A Sequence Stratigraphic Framework for the Niobrara Formation in the Denver-Julesburg Basin*

William R. Drake¹ and Sarah J. Hawkins²

Search and Discovery Article #50757 (2012)**
Posted November 30, 2012

*Adapted from oral presentation given at AAPG Rocky Mountain Section meeting, Grand Junction, Colorado, 9-12 September 2012
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Abstract

The Upper Cretaceous Niobrara Formation in the Denver-Julesburg Basin records late Turonian to early Campanian climate and orbital cycles and tectonic events. The third-order transgressive-regressive events of the Niobrara Cyclothem govern the character of the pelagic and hemipelagic sedimentation of the formation. During sea-level high stands, the depositional system was dominated by increased biogenic productivity and lesser preservation of organic material. In contrast, low stands involved increased terrigenous sediment influx and greater preservation of organic material. Mapping sequences that comprise these stratigraphic trends is important to operators currently exploiting the Niobrara petroleum system.

We employ a sequence stratigraphic framework for the Niobrara Formation in the Denver-Julesburg Basin, based on log character but independent of lithostratigraphy, that reveals the architecture of key depositional packages. Based on detailed correlations using wire-line logs from over 2,000 wells, we present a series of isochore maps and cross sections that show 1) stratigraphic thinning that we interpret as seafloor topographic features such as subtle submarine channel floors, 2) stratigraphic thickening that we suggest is compensational infilling of accommodation space, and 3) the chronology of abrupt shifts in the trends of these depositional features. We constrain the timing of tectonic/geomorphic features revealed in the isochore maps with published cyclostratigraphic analysis, biostratigraphy, and geochronology data.

Findings include the following: 1) generally broad shelf deposition during the late Turonian was replaced in the Coniacian by subtle NW-SE- and E-W-oriented submarine channels, with compensational infilling by younger sequences; 2) the first evidence of paleobathymetric highs (e.g., the “Wattenberg High”), and disruption of submarine channel orientations, appears during the middle Santonian (~85-84 Ma), and 3) upper Santonian-lower Campanian sequences are dominated by SW-NE-oriented architecture.
References


Laurin, J., and D. Ulicny, 2004, Controls on a shallow-water hemipelagic system adjacent to a siliciclastic margin - example from late Turonian of Central Europe: Journal of Sedimentary Research, v. 74, p. 697-717.


Weimer, R.J., 1986, Relationship of unconformities, tectonics, and sea level changes in the Cretaceous of the Western Interior, United States, in J.A. Peterson, (ed.), Paleotectonics and sedimentation in the rocky Mountain Region, United States: AAPG Memoir 41, p. 397-422.

**Website**

A sequence stratigraphic framework for the Niobrara Formation in the Denver-Julesburg Basin

William R. Drake\textsuperscript{1} and Sarah J. Hawkins\textsuperscript{2}

AAPG Rocky Mountain Section
September 10, 2012

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Outline

- Overview of Niobrara Cyclothem
- Reference section and lithostratigraphy
- Set up of sequence stratigraphy, cyclostratigraphy, isotopic ages
- Well control and correlations
- Previously identified tectonic features
- Sequence maps, timing, and interpretive cross sections
- Conclusions

Libsack 43-27 (reference well)

Upper Cretaceous Cycles

STRATIGRAPHIC FRAMEWORK: WESTERN INTERIOR SEAWAY

<table>
<thead>
<tr>
<th>Age (Ma)</th>
<th>Age</th>
<th>Regional sea level</th>
<th>Cycle</th>
<th>Biostratigraphic markers</th>
<th>Global Eustatic Curve</th>
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Kauffman and Caldwell, 1993

OAE 2
The Niobrara Cyclothem

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</table>

Kauffman and Caldwell, 1993

Reference well
Libsack 43-27
API: 0512321838
Weld Co., Colorado

Modified after Longman et al. (1998)
Lithostratigraphy of the D-J Basin Niobrara Fm

- Our sequence stratigraphic framework and methodology are preferred over the commonly-used lithostratigraphy shown here.

Sharon Springs Member (Pierre Shale)
- Upper chalk (“A Chalk”)
- Upper marl
- Middle chalk (“B Chalk”)
- Middle marl
- Lower chalk (“C Chalk”)
- Lower marl
- Lower chalk & shale
- Fort Hays Limestone
- Carlile Shale
D-J Niobrara Highstands vs. Lowstands

Sedimentary record inherently complicated by relative sea level, global eustasy, basin subsidence, sediment supply rates, tectonic forcing, differential tectonic subsidence and rates of sediment supply. However, general trends in the Niobrara of the D-J Basin are apparent:

**Generalized trends in the Niobrara of the D-J Basin**

<table>
<thead>
<tr>
<th>Highstands</th>
<th>Lowstands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoreward shift in facies</td>
<td>Basinward shift in facies</td>
</tr>
<tr>
<td>Warm Tethyan water extends northward into the WIS</td>
<td>Retreat of Tethyan water and carbonate-promoting conditions</td>
</tr>
<tr>
<td>Increased biogenic pelagic and hemipelagic productivity</td>
<td>Reduced biogenic production, increased siliciclastic input</td>
</tr>
<tr>
<td>Lower preservation of organic carbon</td>
<td>Relative enrichment of organic carbon</td>
</tr>
<tr>
<td>“Condensed” sections and skeletal accumulation</td>
<td>Dilution of chalk by siliciclastic (silt, clay) sediments</td>
</tr>
<tr>
<td>Lower rate of deposition</td>
<td>Higher rate of deposition</td>
</tr>
<tr>
<td>Dominantly pelletal chalk, interbedded with pelletal marlstone</td>
<td>Dominantly organic-rich marlstone, interbedded with pelletal chalks</td>
</tr>
</tbody>
</table>

e.g., Laurin et al. (2004), Jarvis et al. (2006), Locklair and Sageman (2008)
Sequence Stratigraphy

**Interpretation**

- Max Regressive Surface/Seq. Boundary
- Flooding/Max Transgressive Surface
- Max Regressive Surface
- Flooding/Max Transgressive Surface
- Max Regressive Surface
- Flooding/Max Transgressive Surface
- Max Regressive Surface
- Flooding/Max Transgressive Surface
- Max Regressive Surface/Seq. Boundary

Libsack 43-27
API: 0512321838
Weld Co., Colorado

**Regressions**

- R₇₆
- R₇₅
- R₇₄
- R₇₃
- R₇₂
- R₇₁
- R₇₀
- R₇₉
- R₇₈
- R₇₇
- R₇₆

**Unconformities**

- Unconformity
- Unconformity
- Unconformity
- Unconformity
- Unconformity
Niobrara Isotopic Ages

Modified from Locklair and Sageman (2008), *Siewert et al. (in review)

**Age dates (Ogg et al., 2004) are recalibrated bentonite ages (Obradovich, 1993), imported after Locklair and Sageman (2008).**
Cyclostratigraphic Packages and Ages

Libsack 43-27
API: 0512321838
Weld Co., Colorado

*All ages, including interpolated stage boundary ages in italics, from Siewert et al. (in review)

Fourth 3rd order cycle
84.6 Ma – ~82.8 Ma

Third 3rd order cycle
~86.0 – 84.6 Ma

Second 3rd order cycle
~88.2 – ~86.0 Ma

First 3rd order cycle
89.9 – ~88.2 Ma

40Ar/39Ar age* 206Pb/238U age*

San-Cam: 83.82 ± 0.17 Ma or 83.75 ± 0.11 Ma

Con-San: 86.32 ± 0.32 Ma or 86.35 ± 0.11 Ma

Tur-Con: 89.65 ± 0.28 Ma or 89.75 ± 0.11 Ma

89.32 ± 0.24 Ma 89.37 ± 0.15 Ma

89.65 ± 0.28 Ma or 89.75 ± 0.11 Ma

89.87 ± 0.18 Ma

81.84 ± 0.22 Ma

84.41 ± 0.24 Ma 84.43 ± 0.15 Ma

84.55 ± 0.37 Ma

85.66 ± 0.19 Ma

87.13 ± 0.19 Ma 87.11 ± 0.15 Ma

87.13 ± 0.19 Ma 87.11 ± 0.15 Ma

89.32 ± 0.24 Ma 89.37 ± 0.15 Ma

89.65 ± 0.28 Ma or 89.75 ± 0.11 Ma

89.87 ± 0.18 Ma
Well Control for Mapping

- >2000 wells correlated within D-J Basin
- 11 mapped surfaces

Libsack 43-27  
API: 0512321838  
Weld Co., Colorado

- [Map of the region showing wells and mapped surfaces]
- [Graph showing depth and GR values for MRS]
Isochore Controls: Paleohighs and Basement Structures

- Isochore thins associated with paleohighs, and thicks associated with paleolows (e.g., Weimer, 1986)
- Paleohighs align with structural trends (Precambrian shear zones) along Front Range

Weimer, 1986
First 3rd Order Cyclostratigraphic Package

89.9 – ~88.2 Ma: Upper Turonian – Middle Coniacian

- Dominantly NW-SE-oriented stratigraphic architecture
- More uniform thickness than subsequent sequences (note contour values): relatively broad shelf deposition compared to later sequences

Present outcrops and counties for reference

- Stratigraphic thick
- Stratigraphic thin

100 miles

Interpretive conceptual cross section

1

Fourth 3rd order cycle
Third 3rd order cycle
Second 3rd order cycle
First 3rd order cycle

Libsack 43-27

GR Res
Second 3rd Order Cyclostratigraphic Package

- Persistent NW-SE-oriented stratigraphic architecture
- Nearly all stratigraphic thins replaced by thick: compensational infilling of accommodation space provided by previous sequence
- Stratigraphic thicks replaced by thins: paleohighs with less accommodation space provided by previous sequence

Present outcrops and counties for reference

Interpretive conceptual cross section

Fourth 3rd order cycle
Third 3rd order cycle
Second 3rd order cycle
First 3rd order cycle
Third 3rd Order Cyclostratigraphic Package

~86.0 – 84.6 Ma: Lower Santonian – Upper Santonian

- Earlier NW-SE-oriented stratigraphic architecture disrupted by SW-NE-oriented architecture: First significant uplifts are recorded ~86.0 – 84.6 Ma
- Stratigraphic thicks are shifted laterally: forced reorganization of depocenters
- Persistent stratigraphic thicks in southern D-J Basin

Present outcrops and counties for reference

Stratigraphic thick
Stratigraphic thin

100 miles

C.I. = 20 ft

Interpretive conceptual cross section

Fourth 3rd order cycle
Third 3rd order cycle
Second 3rd order cycle
First 3rd order cycle

Libsack 43-27
Fourth 3rd Order Cyclostratigraphic Package

- 84.6 Ma – ~82.8 Ma: Upper Santonian – Lower Campanian

- Reorganization to SW-NE-oriented architecture is more pronounced
- Major stratigraphic thins align with noted paleohighs (i.e., Wattenberg, Morrill County, Hartville, and Turkey Creek highs): long-lived paleohighs
- New stratigraphic thins emerge: possibly due to sequence boundary marking end of Niobrara
Interpretation of Stratigraphic Architecture

**Possible factors contributing to complexities observed in the D-J Basin Niobrara:**
- Currents and redistribution of pelagic sediments along distal carbonate ramp
- Areas of higher productivity and accumulation (planktonic blooms, upwellings)
- Basement uplifts
- Post-depositional differential compaction

**Stratigraphic thins consistent with bypassed sedimentation, minor disconformity, nondepositional unconformity, condensed section, scouring:**
- Benthic currents (e.g., tidal, hyperpycnal, contouritic, or storm event) producing channel forms
- Long-lived basement uplifts forcing disruption of stratigraphic architectural trends (i.e., shifted channel forms)

**Stratigraphic thicks consistent with compensational infilling of thins and accommodation space provided by previous sequence:**
- Subsequent infilling of submarine channel forms
- Long-lived stratigraphic thicks involve long-lived accommodation space
Sub-interval 1 Tur400-Con100

89.9 Ma – ~89.4 Ma: Upper Turonian – Lower Coniacian

- General thinning trend towards NE
- Combination of SW-NE- and NW-SE-oriented stratigraphic architecture
- Roughly same as Fort Hays Limestone

Libsack 43-27
API: 0512321838
Weld Co., Colorado

C.I. = 10 ft

Present outcrops and counties for reference

100 miles
~89.4 Ma – ~88.4 Ma: Lower Coniacian

- General thinning trend towards NE
- Dominantly uniform sequence thickness: broad carbonate platform/ramp deposition
- W-E- to NW-SE-oriented stratigraphic architecture

C.I. = 10 ft

Present outcrops and counties for reference

100 miles

Libsack 43-27
API: 0512321838
Weld Co., Colorado
Sub-interval 3 Con200-Con300

- Source-prone interval
- Persistent E-W- to NW-SE-oriented stratigraphic architecture

~88.4 Ma – ~87.8 Ma: Lower Coniacian – Mid. Coniacian

Libsack 43-27
API: 0512321838
Weld Co., Colorado

C.I. = 10 ft

Present outcrops and counties for reference

100 miles
~87.8 Ma – ~86.3 Ma: Mid. Coniacian – Lower Santonian

- Dominant NW-SE-oriented stratigraphic architecture
- Stratigraphic thicks overlie older thins: compensational infilling of available accommodation space
- Interval includes “C Chalk”

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API: 0512321838
Weld Co., Colorado

C.I. = 10 ft
Sub-interval 5 Con400-San100

- Source-prone interval
- Dominant NW-SE-oriented stratigraphic architecture, similar to previous interval

~86.3 Ma – ~86.0 Ma: Lower Santonian

Present outcrops and counties for reference

C.I. = 10 ft

100 miles

Libsack 43-27
API: 0512321838
Weld Co., Colorado
~86.0 Ma – ~85.1 Ma: Low. Santonian – Up. Santonian

- Earlier NW-SE-oriented stratigraphic architecture disrupted by SW-NE-oriented architecture: First significant uplifts are recorded ~86.0 – ~85.1 Ma
- Hartville High is evident
- Stratigraphic thicks are shifted laterally: forced reorganization of depocenters
- Persistent stratigraphic thicks in southern D-J Basin
- Interval includes “B Chalk”
~85.1 Ma – 84.6 Ma: Upper Santonian

- Increased NW-SE-oriented stratigraphic architecture
- Several paleohighs (e.g., Wattenberg, Turkey Creek) are evident
- Evidence of stratigraphic thicks compensationally infilling accommodation space of previous interval
- Persistent stratigraphic thicks in southern D-J Basin
- Interval includes “Upper B Chalk”
Sub-interval 8  San300-Cam50

84.6 Ma – 83.8 Ma: Upper Santonian – Low. Campanian

- Source-prone interval
- Pronounced NW-SE-oriented stratigraphic architecture, similar to previous intervals
- Thinning apparent in southern D-J Basin

Present outcrops and counties for reference

C.I. = 10 ft

Libsack 43-27
API: 0512321838
Weld Co., Colorado

MRS

GR

Res

0 100 200 300 400 500 600 700 800 900 1000

100 miles
83.8 Ma – ~82.8 Ma: Lower Campanian

- Persistent NW-SE-oriented stratigraphic architecture, similar to previous intervals
- Persistent thinning apparent in southern D-J Basin
- Interval includes “A Chalk”
Conclusions

- Sequence-based stratigraphic mapping, constrained with biostratigraphy and isotopic ages, reveals:
  - Complex stratigraphic architecture of the Niobrara Fm of the D-J Basin
  - Evolution and timing of organized bathymetric and structural features

- Observations based on detailed mapping include the following:
  - Generally broad shelf deposition during late Turonian was replaced in Coniacian by NW-SE-oriented submarine channel forms and compensational infilling by subsequent sequences
  - Abrupt disruption of channel architecture by SW-NE-oriented paleobathymetric highs first appears in lower Santonian (~86 Ma)
  - Upper Santonian-lower Campanian sequences are dominated by SW-NE-oriented architecture consistent with structural (basement) influence

- Subtle Niobrara stratigraphic and architectural trends in the D-J Basin have implications for facies distributions in the Niobrara’s source rock intervals and tight reservoir intervals

Acknowledgments: Pioneer Natural Resources, Siewert, S.E., et al.