Sequence Stratigraphy of Lower Madison Strata in the Greater Williston Basin Area*

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Abstract

The Madison 2nd-order sequence is a late Devonian to early Carboniferous sequence that was originally defined in Wyoming outcrops, where it is bounded by major, regional, subaerial unconformities. The basal unconformity beveled the Williston basin area during Famennian exposure forming a low-relief surface. Following unconformity development, a slow transgression occurred, and this led to shallow-water deposition of Bakken and Bakken-equivalent sediments in partially connected basins. In the greater Williston basin area, a 2nd-order maximum flooding surface separates underlying Bakken and equivalent stratal units (Englewood, Cottonwood Canyon) that were deposited in separate basins, from overlying Lodgepole stratal units that represent sediments deposited after maximum flooding. The 2nd-order transgression corresponded with a rapid, 100-meter relative sea-level rise that inundated western North America with open-marine Lodgepole deposition.

Regionally, the maximum flooding surface may overlie: 1) a stylolitic contact, 2) a transgressive lag deposit, or 3) a heterogeneous, glauconitic, skeletal-intraclastic grainstone, packstone and wackestone unit. In western basin-flank outcrops (Little Rocky Mountains, Big Snowy Mountains, and Little Belt Mountains), the maximum flooding surface is overlain by dark, thinly bedded, argillaceous, deep-water mudstone and skeletal mudstone. Deep-water carbonate bioherms grew locally in the sediments overlying the maximum flooding surface. The dark mudstone transitions upward and landward (Bighorn Mountains, Black Hills) into skeletal wackestone. These deposits are overlain by five cycles that are defined in landward areas by vertical transitions from a skeletal-oolitic grainstone to a peloidal mudstone. The cycles parallel biozones, marker beds and sequence boundaries. Cycles are progradational into the Williston Basin and aggradational in central Montana. In the Williston Basin, the basal skeletal-oolitic unit (Scallion) transitions seaward to a crinoid-dominated packstone and wackestone facies that transitions further seaward to a clinoform-toe skeletal wackestone and mudstone-dominated facies that downlaps on the maximum flooding surface.

References Cited


Skinner, O.L., K.L. Canter, M.D. Sonnenfeld, and M.R. Williams, 2015, Discovery of “Pronghorn” and “Lewis and Clark” Fields: Sweet-Spots within the Bakken Petroleum System Producing from the Sanish/Pronghorn Member NOT the Middle Bakken or Three Forks: Forum: Discovery Thinking, at AAPG Annual Convention and Exhibition, Long Beach, California, USA, April 22-25, 2012 Search and Discovery Article #110176 (2015). Website accessed November 2019


Wilson, J.L., 1975, Carbonate Facies in Geologic History: Springer-Verlag, New York, 471 p.
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EARLY MISSISSIPPIAN PALEOGEOGRAPHY
Lower Lodgepole Deposition

Note: 1) Study area location, 2) Epeiric sea (light blue), and 3) paleo-equator

Williston Basin Stratigraphic Column

Major Basin Margin Unconformity

Madison 2nd-order MFS

Acadian Unconformity

Williston Basin Stratigraphic Column

Subject of this presentation
Overview of Controversial Issues Related to Lower Madison Sequence Stratigraphy

• Bakken sequence stratigraphy is controversial
• Origin of Bakken shale controversial
  • Deep-water vs. shallow-water origin
  • Depositional environment interpretation
• Bakken to Lodgepole transitional nature controversial
• Placement of Madison MFS debated
• Origin of Lodgepole cycles has been debated
• Exact number of Lodgepole cycles has been argued
• Chronostratigraphy of Lodgepole facies controversial
Williston Basin Stratigraphic Column

**Williston Basin Stratigraphic Column**

- **Southern Basin**
  - Upper Kibbey Fm.
  - Lower Kibbey Fm.

- **Central Basin**
  - Poplar Interval
  - Charles Formation
  - Ratcliffe Interval
  - Mission Canyon Fm.
  - Frobisher-Alida Int.
  - Lodgepole Fm.
  - Tilston Interval
  - Bottleineau Interval
  - Bakken Formation

**DEVONIAN**
- Frasnian
  - Visean

**CARBONIFEROUS**
- ONLAP
- Upper Member
- Middle Member
- Lower Member
- Pronghorn Mb.
- Three Forks Formation
- Birdbear Formation
- Duperow Formation

**HST**
- Madison 2nd-Order Sequence


**LST/TST** = (Skinner et al., 2010, 2015)
- Pronghorn = LST
- Bakken Mbs. = TST
PALEOGEOGRAPHY

Lower Bakken and Equivalent

Lower Bakken deposition in low-accommodation, partially connected sub-basins

Lower Lodgepole

Basal Lodgepole deposition in an epeiric sea

Stratigraphic characteristics indicate shallow-water deposition:

- Bakken and equivalent units confined to basinal areas
- No direct landward equivalent strata
- Unequivocal shallow-water middle Bakken deposition
- Shallow-water coastal onlap during Bakken deposition

Interpretation: epeiric lagoonal environment with 0-30 m water depth

Williston Basin Stratigraphic Column

100 m sea-level rise
Smith (1977); Petty (2019)

2nd-Order Maximum
Flooding Surface

Note: Bakken shale deep-water advocates place a MFS within the Bakken shales
Maximum Flooding Surface

- To the extent that they define it, advocates for deep-water Bakken mud deposition commonly place a maximum flooding surface somewhere within the Bakken shales (e.g., Angulo and Buatois 2012; Egenhoff and Fishman 2013; Jin et al. 2015; Nandy et al. 2014, 2015; Borcovsky et al. 2017; Sonnenberg 2017), although it is usually not clear whether this refers to a 2\textsuperscript{nd}, 3\textsuperscript{rd} or 4\textsuperscript{th}-order flooding surface.
- Most Madison sequence stratigraphy researchers place the Madison 2\textsuperscript{nd}-order maximum flooding surface (or a major flooding event) above the Bakken, and at or near the base of the Lodgepole (e.g., Smith, 1977; Hendricks, 1995; Sonnenfeld, 1996; Petty, 2003, 2006, 2010, 2019; Skinner et al., 2010)
**Line B-B’**

- **Seaward**
  - Dry Fork Section
  - Little Chief Canyon Section
  - Little Tongue River Section

- **Landward**
  - Boxelder Section

**Shallow-Water Paine facies**
- Dominantly skeletal wackestone

**Paine “dark mudstone facies”**
- DEEP-WATER DEPOSIT
  - Thinly bedded mudstone and skeletal mudstone

**“Basal Paine facies”**
- SHALLOW-WATER OPEN-MARINE DEPOSIT
  - LAGOONAL DEPOSIT

Facies from Smith (1977)
Basal Paine Facies

- Discontinuous, glauconitic, heterogeneous, skeletal wackestone and packstone, minor grainstone
- Smith (1977, p. 192) argued that the “basal Paine facies” represents a “relatively rapid transgression of the Madison sea.”

**Interpretation:**

- *Transgressive deposit formed during maximum flooding*

**Note:**

- *Not same unit as Scallion*
“Shallow-water Paine facies”
Dominantly skeletal wackestone

Paine “dark mudstone facies”:
**DEEP-WATER DEPOSIT**
Thinned bedded mudstone and
skeletal mudstone

“Basal Paine facies”
**SHALLOW-WATER OPEN-MARINE DEPOSIT**

Facies from Smith (1977)
Lodgepole Cycles

- Exact number of cycles is controversial
- Five cycles widely recognized in Lodgepole and equivalent strata:
  - Smith (1972a, 1972b) in central Montana
  - Haines (1999) in southern Alberta
  - Petty (2003) in northwest South Dakota
  - Petty (2005) in northern Wyoming
  - Petty (2019) in Williston basin
- Middle cycles are generally thinner, may be discontinuous and may not be recognized in some areas
Cycle Definition Varies:

Williston basin: Tilston interval
Petty, 2005

Anhydritic Mudstone-dominated

Grainstone

Mudstone

Central Montana: Cycle 5 of Smith, 1972a, 1972b

Bottom line: As used here, correlations start in Williston basin and extend to other areas
1. Monarch-Dry Fork Section; T16N-R7E, Sec. 27 & 35; Sando and Dutro, 1974
2. Swimming Woman Section; T11N-R19E, Sec. 9; Smith, 1972
3. Little Tongue River Section; T56N-R87W, Sec. 15, 26, 27; Sando, 1976; Petty, 2005
4. Boxelder Section; 2N-6E, Sec. 16 & 17; Petty, 2003

**Dominant Lithologies**

- Skeletal-oolitic grainstone
- Laminated dolomitic mudstone & skeletal mudstone; peloidal limestone
- Dolomitic mudstone & peloidal limestone with solution breccia or anhydrite
- Open-marine skeletal-peloidal limestone
Nomenclature Terminology Used Here
Taken from Williston Basin Usage

Note: Tilston interval is best-constrained sequence biostratigraphic unit in study area

Dominant Lithologies
- Skeletal-oolitic grainstone
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Lower Tilston Oolite

Note: massive, fabric-destructive dolomitization occurred in some landward areas

Scallion Oolite
Top-Scallion Contact in Little Tongue River Section, Wyoming

Skeletal Grainstone, Packstone and Wackestone

Starved Basin
Condensed Deposition
Scallion Very Thin in Basin-Center

Scallion Oolite Limit

Little Tongue River Section

Scallion Oolite Distribution

Data used is from Sando, 1967; Smith, 1972; Sando and Dutro, 1974; Peterson, 1987; Elrick and Read, 1991; Sonnenfeld, 1996; Petty, 2003, 2005; Commercial sample logs
Little Tongue River Section

Peloidal Mudstone
Scallion Grainstone

Photograph Next Slide
Little Tongue River Section
Section 27, T56N-R87W
Bighorn Mountains, WY

Thickly bedded, cross-stratified Scallion, overlain by thinly bedded Lower Virden
Discussion: End-Member Mechanisms for Cycle Formation

**Seaward**

Red = Time Lines

- Dolomitic Peloidal Mudstone
- Anhydrite
- Oolite
- Open-Marine Skeletal-Peloidal Limestone

**Landward**

One Cycle

**Mechanism 1.**
- Single facies association with diachronous facies; cyclicity caused by transgression induced by sea-level rise
- Most popular mechanism
- These facies relationships are not mappable in areas with dense control

**Mechanism 2.**
- Two facies associations; each is broadly synchronous; cyclicity caused by paleoclimate change: arid (mudstone) to humid (oolite)
- These lateral facies transitions can be mapped within an inferred chronostratigraphic interval in an area with dense control (Tilston in North Dakota; Petty, 2005)
Lower Madison Sequence Stratigraphy
Key Conclusions

- Bakken is Transgressive Systems Tract for Madison
  - Shallow-water Bakken and Bakken-equivalent units formed by coastal onlap in partially-connected basins
- Madison Maximum Flooding
  - Occurred after all Bakken deposition
  - Relatively rapid, regional sea-level rise (≈100 m)
- Basal Lodgepole (Paine equivalent)
  - Widespread open-marine, deep-water deposition
- Middle/Upper Lodgepole shallow-water cyclic deposition
  - Hemi-cycles represent synchronous facies associations linked to specific environmental conditions