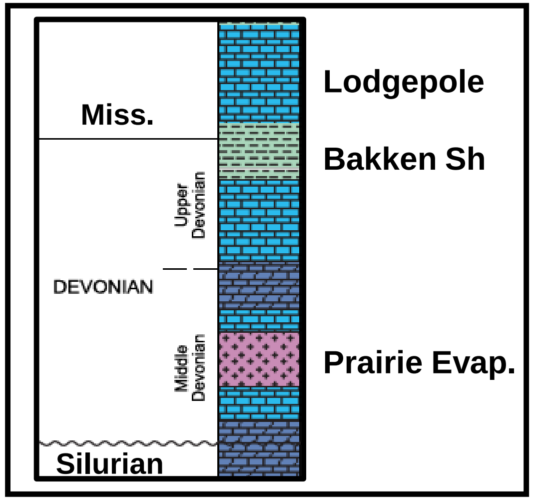
Bakken Shale Seismic Amplitude

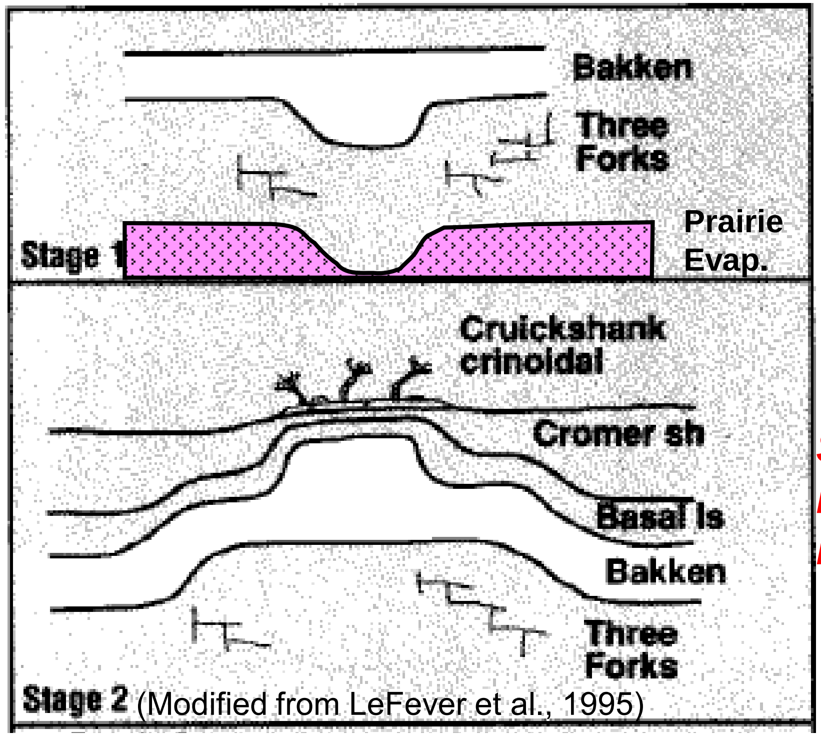


- Higher negative amplitudes (green) correspond to Bakken Shale thicks
- Overlying mounds are associated with thick upper Bakken Shale
- Why are Bakken thicks situated over areas presumed to be highs at time of mound initiation, based on analogue mound systems?

Hypotheses for Mound Nucleation on Thickened Bakken Shale in the Dickinson Area

Multi-phase Salt Dissolution

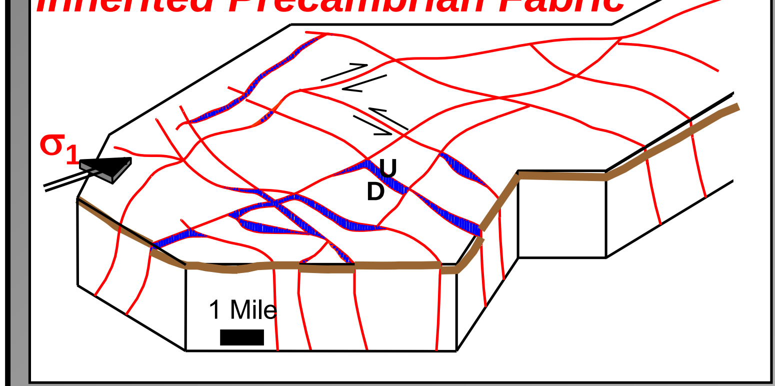


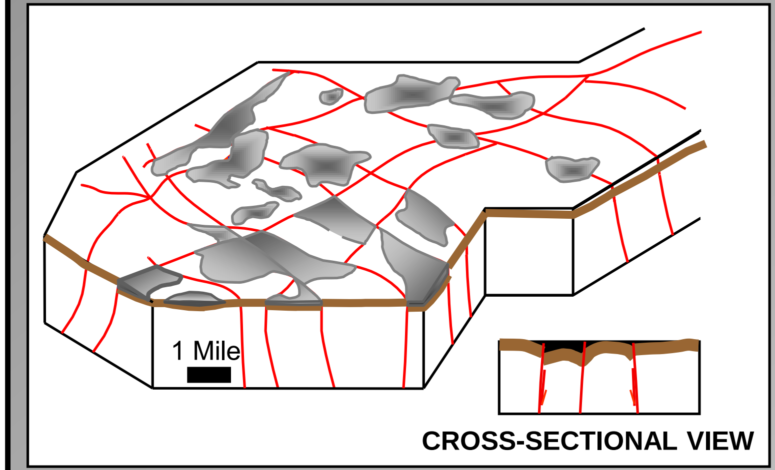


Stage 1 Local Salt Dissolution

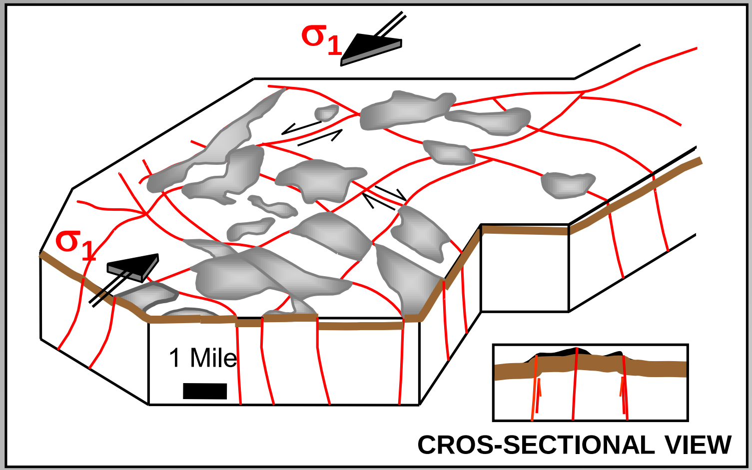
Stage 2 Regional Salt Dissolution

Upper Bakken Lows - Inherited Precambrian Fabric

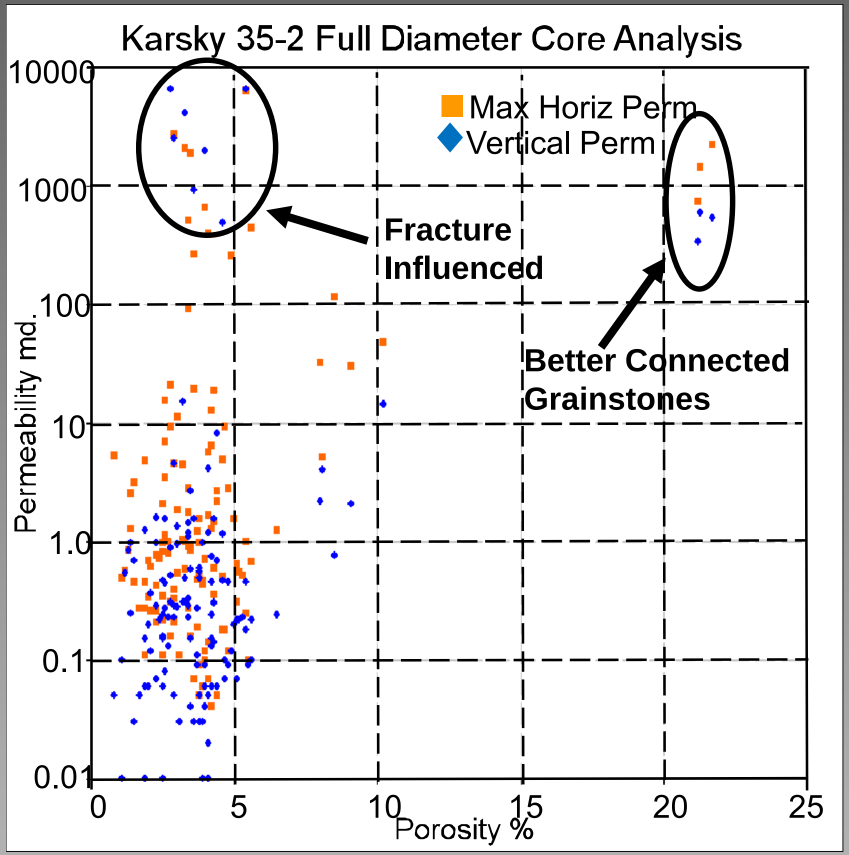


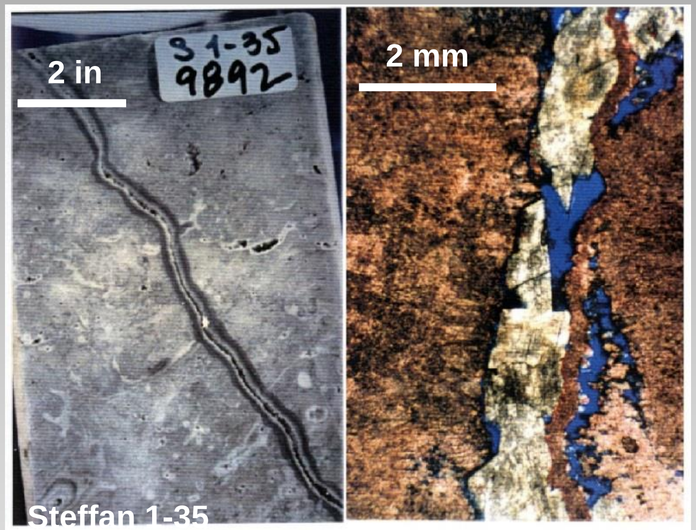


Lows filled with Upper Bakken Shale



Change in Stress Field Associated with Antler Orogeny in early Late Devonian Inverts Bakken Thicks





Reservoir Characteristics

- Average porosity of mound facies is 5%
  - Mostly diagentically enhanced interparticle porosity in grainstones and stromatactis vug porosity
- Low matrix permeability, but reservoir permeability 200-2000 md
  - Connectivity provided by fractures (syndepositional and tectonic)
- Initial rates of 325 to 2050 BOPD
- 180 ft oil column
- 104 MMBOIP at discovery in 1993
- Approx. 60 MMBO and 40 BCFG produced through 2015
  - Primary solution gas drive; secondary water flood

Conclusions

- Dickinson mounds located unusually distant from the toe-of-slope, possibly on subtle highs associated with thickened upper Bakken Shale.
- Strong microbial influence on mound growth.
- Interparticle porosity in grainstones and stromatactis cavities – both modified by later diagenesis
- Excellent reservoir connectivity resulted from syn- and post-depositional fractures creating good intra-mound permeability.

Our Thanks to ConocoPhillips for Permission to Present This Talk

A personal thanks to Lloyd, who sparked and encouraged my interest in carbonates and has been a life-long inspiration.

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