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

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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.

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AAPG Rocky Mountain Section
September 10, 2012

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Outline

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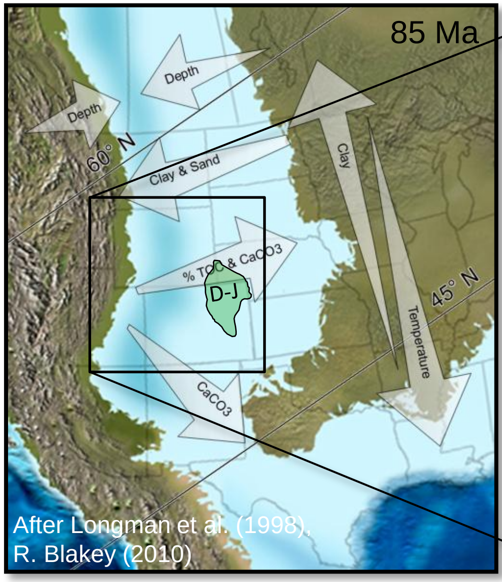
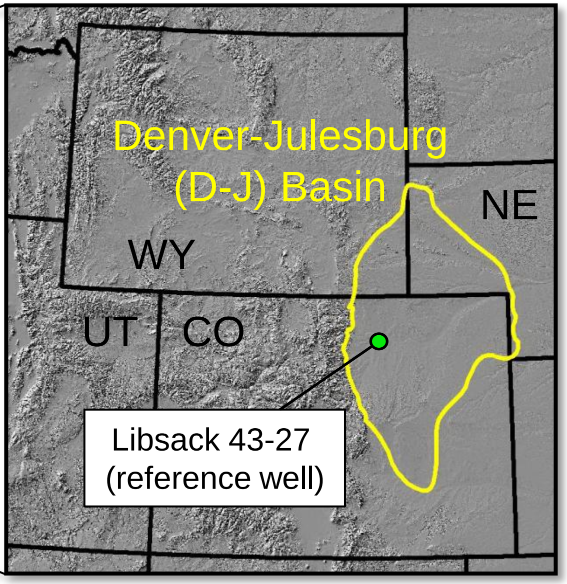
- Overview of Niobrara Cyclothem
- Reference section and lithostratigraphy
- Set up of sequence stratigraphy, cyclostratigraphy, isotopic ages
- Well control and correlations
- Previously identified tectonic features
- Sequence maps, timing, and interpretive cross sections
- Conclusions





Upper Cretaceous Cycles

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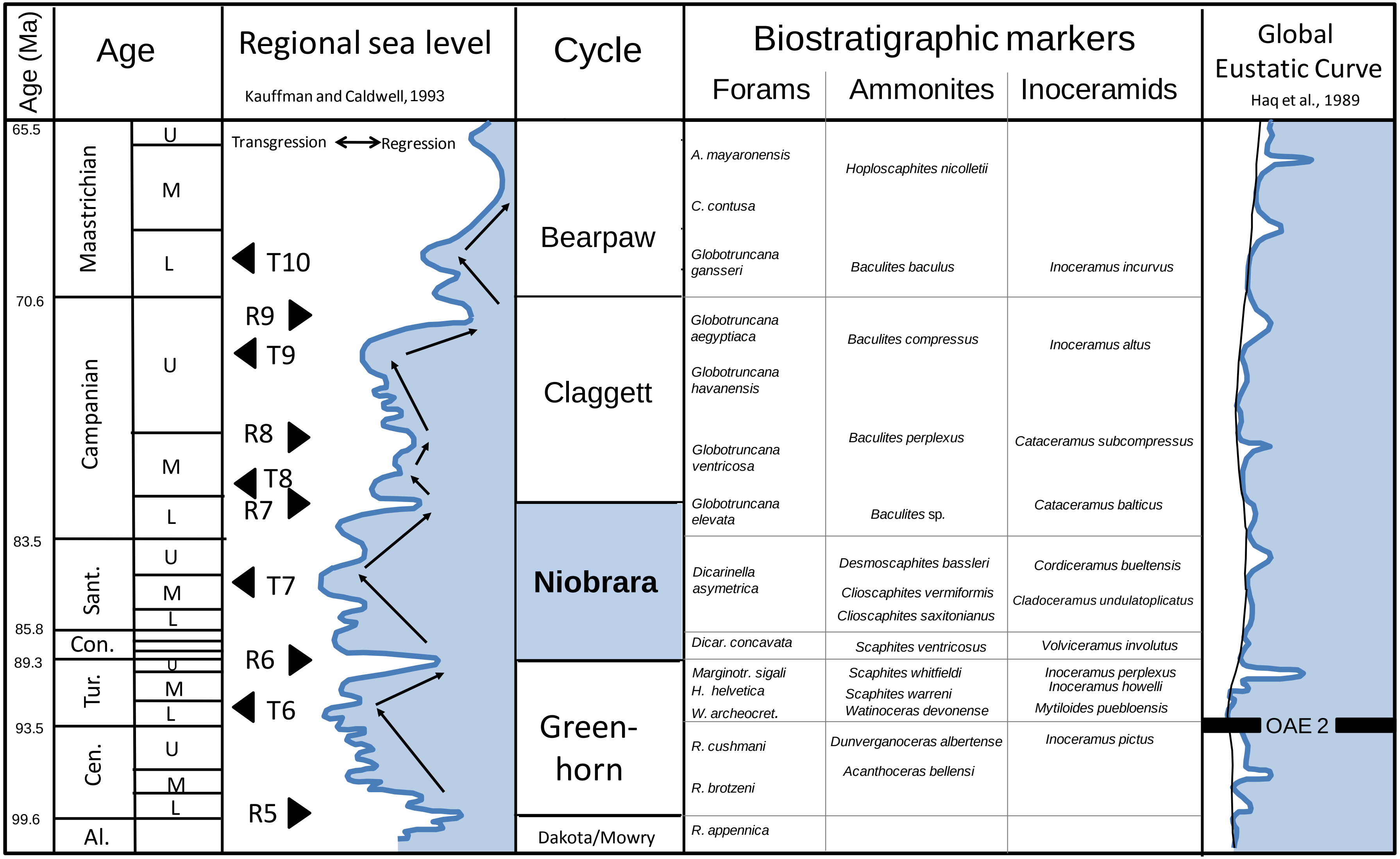
STRATIGRAPHIC FRAMEWORK: WESTERN INTERIOR SEAWAY



The Niobrara Cyclothem

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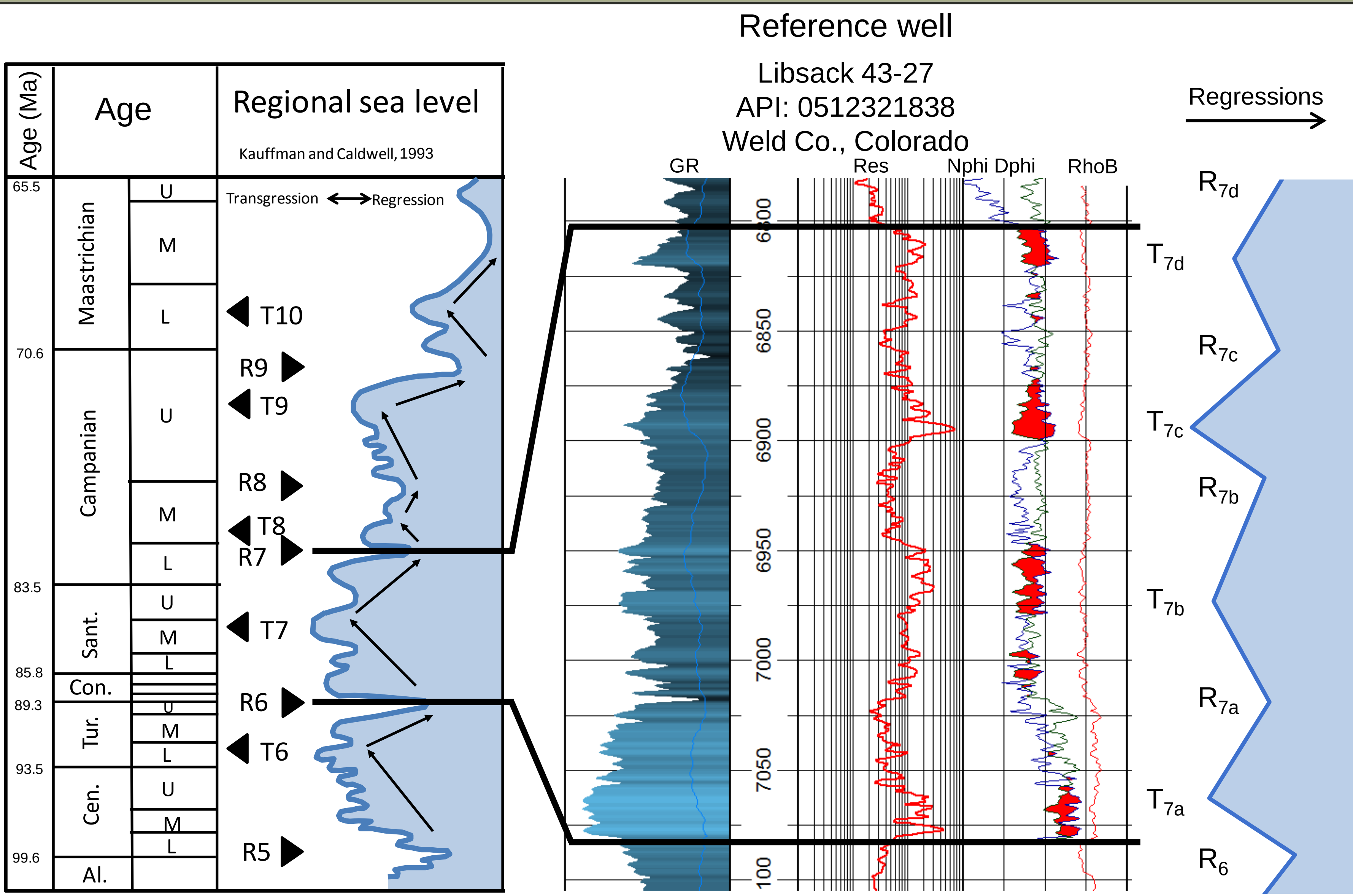

Modified after Longman et al. (1998)

Lithostratigraphy of the D-J Basin Niobrara Fm

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

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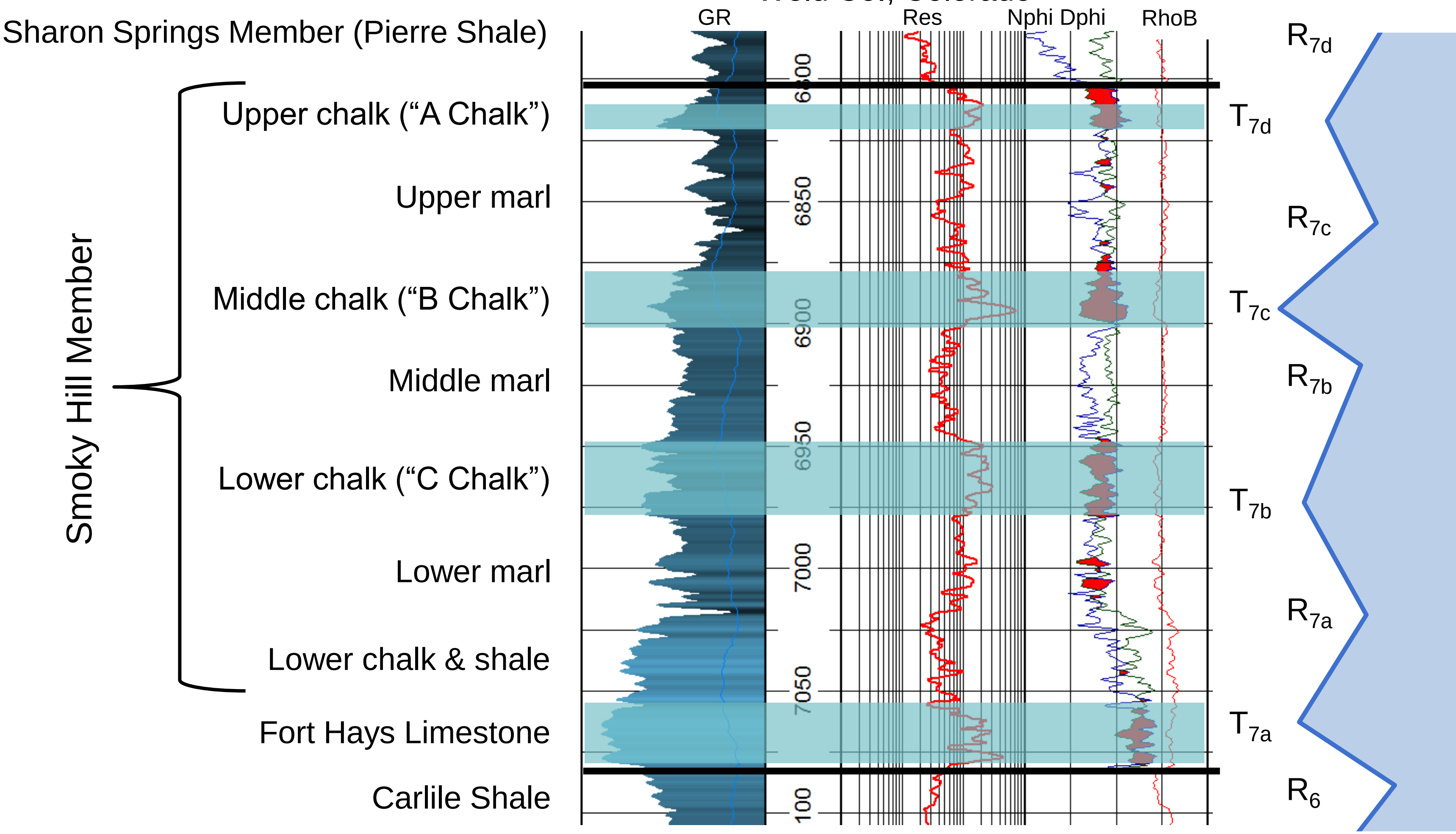
Regressions →



D-J Niobrara Highstands vs. Lowstands

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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

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

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

Sequence Stratigraphy

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Interpretation

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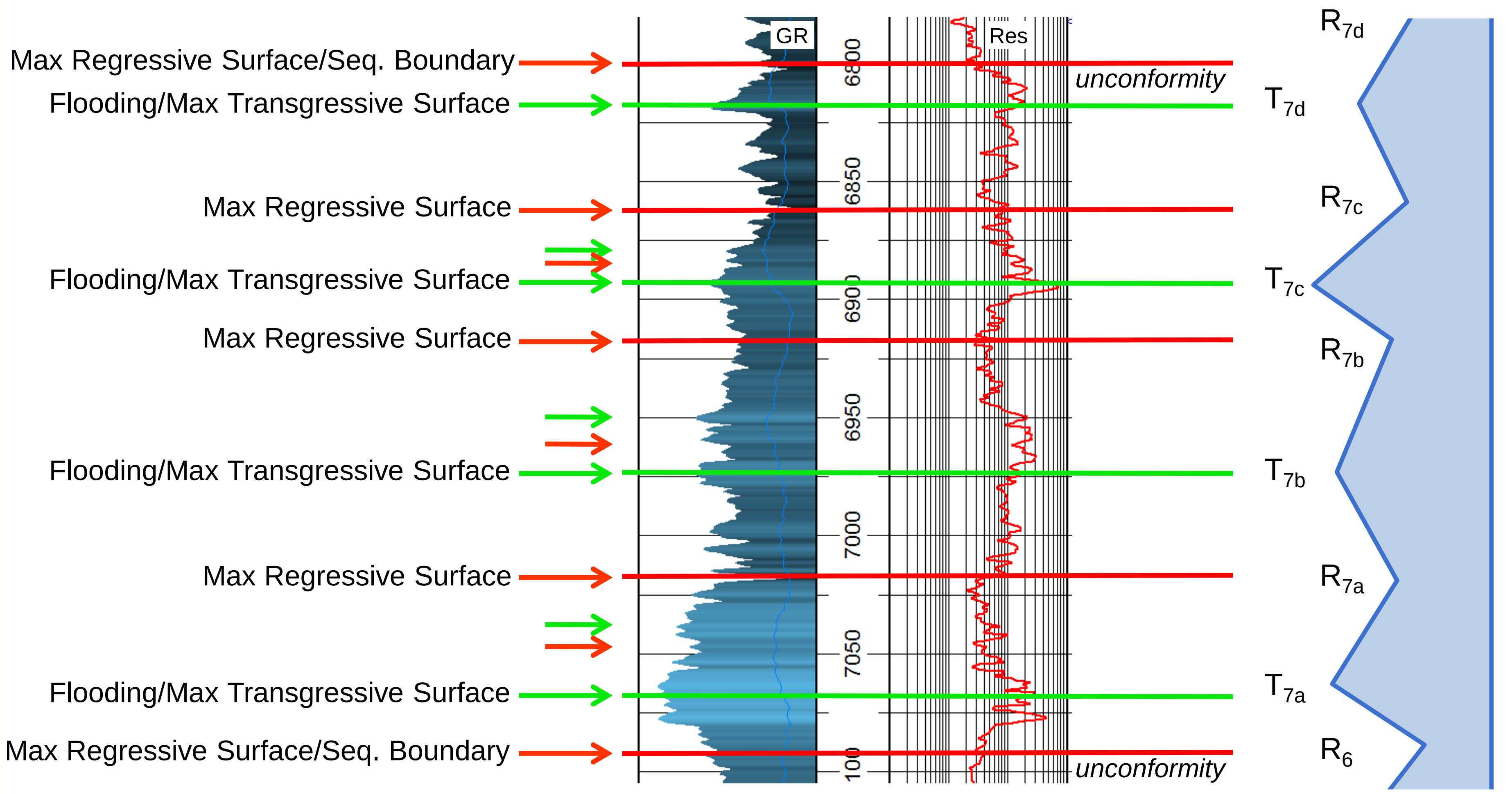

Niobrara Isotopic Ages

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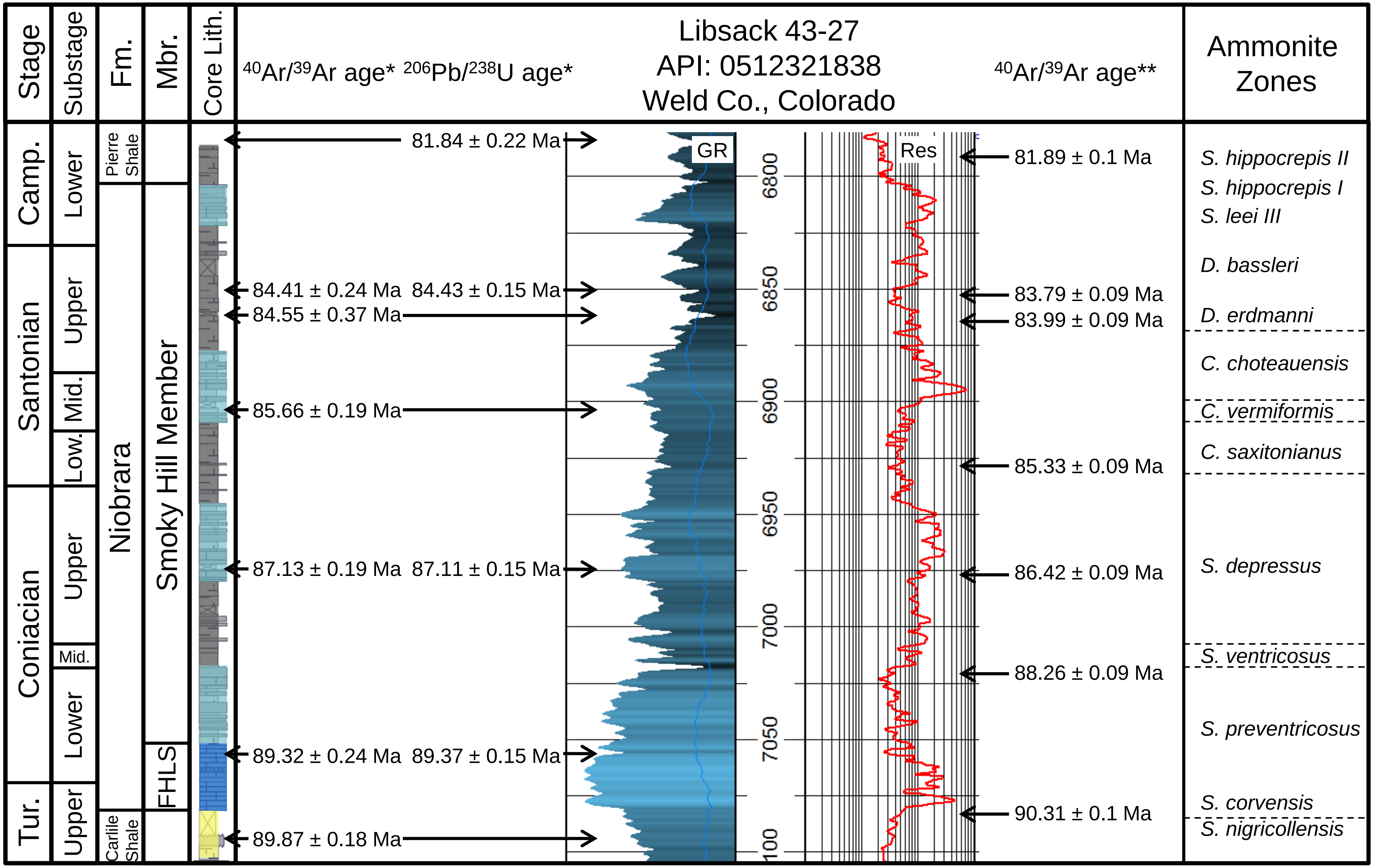

Modified from Locklair and Sageman (2008), *Siewert et al. (in review)

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

Cyclostratigraphic Packages and Ages

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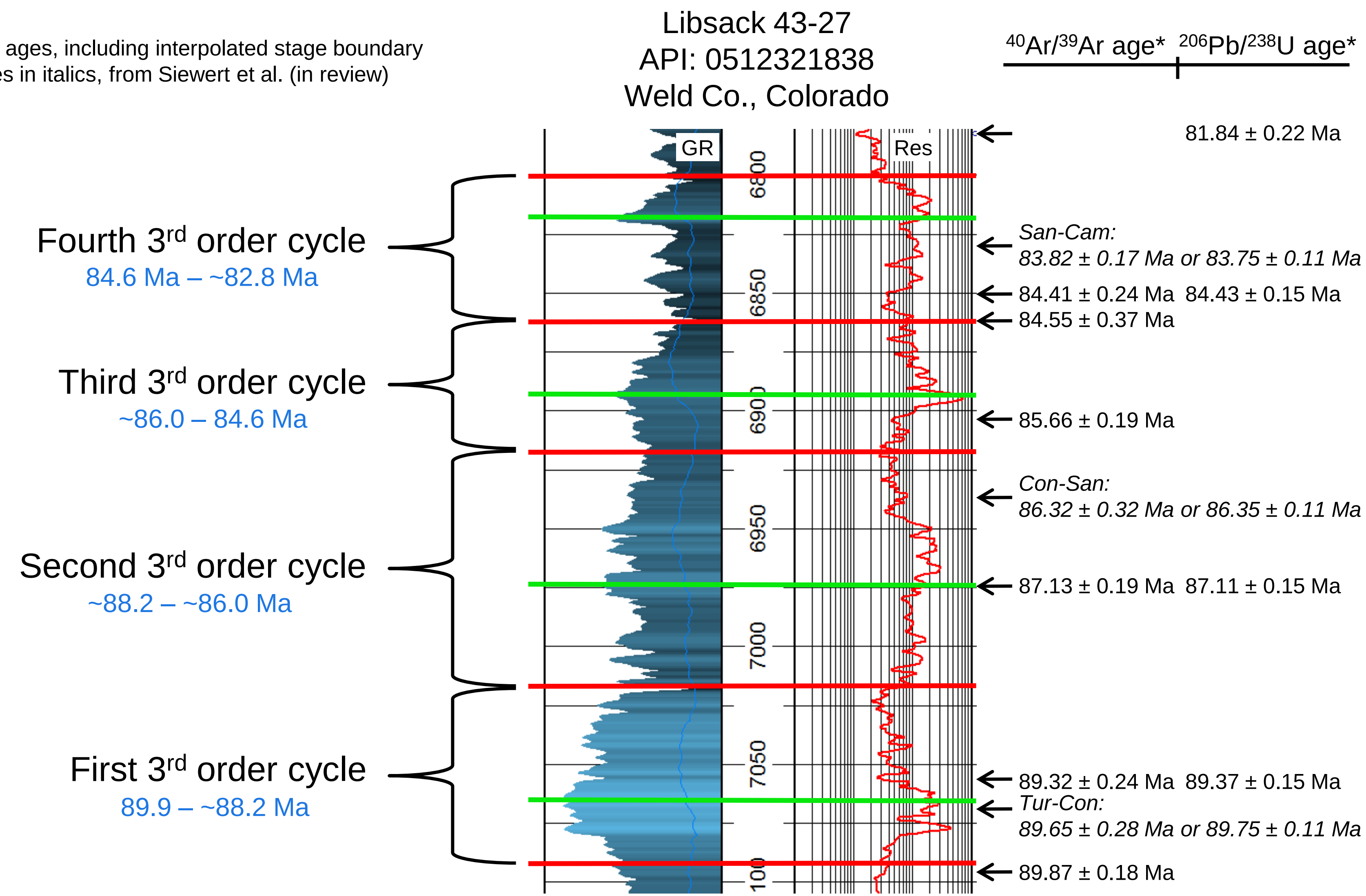
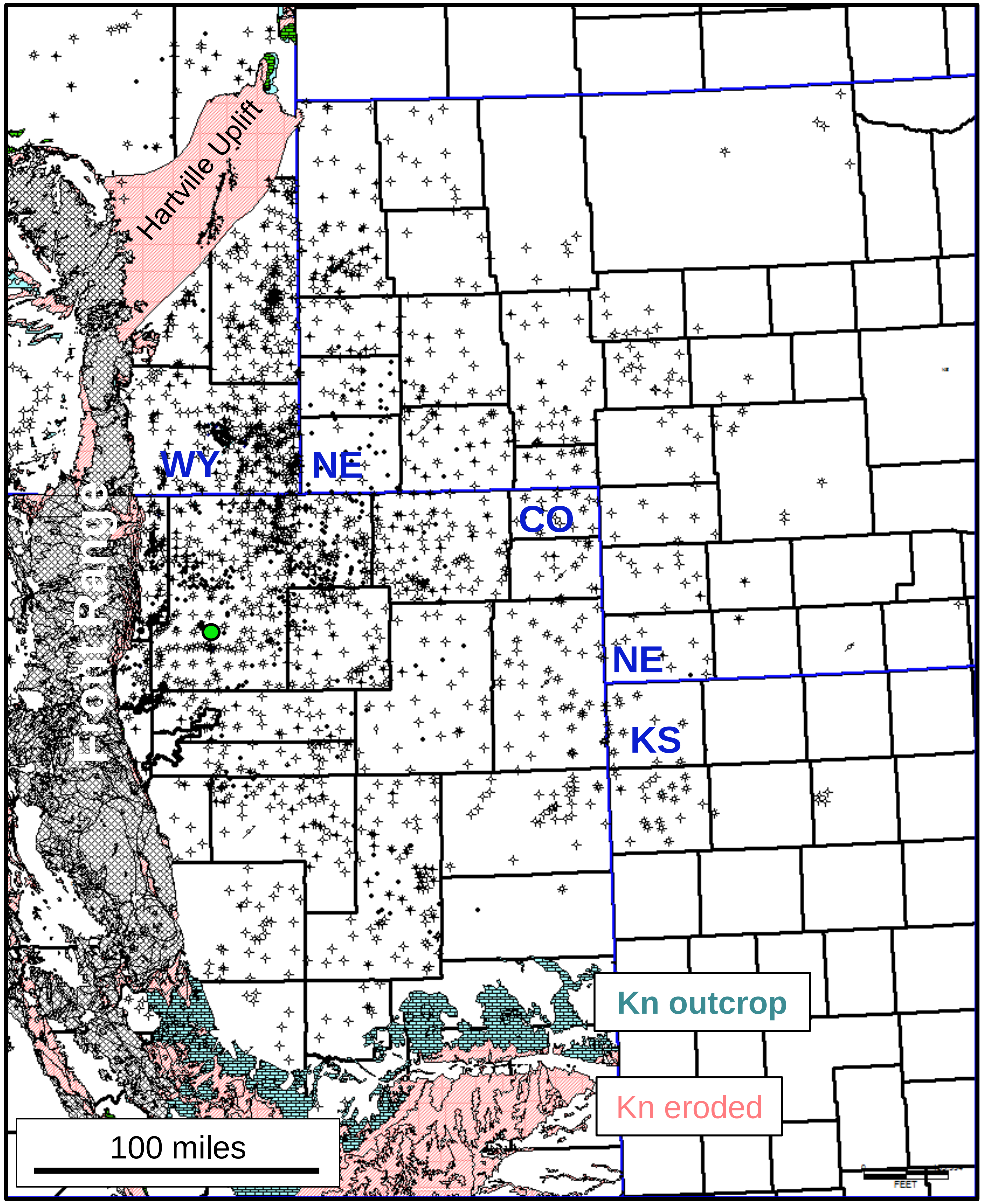
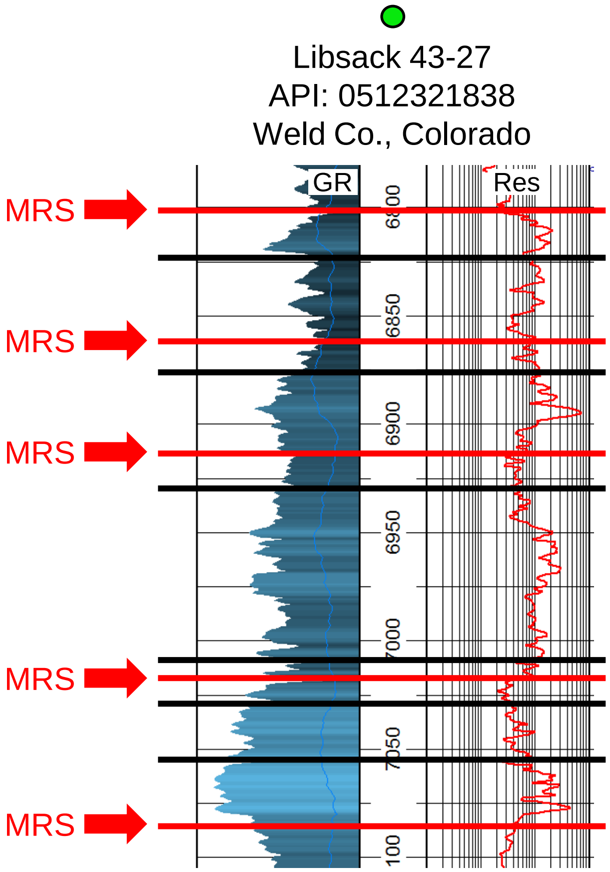
*All ages, including interpolated stage boundary ages in italics, from Siewert et al. (in review)



Well Control for Mapping



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



Isochore Controls: Paleohighs and Basement Structures

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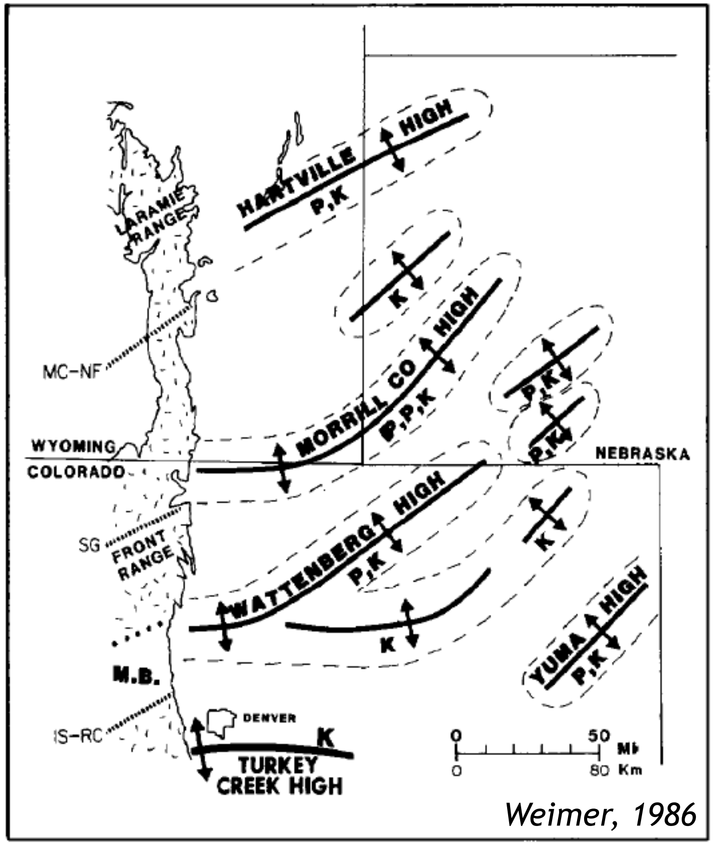

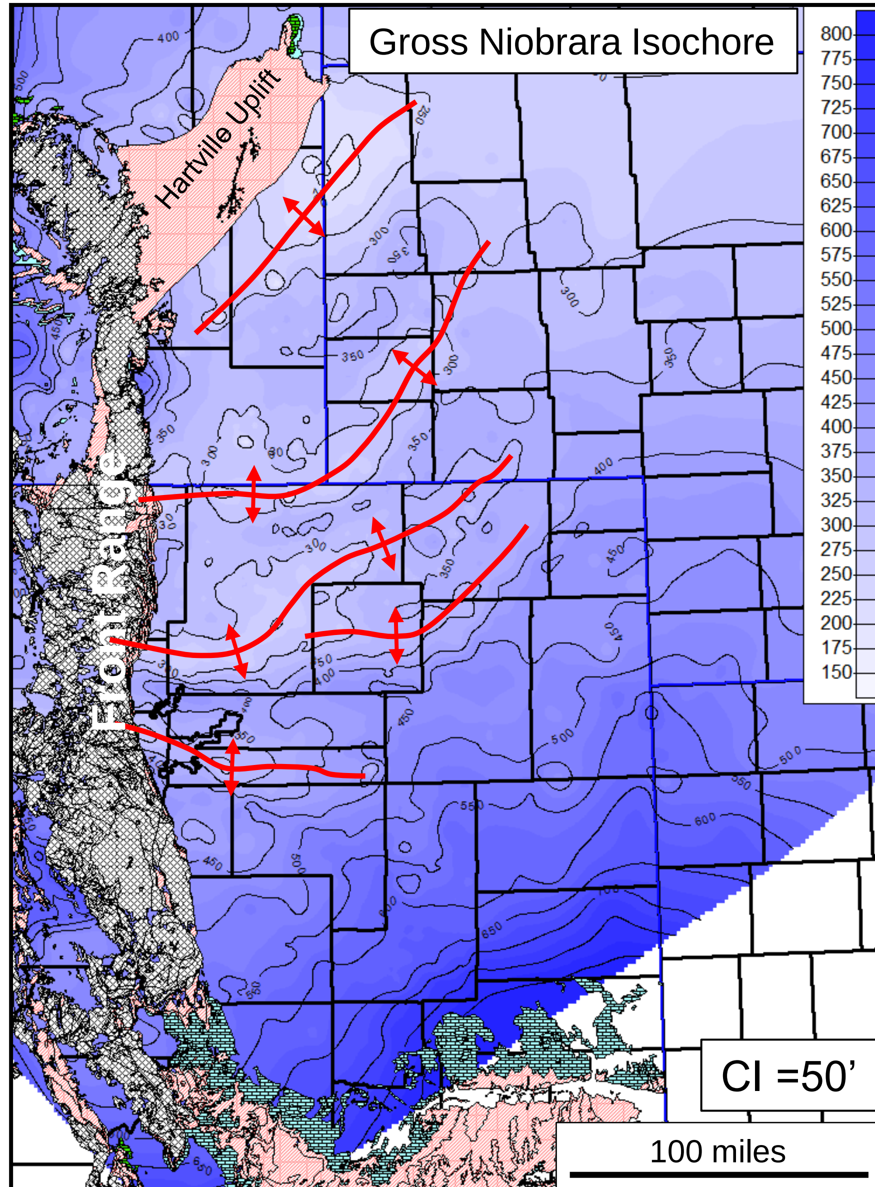

- Isochore thins associated with paleohighs, and thicks associated with paleolows (e.g., Weimer, 1986)
- Paleohighs align with structural trends (Precambrian shear zones) along Front Range

First 3rd Order Cyclostratigraphic Package

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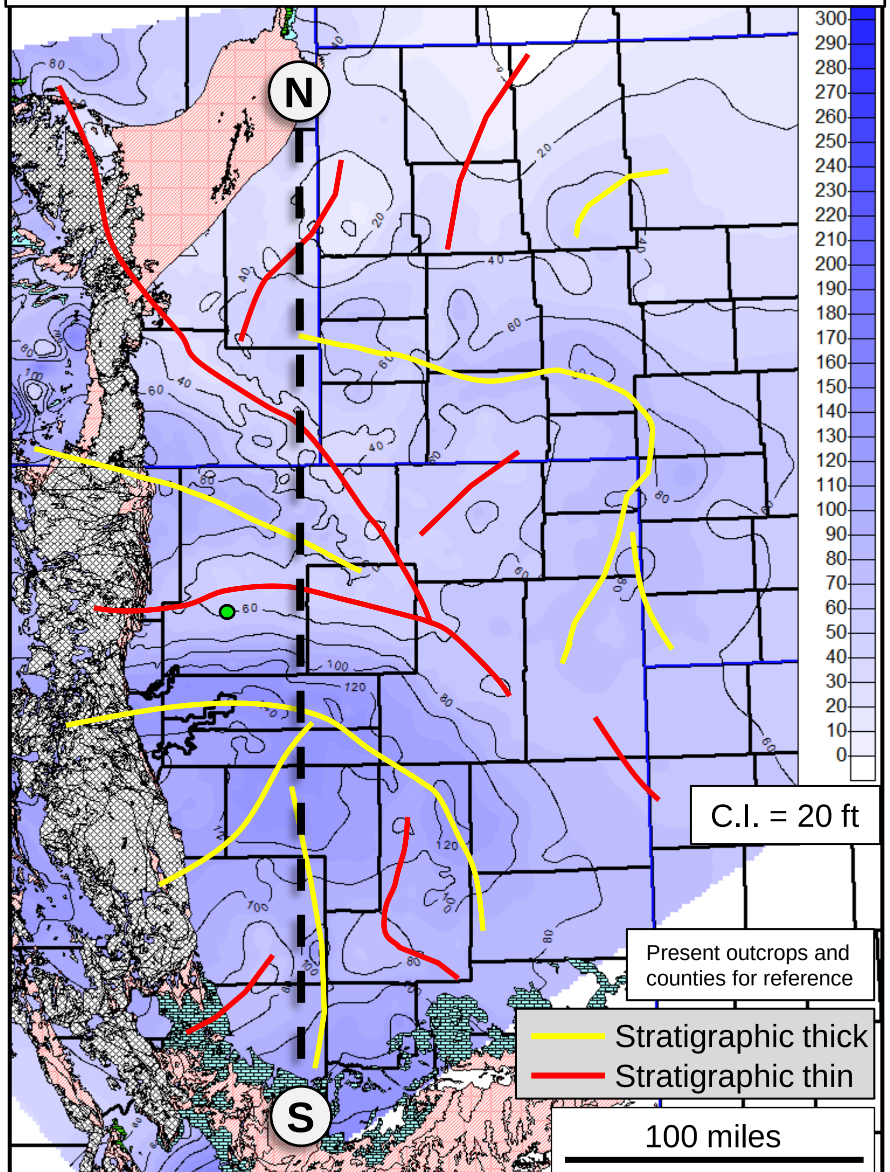
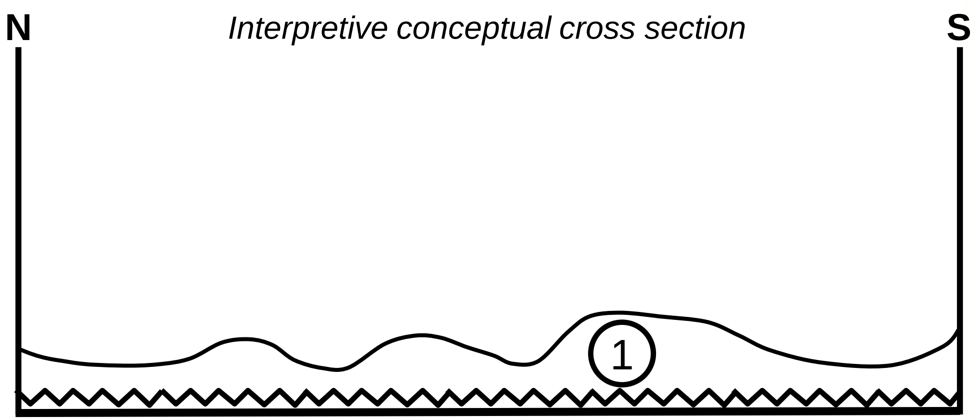
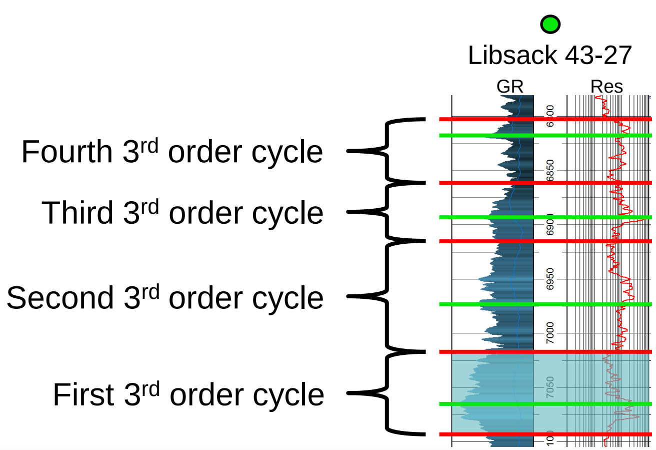
89.9 – ~88.2 Ma: Upper Turonian – Middle Coniacian



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





Second 3rd Order Cyclostratigraphic Package

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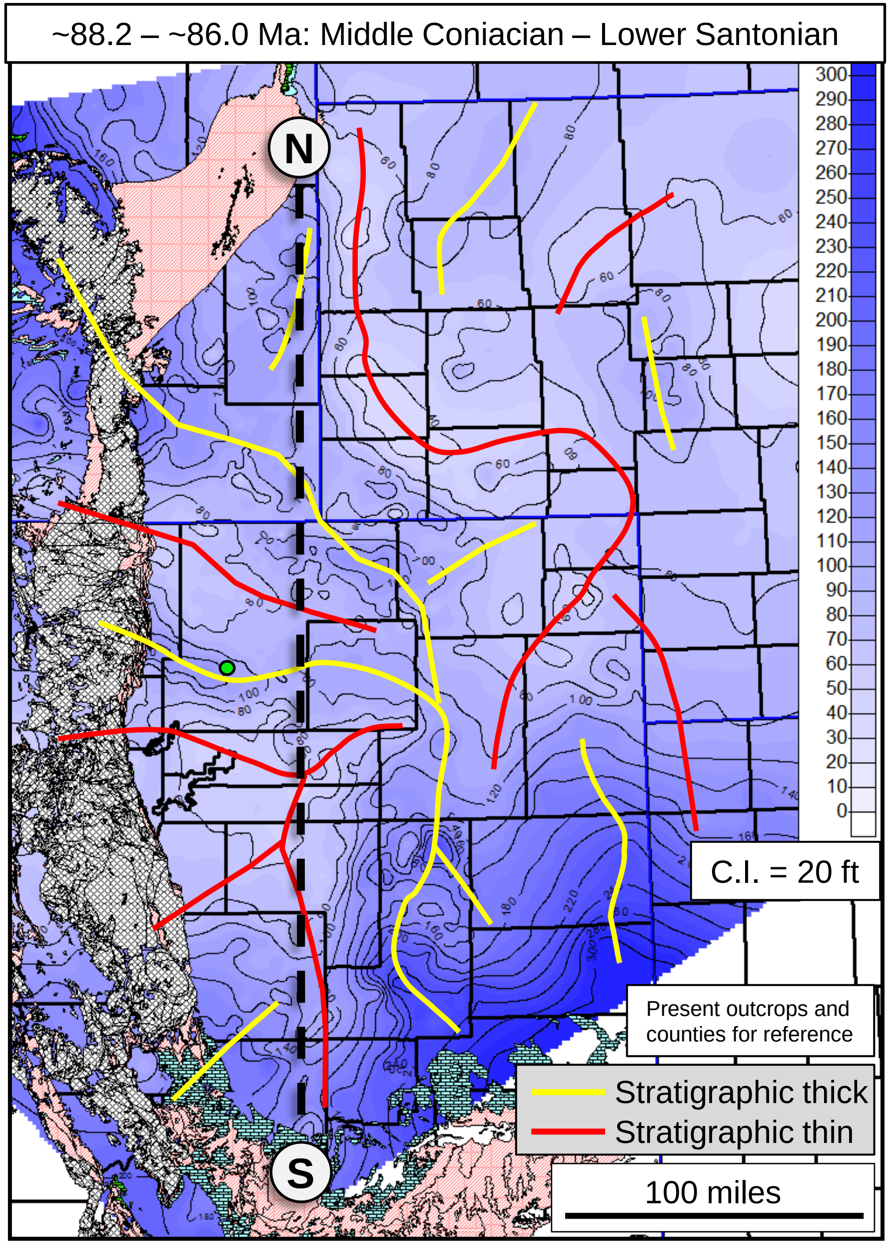
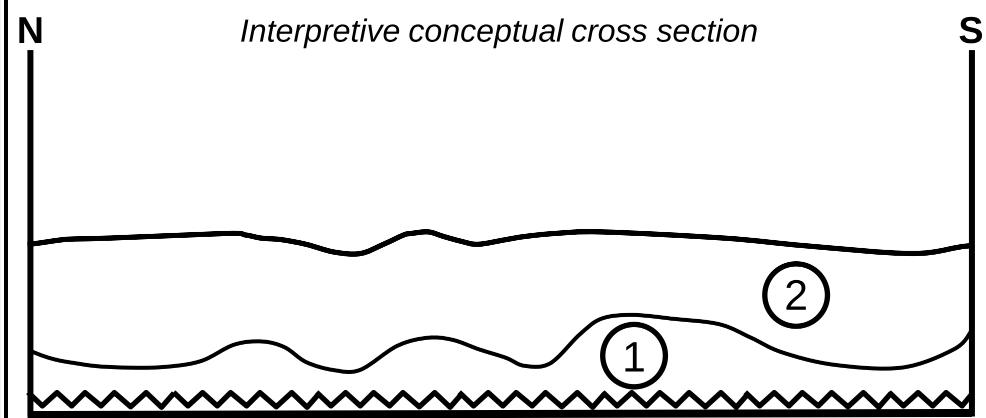
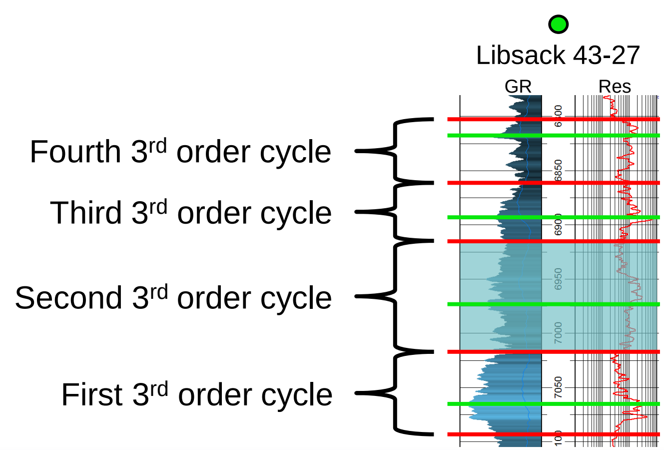


- Persistent NW-SE-oriented stratigraphic architecture
- Nearly all stratigraphic thins replaced by thicks: compensational infilling of accommodation space provided by previous sequence
- Stratigraphic thicks replaced by thins: paleohighs with less accommodation space provided by previous sequence





Third 3rd Order Cyclostratigraphic Package

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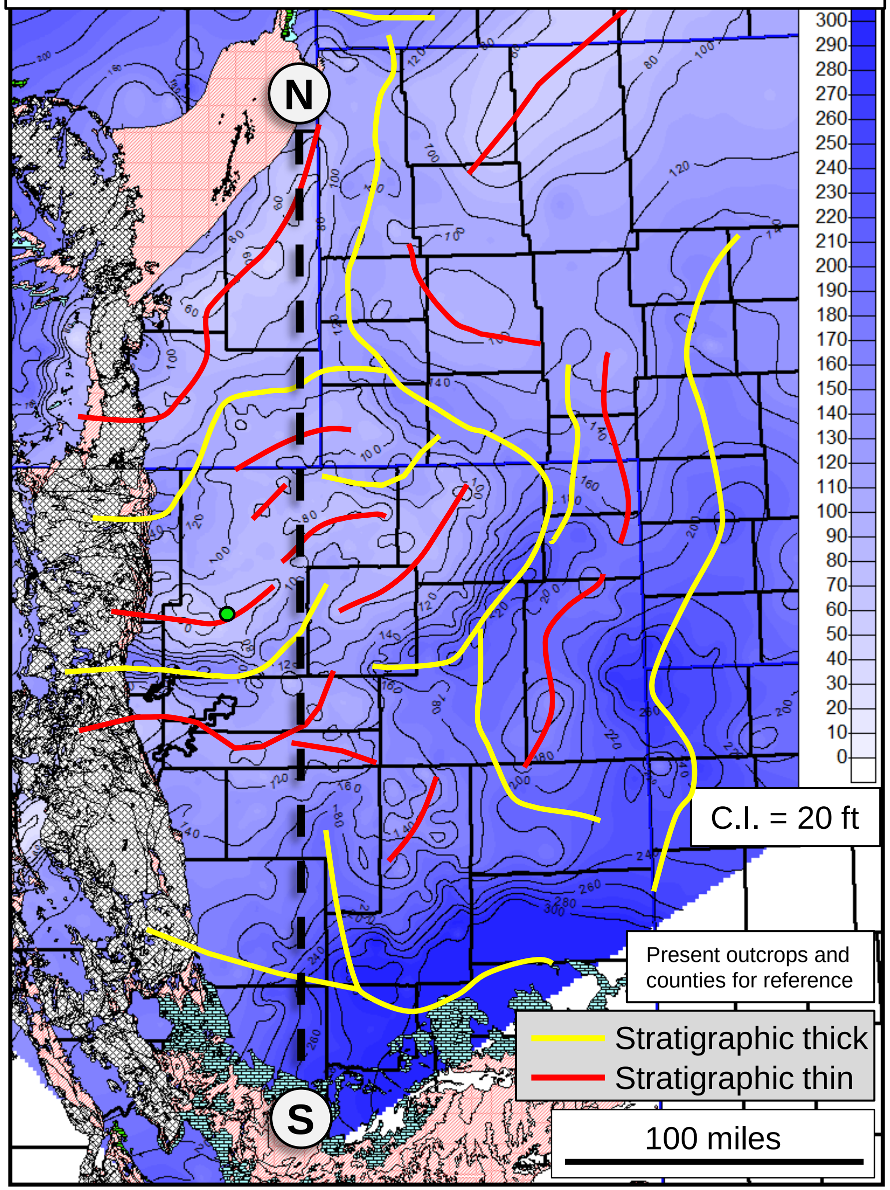
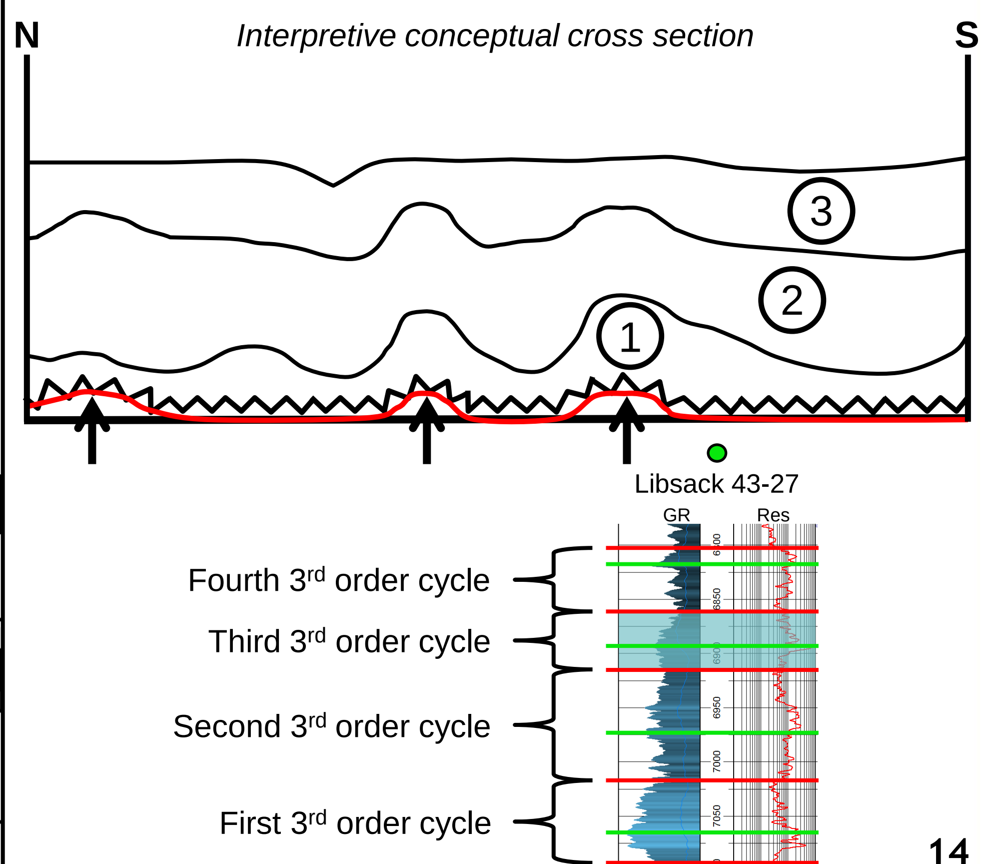
~86.0 – 84.6 Ma: Lower Santonian – Upper Santonian



- 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



Fourth 3rd Order Cyclostratigraphic Package

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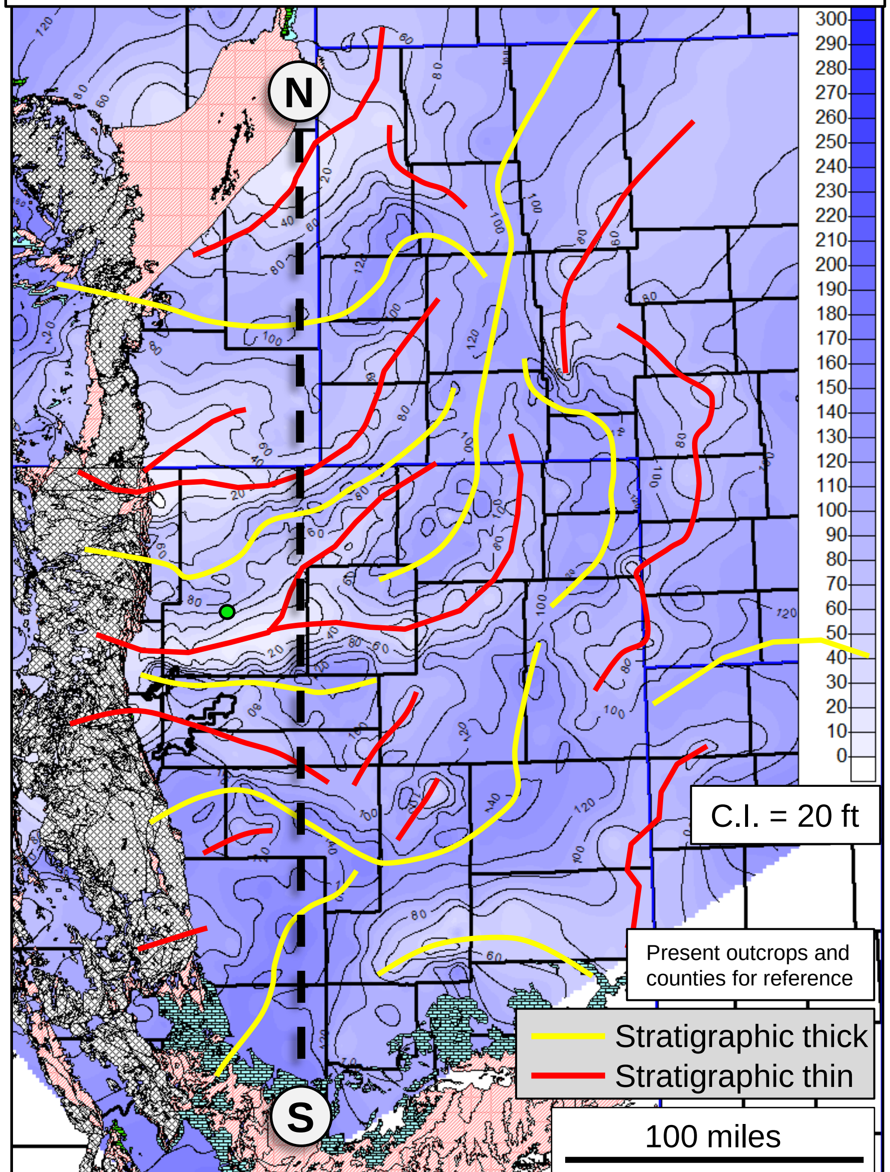
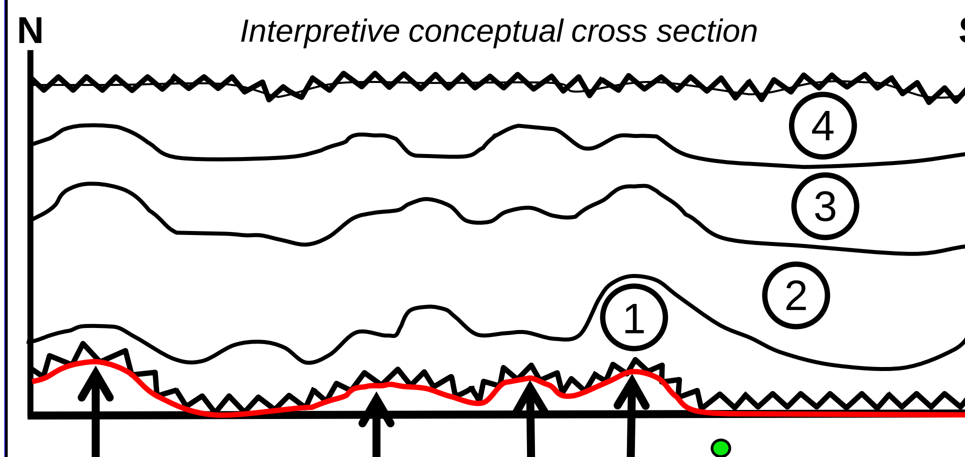
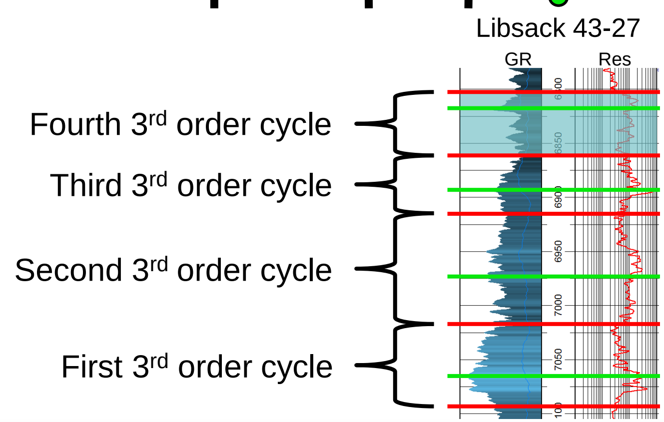
84.6 Ma – ~82.8 Ma: Upper Santonian – Lower Campanian



- 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

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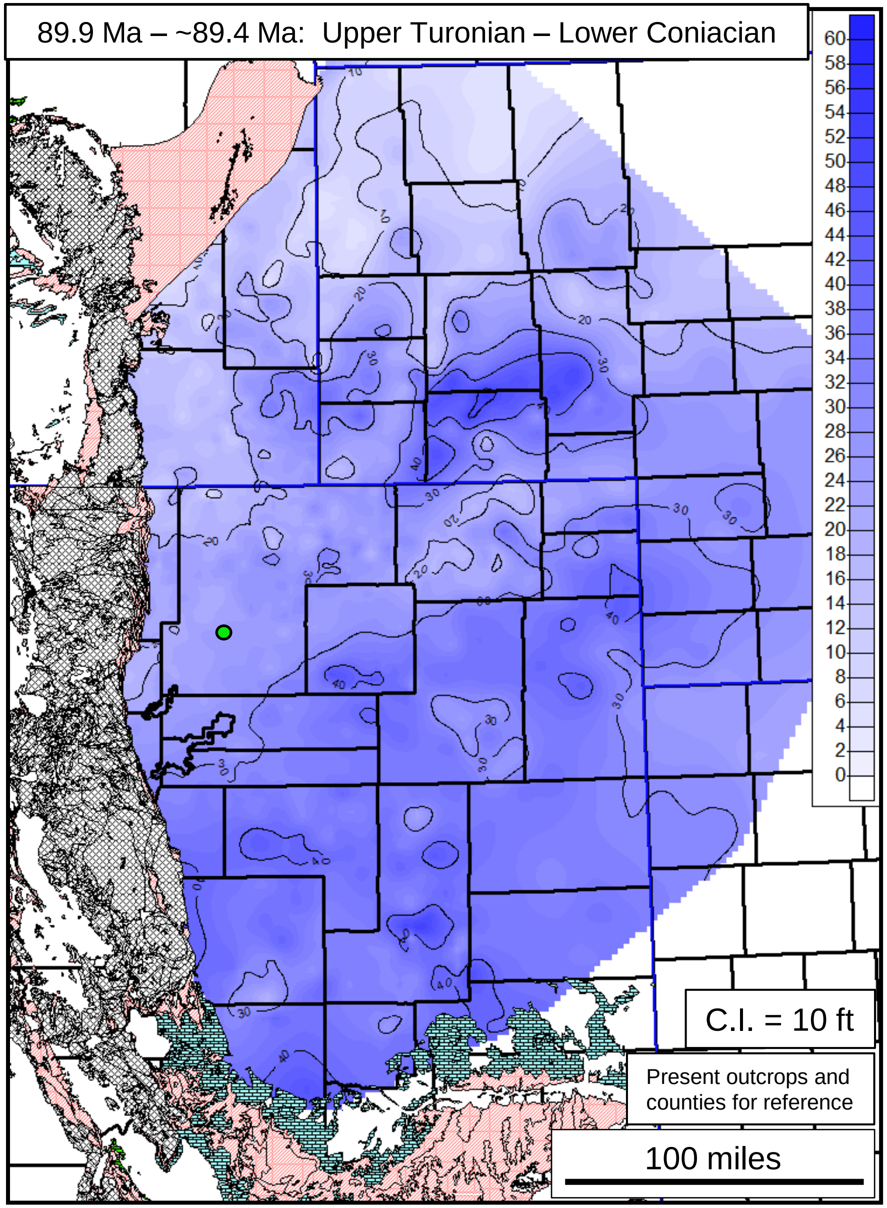
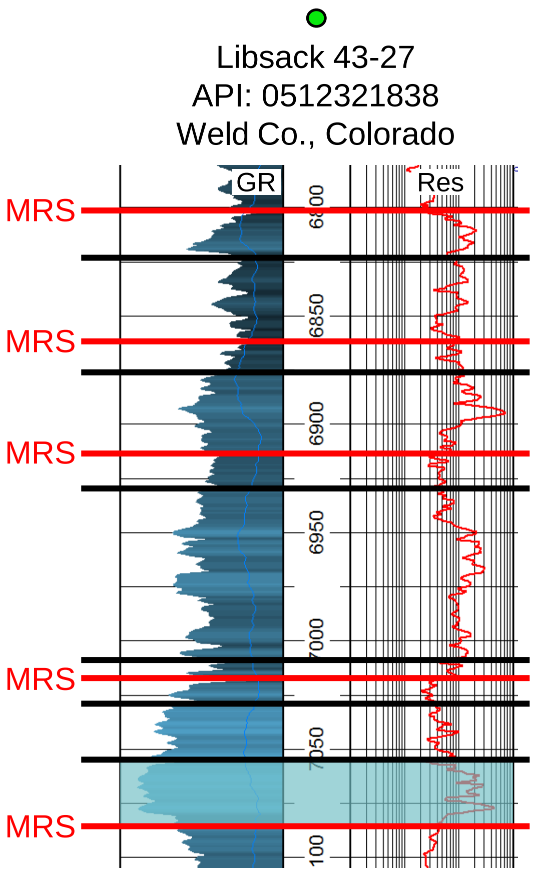
- **Possible factors contributing to complexities observed in the D-J Basin Niobrara:**
  - Currents and redistribution of pelagic sediments along distal carbonate ramp
  - Areas of higher productivity and accumulation (planktonic blooms, upwellings)
  - Basement uplifts
  - Post-depositional differential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

PIONEER NATURAL RESOURCES

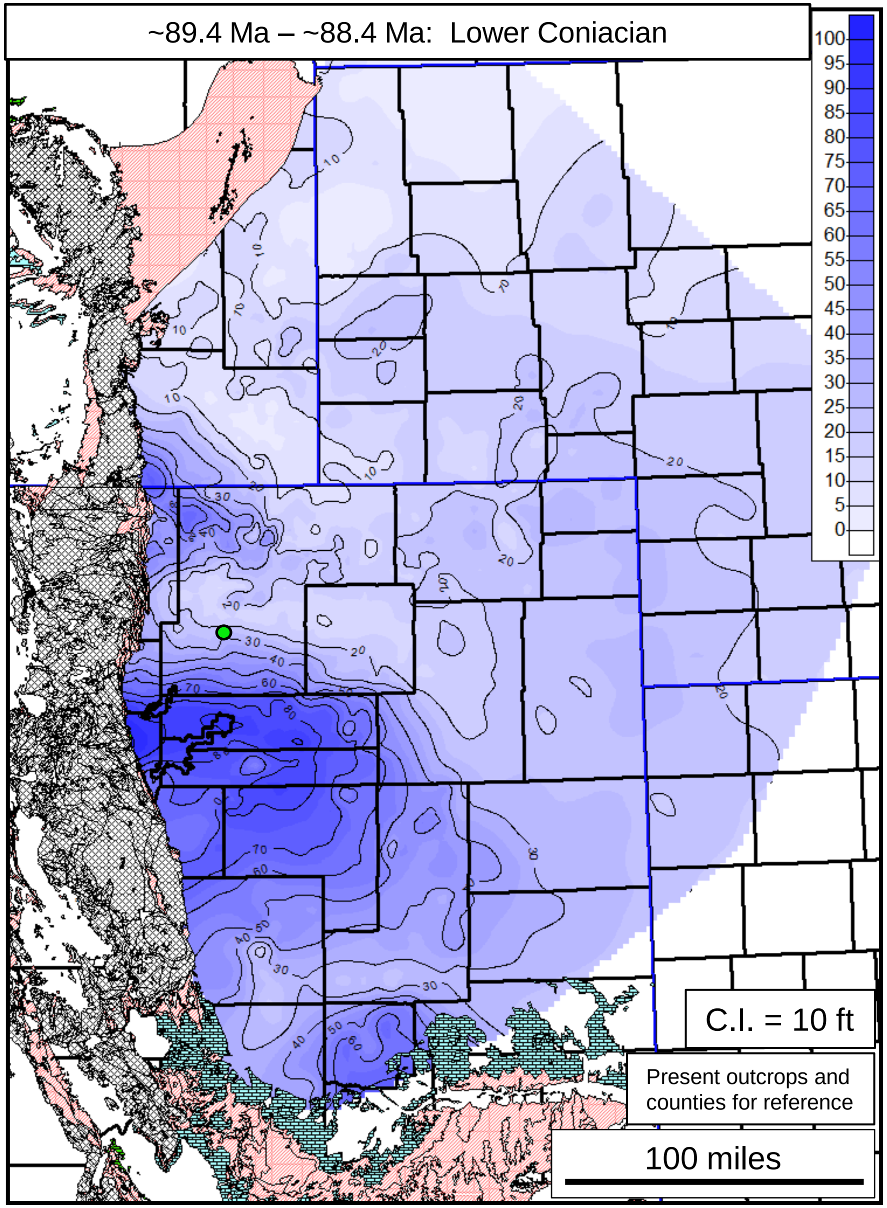


- General thinning trend towards NE
- Combination of SW-NE- and NW-SE-oriented stratigraphic architecture
- Roughly same as Fort Hays Limestone

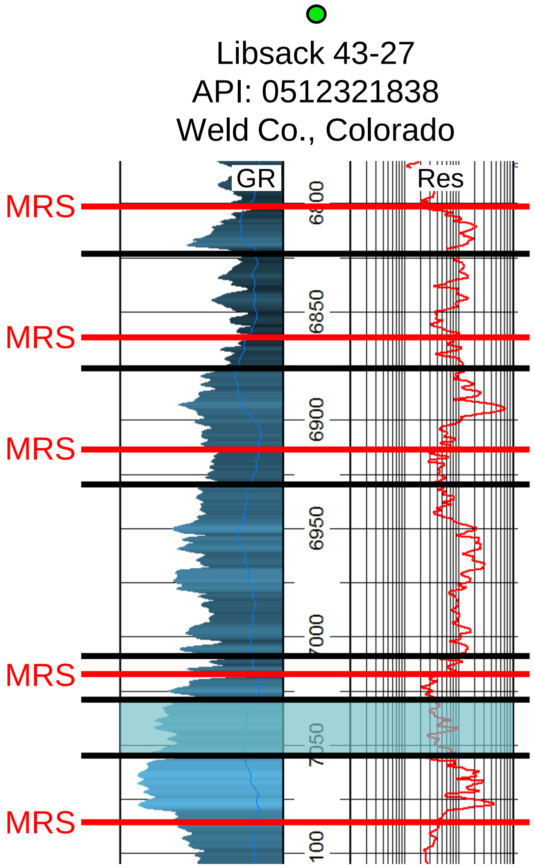


Sub-interval 2 Con100-Con200

PIONEER NATURAL RESOURCES

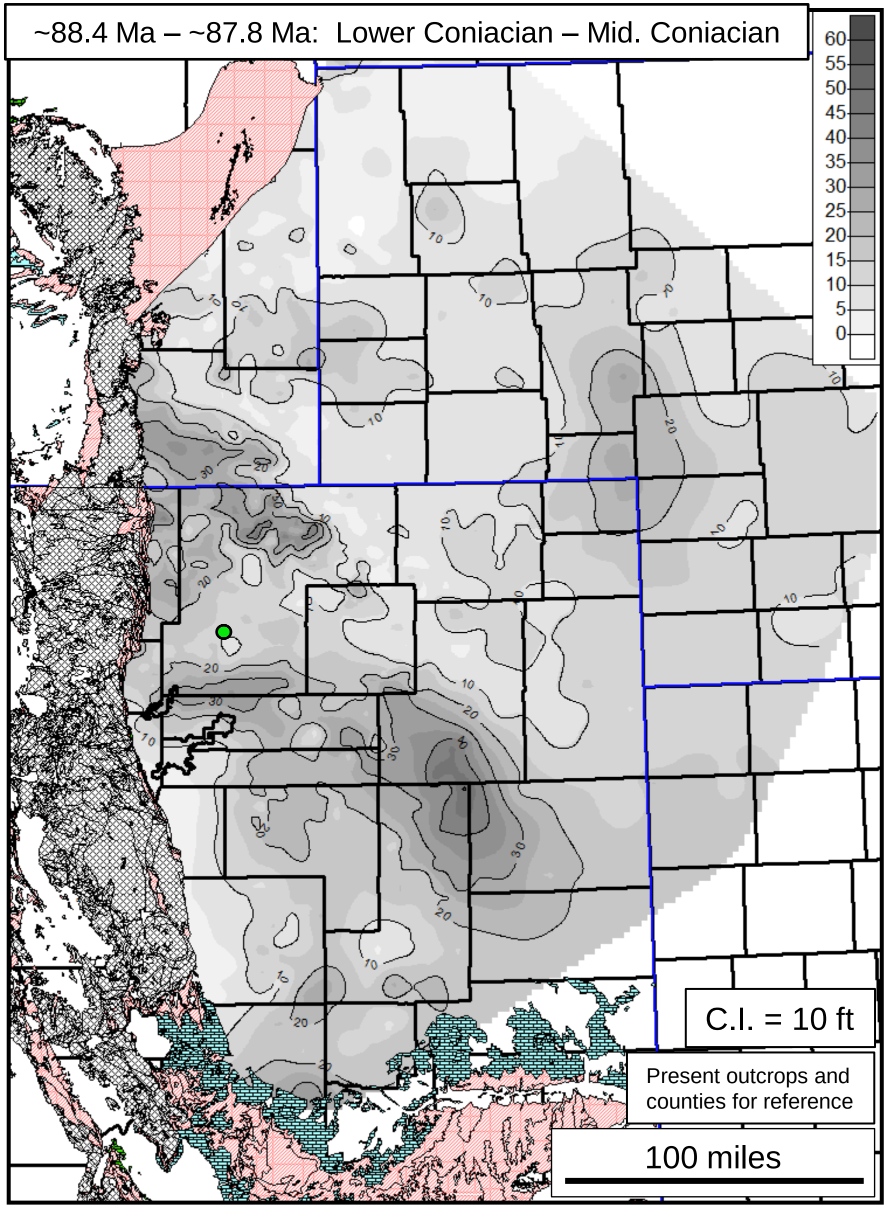


- General thinning trend towards NE
- Dominantly uniform sequence thickness: broad carbonate platform/ramp deposition
- W-E- to NW-SE-oriented stratigraphic architecture

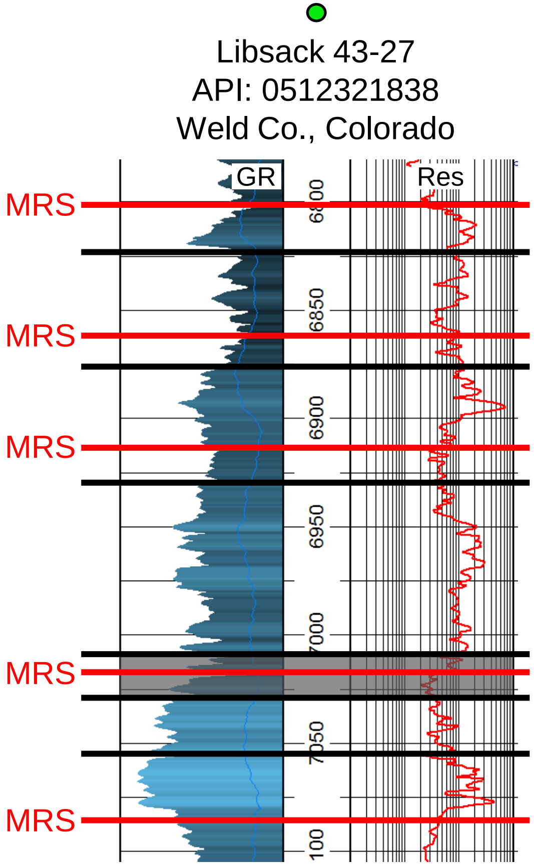


Sub-interval 3 Con200-Con300

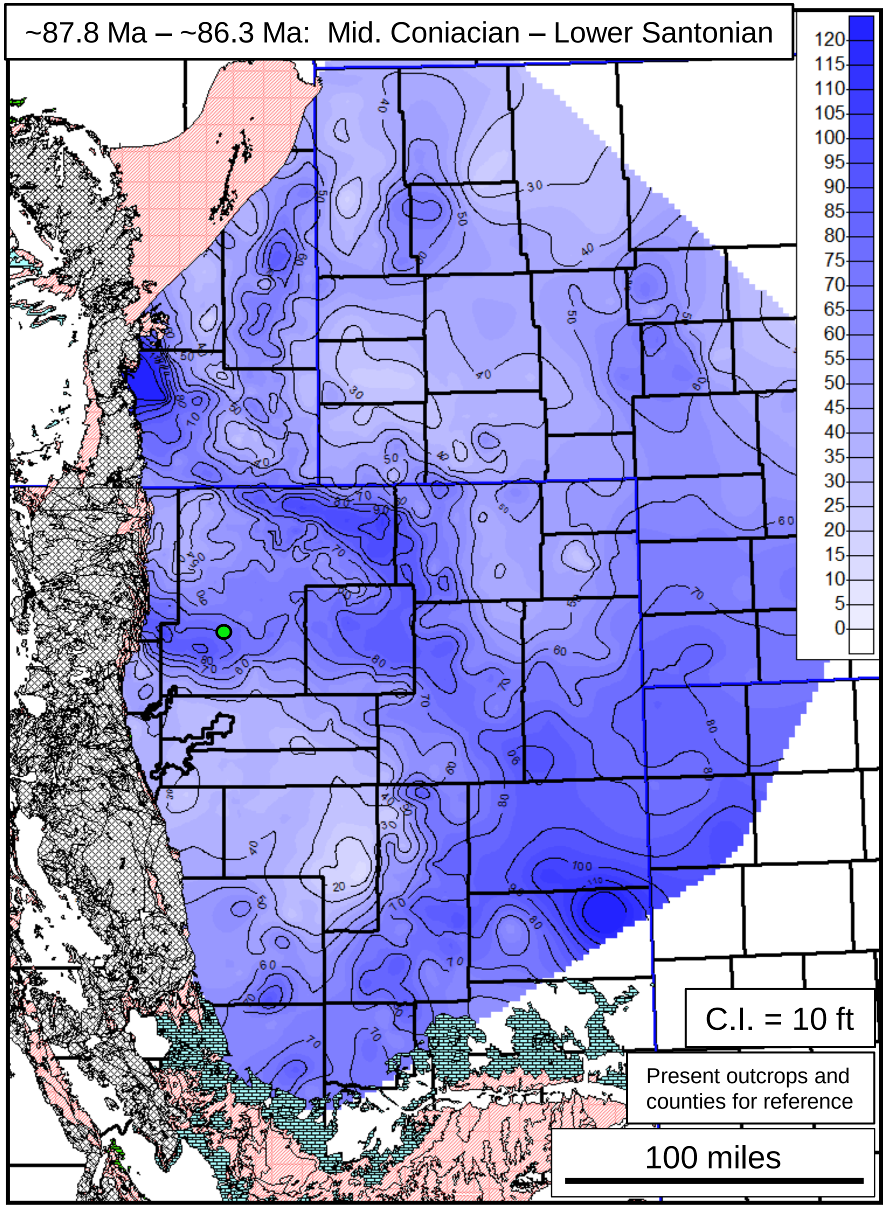
PIONEER NATURAL RESOURCES



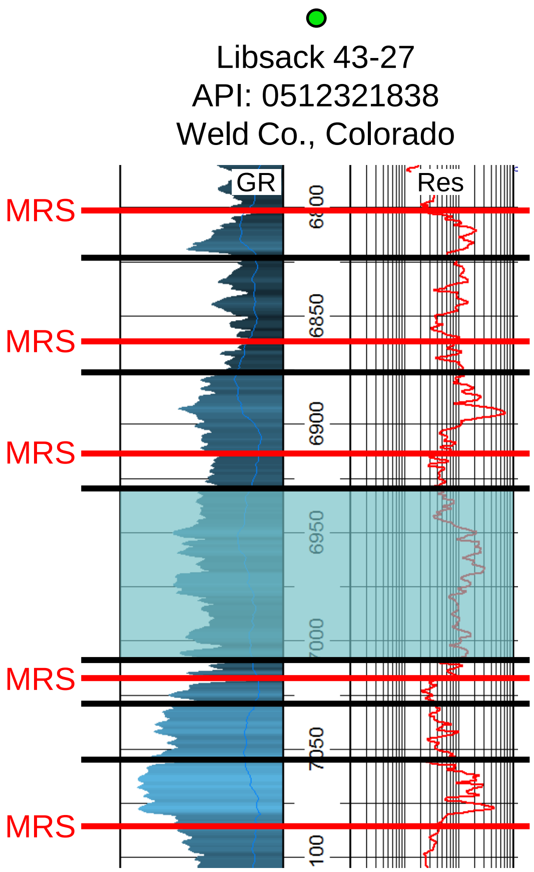
- Source-prone interval
- Persistent E-W- to NW-SE-oriented stratigraphic architecture



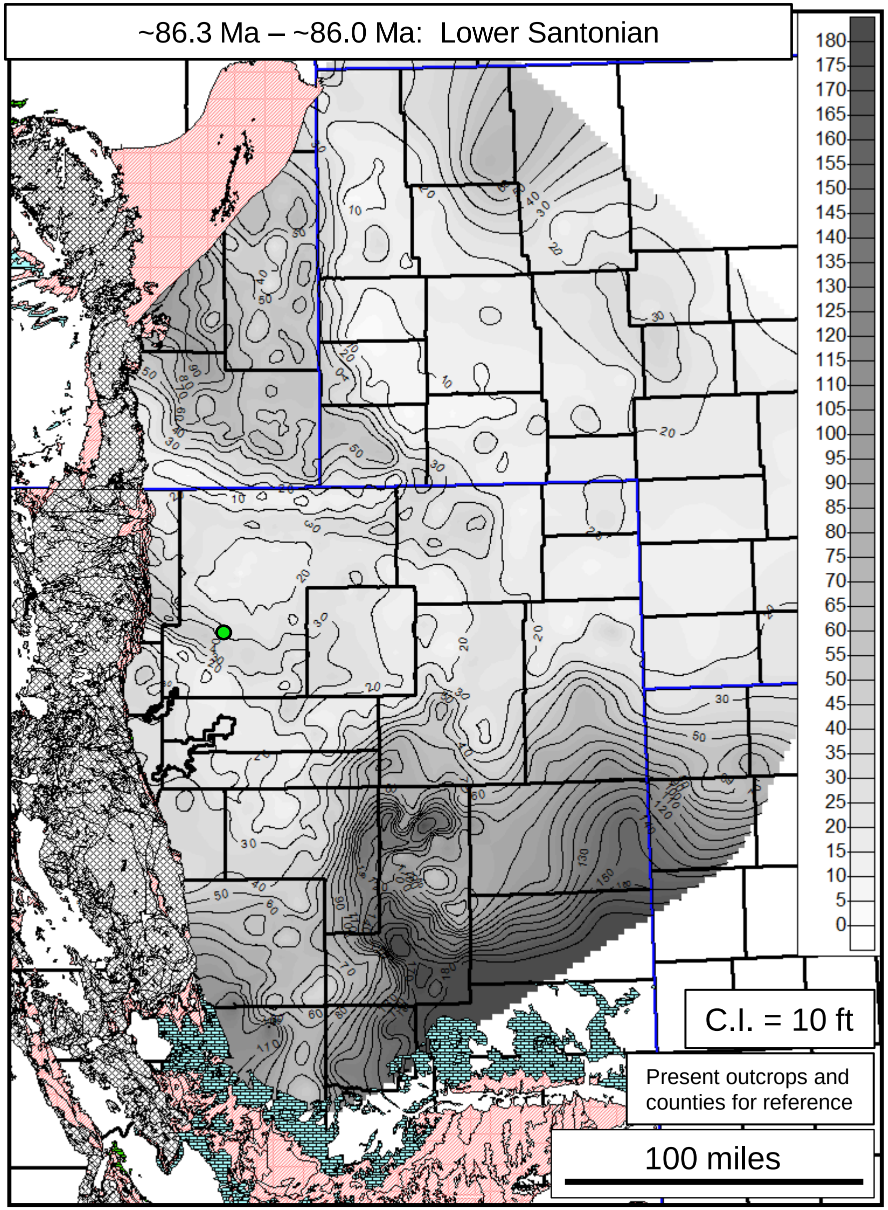
Sub-interval 4 Con300-Con400



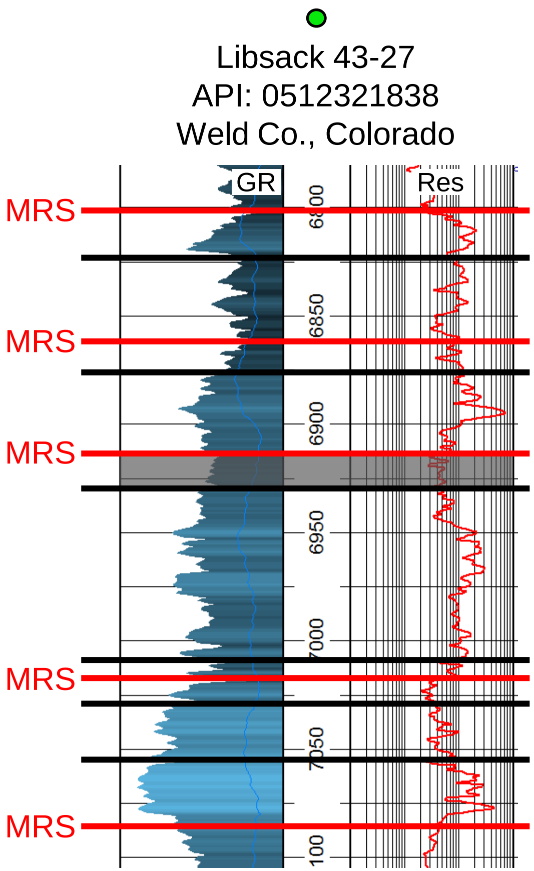
- Dominant NW-SE-oriented stratigraphic architecture
- Stratigraphic thicks overlie older thins: compensational infilling of available accommodation space
- Interval includes "C Chalk"



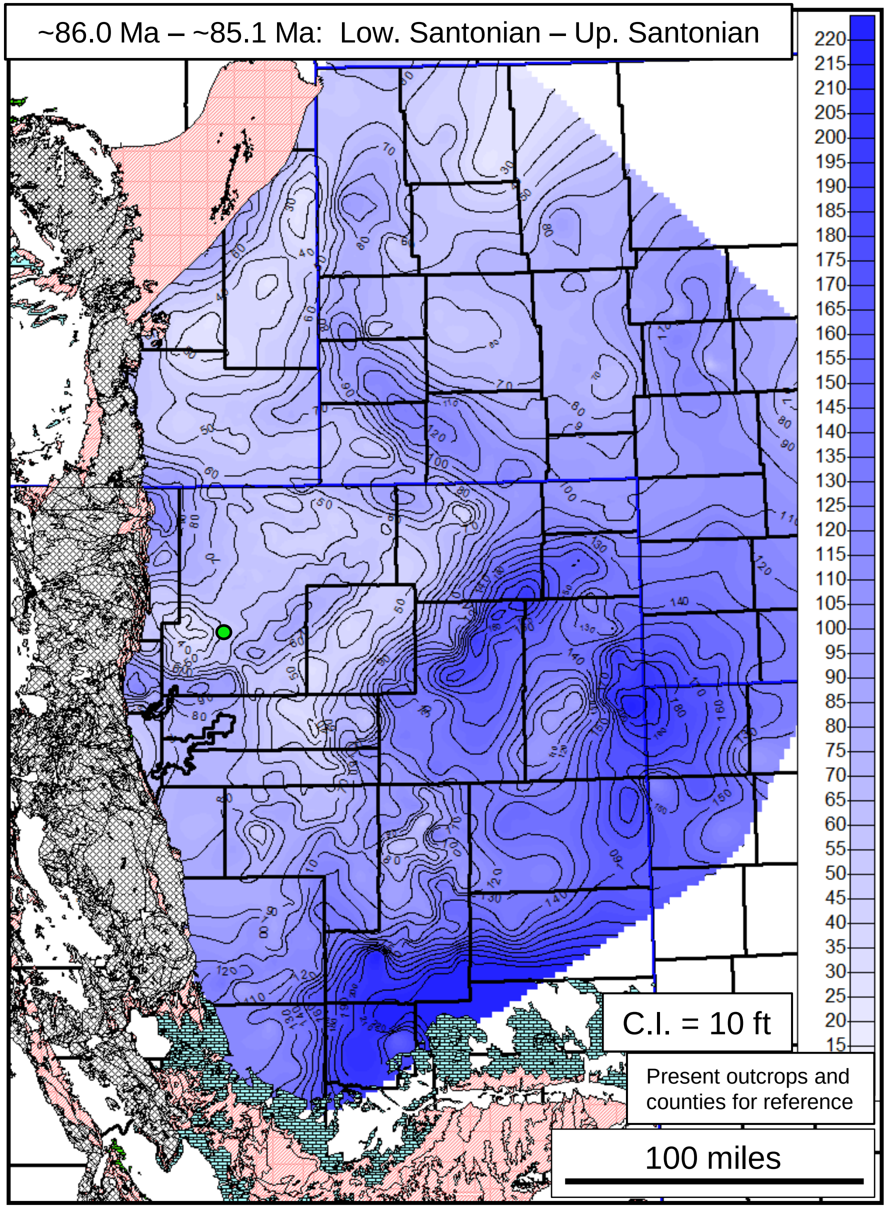
Sub-interval 5 Con400-San100



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



Sub-interval 6 San100-San200



- 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”

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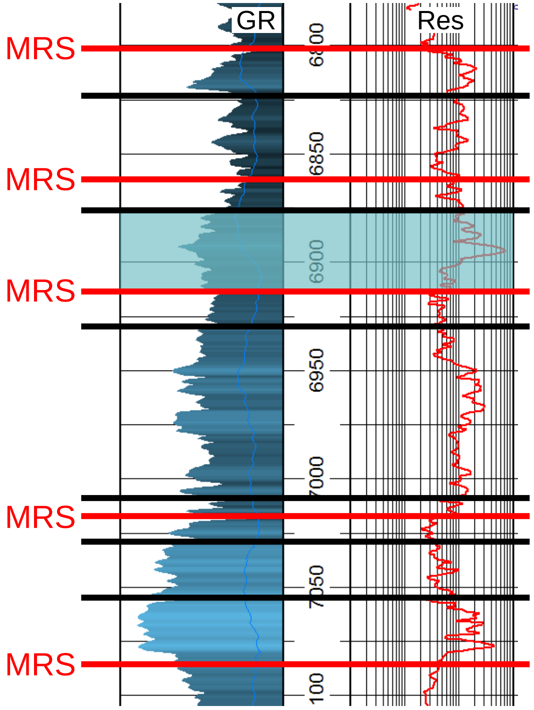
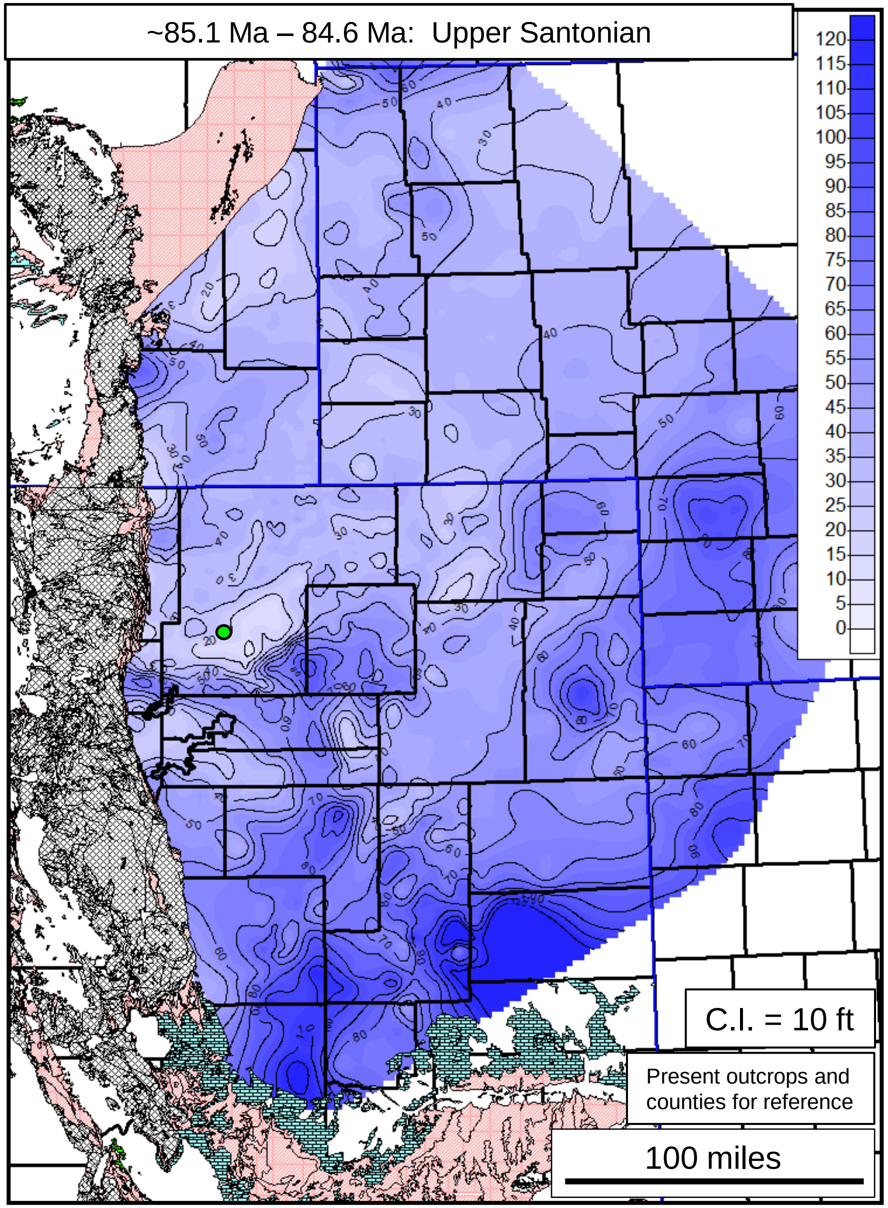
Weld Co., Colorado



Sub-interval 7 San200-San300



- 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"

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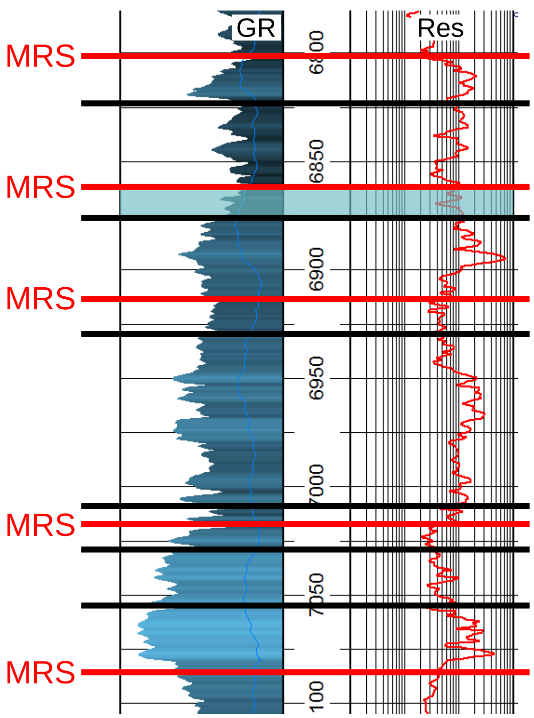
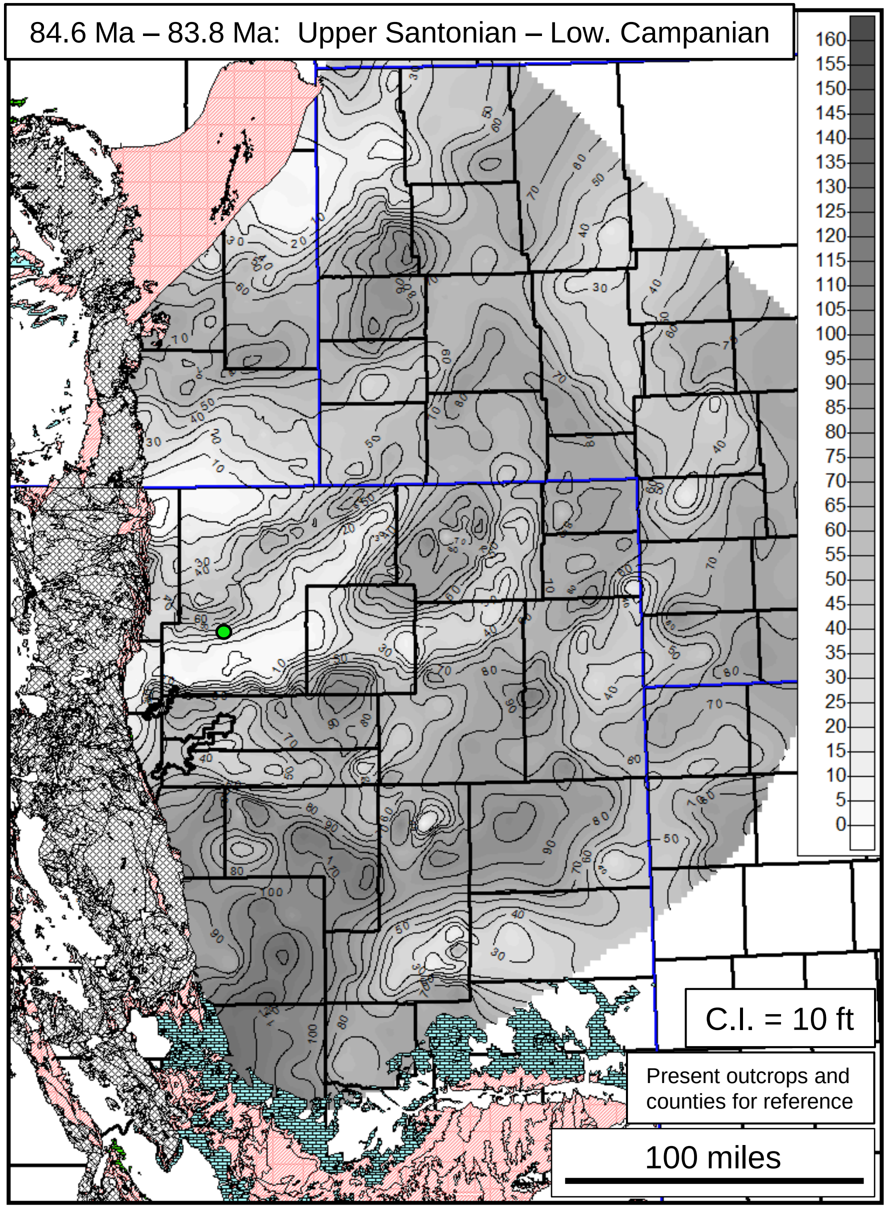
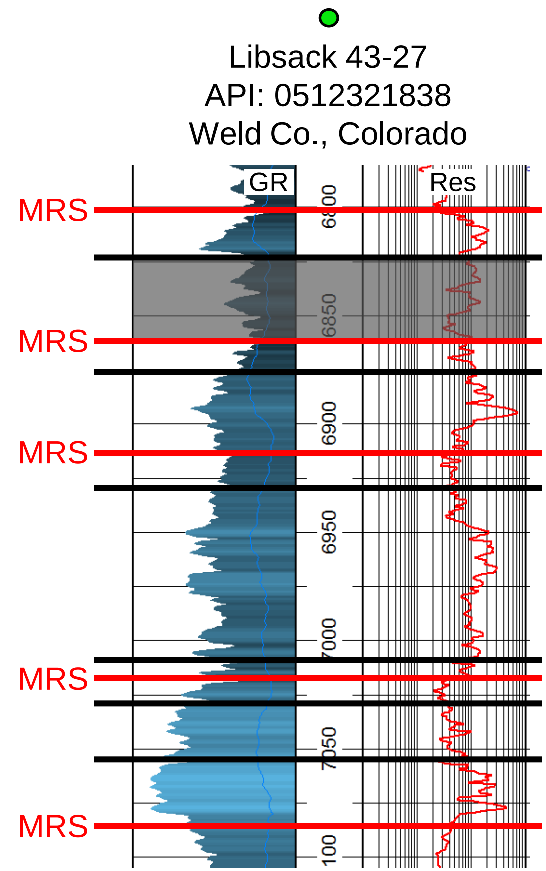


Sub-interval 8 San300-Cam50

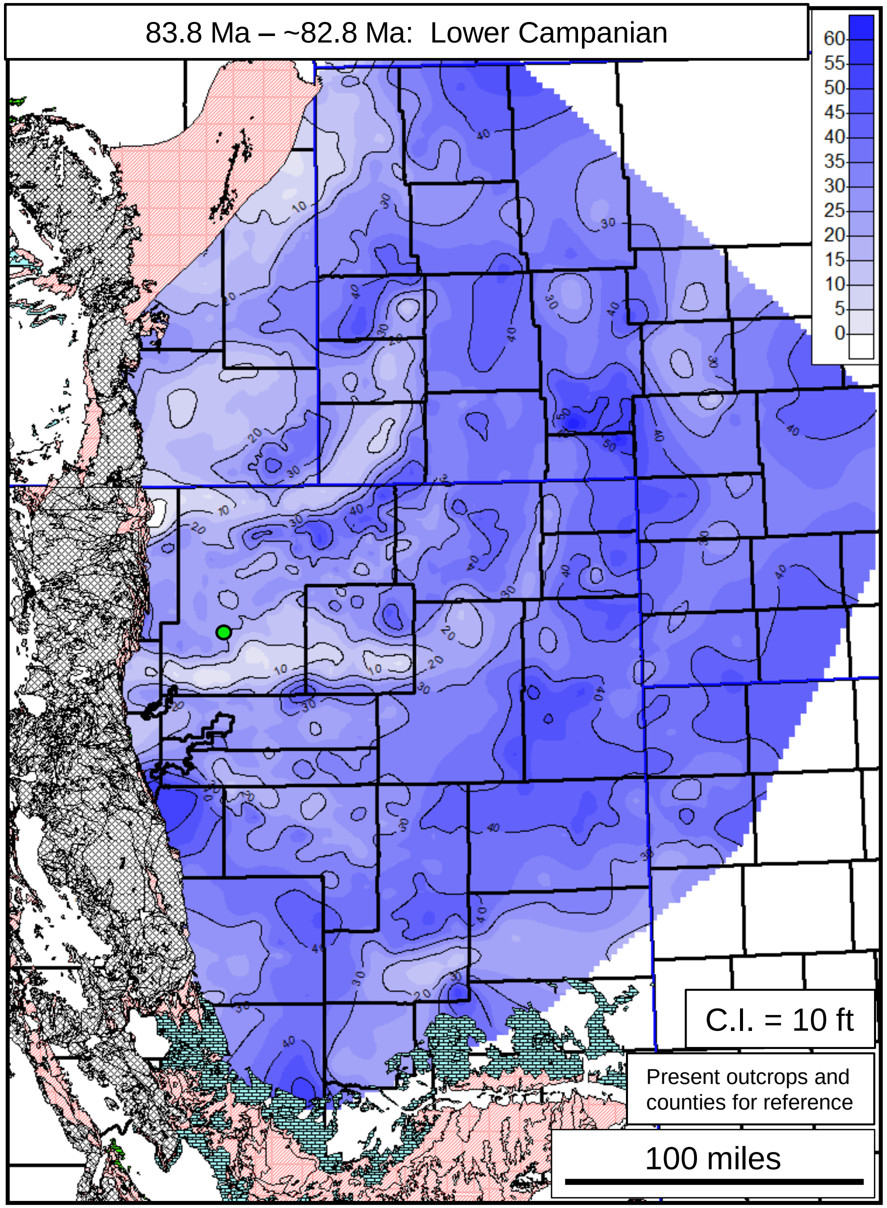


- Source-prone interval
- Pronounced NW-SE-oriented stratigraphic architecture, similar to previous intervals
- Thinning apparent in southern D-J Basin

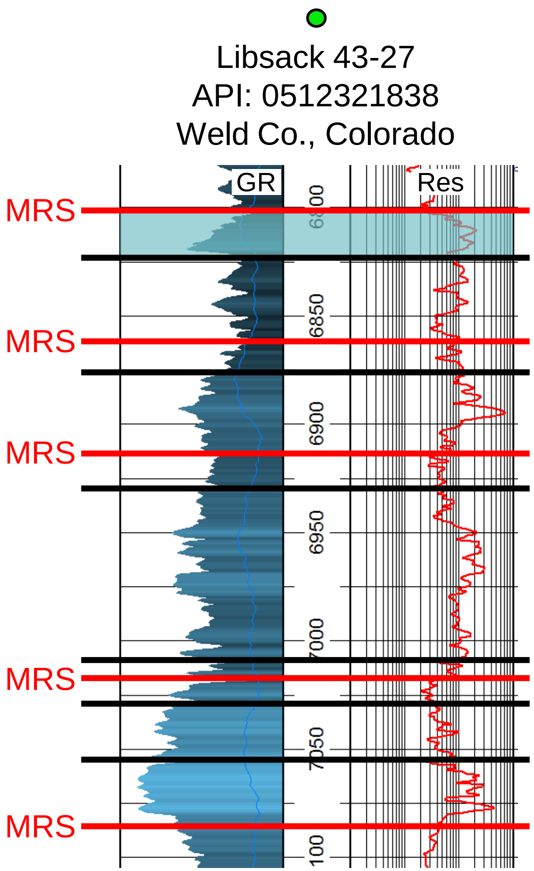


Sub-interval 9 Cam50-Cam100

PIONEER NATURAL RESOURCES



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



Conclusions

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- **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.