Revisiting the Upper Cretaceous Niobrara Petroleum System in the Rocky Mountain Region*

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Abstract

Our 1998 publication based on a regional study of the Niobrara Formation slightly preceded a burst of successful horizontal drilling and much new research into Niobrara stratigraphy and depositional processes. Isopach and facies maps we published as well as our depositional models for the Niobrara have proved useful, and we may have been ahead of the learning curve in attributing the chalk and marl benches primarily to current flow patterns in the Western Interior Seaway rather than eustatic sea level changes. Some lessons learned about the Niobrara in the 21 years since that paper was published are the focus of this presentation.

Our depositional model claimed that current flow patterns in the long, narrow Western Interior Seaway, specifically the flow direction of tropical Gulfian versus colder arctic currents, was the primary control on chalk vs. marl deposition. In the Denver Basin, for example, when warmer Gulfian waters flowed northward, they brought into the seaway the abundant coccoliths, copepods, and planktonic foraminifers that form the chalkier intervals. When arctic waters flowed predominantly southward in the seaway, carbonate productivity was limited and marlier, more organic-rich facies were deposited. Changes in water depth had little to do with the resulting Niobrara rock types, but the associated eddies, swirls, and current vortices did significantly impact chalk vs. marl deposition on a fine scale. New evidence supporting our interpretation is five-fold: 1) Well documented high-resolution interfingering of the chalk and marl facies on a scale of centimeters or less, which is far too thin to be controlled by sea-level fluctuations; 2) Thin (<2 cm) organic-rich marls within the clean chalk benches that cannot be the product of sea-level changes; 3) Lack of evidence for the eustatic sea level changes along the seaway's margins (e.g., in Utah and Kansas); 4) Interbedded chalk and marl facies in the Fort Hays Member, which are commonly attributed to Milankovitch cycles, with

significant current induced scours and up to a meter of relief, and 5) Documentation of modern ocean current flow patterns on deep-water hemipelagic deposits off New Zealand's South Island and in the Mediterranean that have produced bedforms now shown to occur in the Niobrara on high-resolution cross sections (e.g., in the Denver Basin).

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Revisiting the Upper Cretaceous Niobrara Petroleum System in the Rocky Mountain Region

Dark-Gray Chalks and Marls of the Niobrara Formation in the Lyons Quarry near Lyons, Colorado, with superimposed outcrop gamma-ray log from Slatt et al. (1995)

Mark Longman and Barbara Luneau

RMS-AAPG Talk in Cheyenne, September 17, 2019

Outline

I. Results of our Regional Niobrara Study published in 1998

II. Niobrara Research & Exploratory Drilling Since 1998

III. Controls on Chalk vs. Marl Deposition in the Niobrara

A. Sea Level Changes (the "traditional" interpretation)

B. Milankovitch Climatic Cycles (precession = 21 kyr; obliquity=41 kyr; eccentricity=100 kyr, 400 kyr, 1000 kyr; e.g., Locklair & Sageman, 2008)

C. Current Flow Patterns in the Western Interior Seaway

1. Evidence from Regional Trends

2. Thickness of Interfingering Chalk & Marl Beds

3. Modern Analogs offshore New Zealand & Mediterranean

V. Conclusions

Goals of our 1998 Niobrara Publication in *The Mountain Geologist*

1. Define the Internal Stratigraphy of the Niobrara Formation

2. Identify Major Lithologies & Depositional Facies from Cores

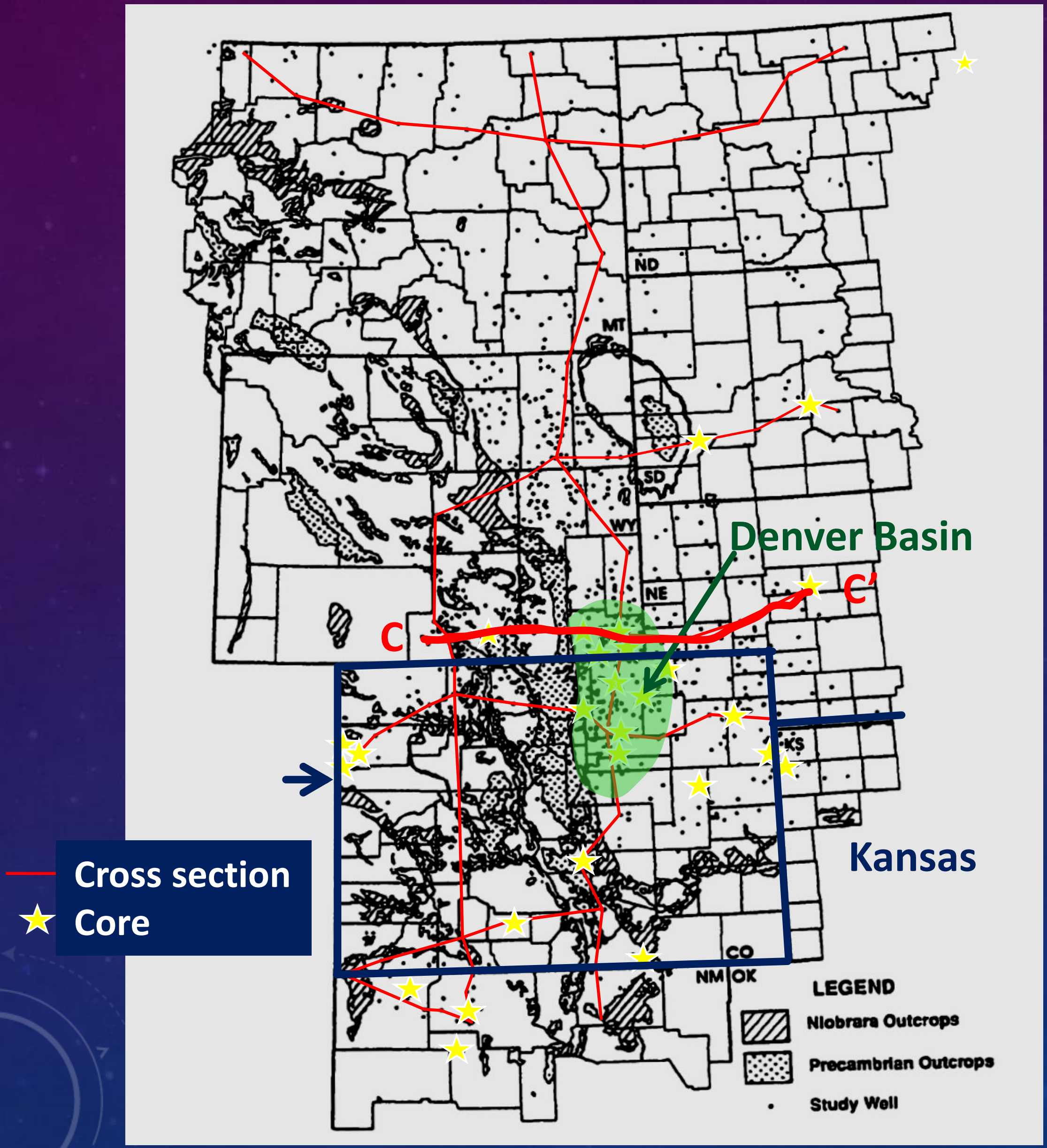
3. Map Thickness Trends of the Various Niobrara Intervals

4. Develop Models for Niobrara Deposition

5. Quantify Hydrocarbon Source Potential

6. Provide an Exploration Framework for the Niobrara

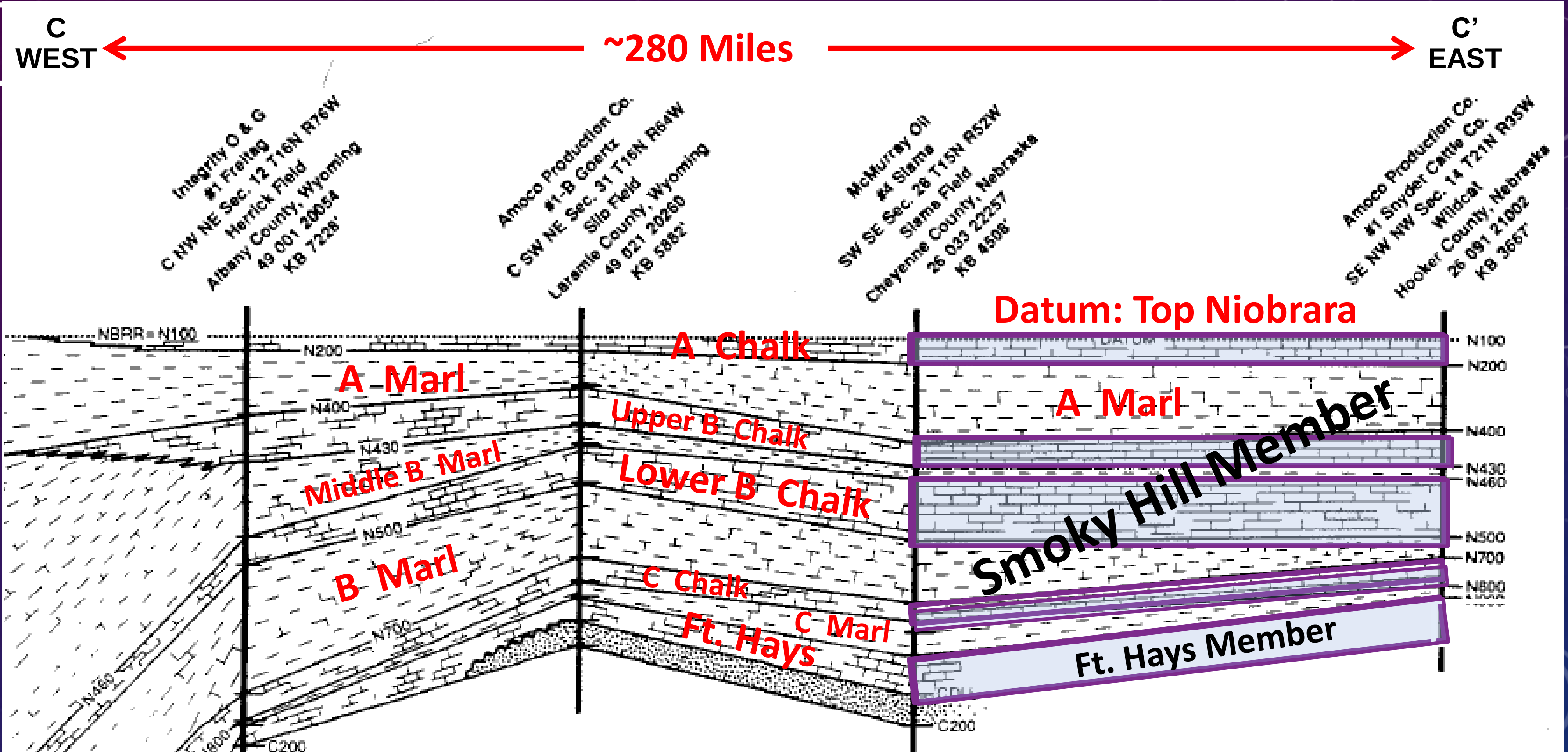
Regional Analysis of the Upper Cretaceous Niobrara Formation in the Rocky Mountain Region

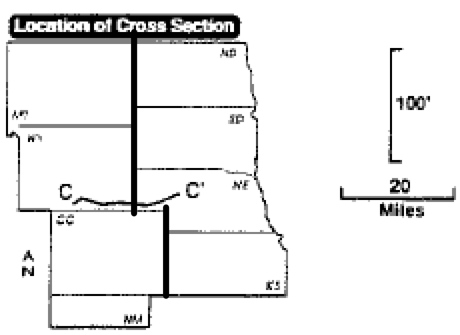


Scope

- 1017 Wells Correlated
- 47 Cores Described
  - Facies Descriptions
  - >100 Thin Sections
  - 100 TOC & Rock-Eval Pyrolyses
- 12 Stratigraphic Markers
- Facies Mapping
- Depositional Models
- Burial History
- Exploration Concepts

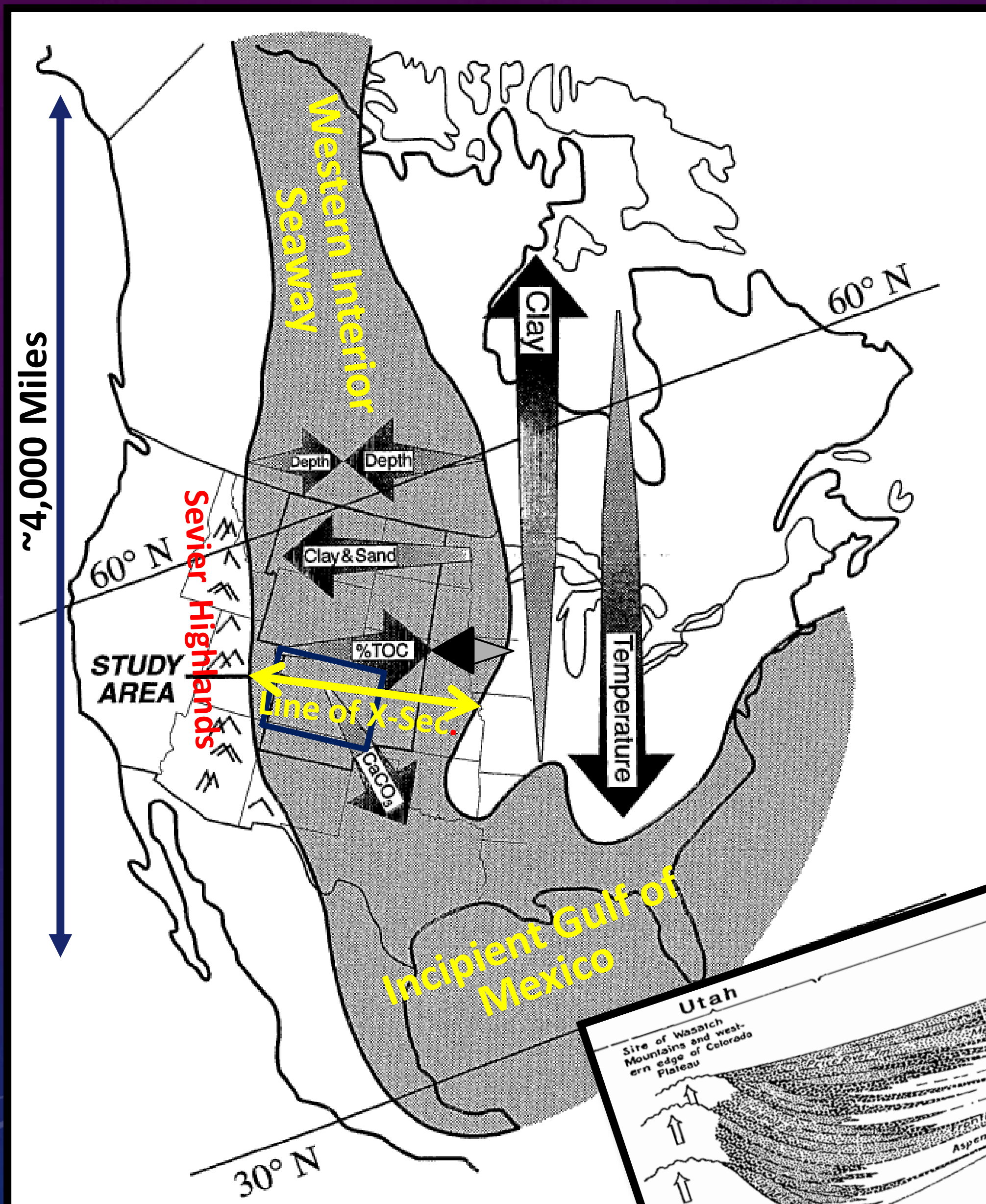
Regional West-to-East cross-section showing blanket-like Niobrara Chalk Benches pinching out Westward





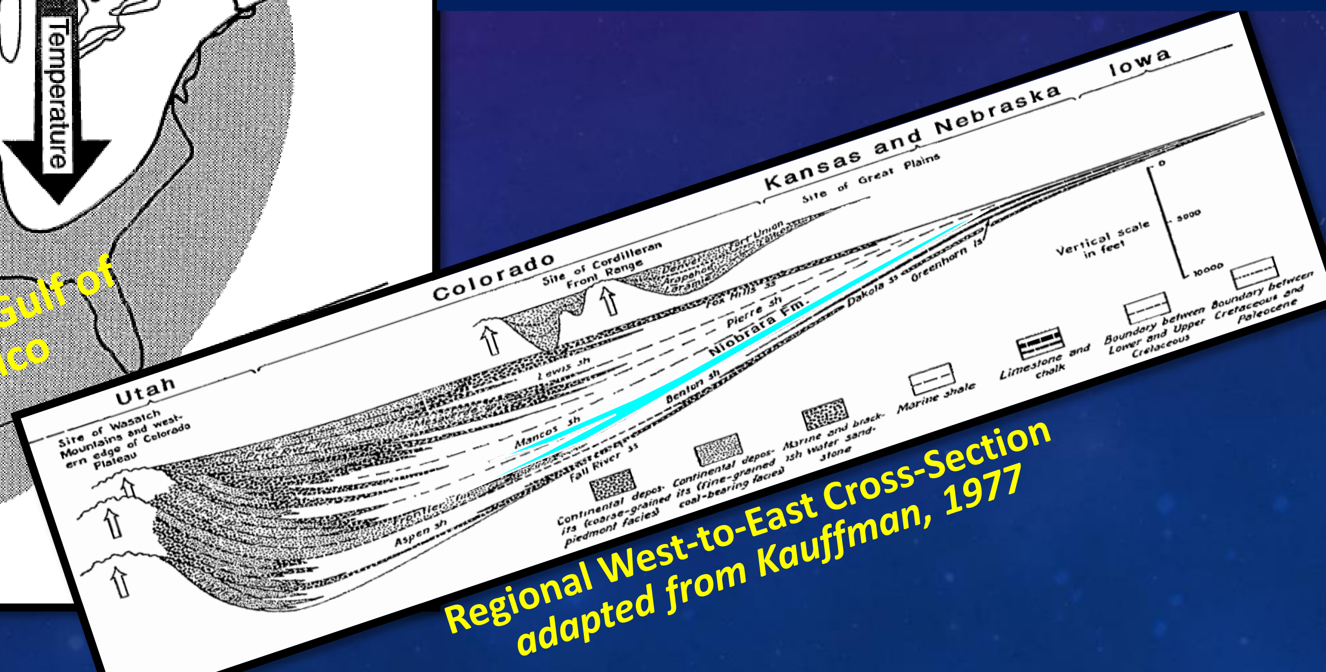
Conclusion: We could correlate the chalk benches across a few hundred miles as relatively blanket-like deposits separated by marl packages.
The "Chalks" behaved as expected based on our model for deep-marine deposition, but they thinned westward and pinched out as the marls thickened.

Niobrara (Upper Cretaceous) Depositional Setting



Key Points

1. Major Orogenic Belt to West shedding siliciclastics eastward
2. Broad, flat shelf to East
3. Continuous N/S Seaway
4. Warmer chalk-rich water to South
5. Cooler, denser, nutrient-rich Arctic water to North
6. Coccoliths, copepods, & planktonic forams thrive in the warmer waters



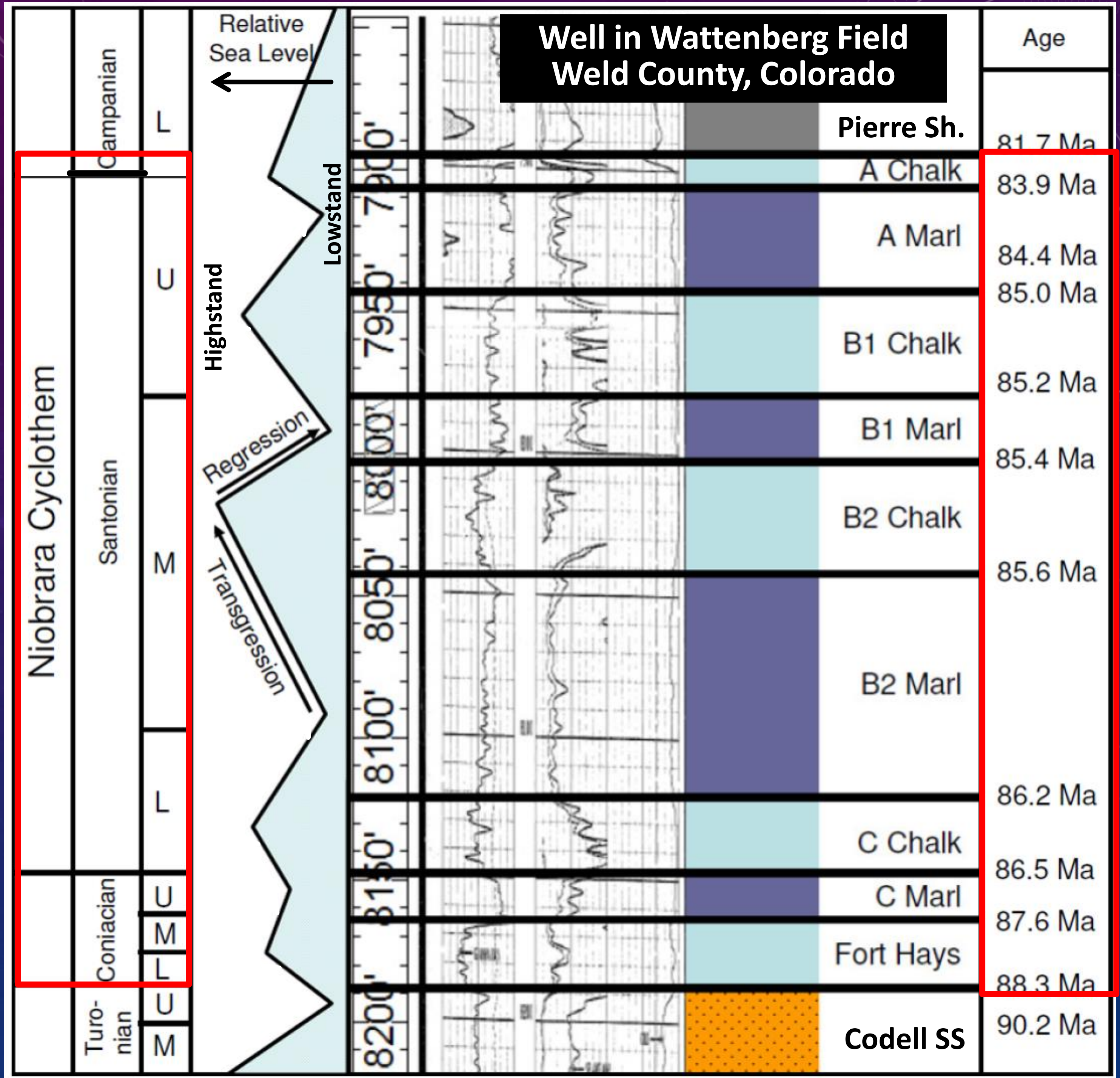
Regional West-to-East Cross-Section adapted from Kauffman, 1977

“Traditional” Sequence Stratigraphic view of Niobrara “chalks & marls”

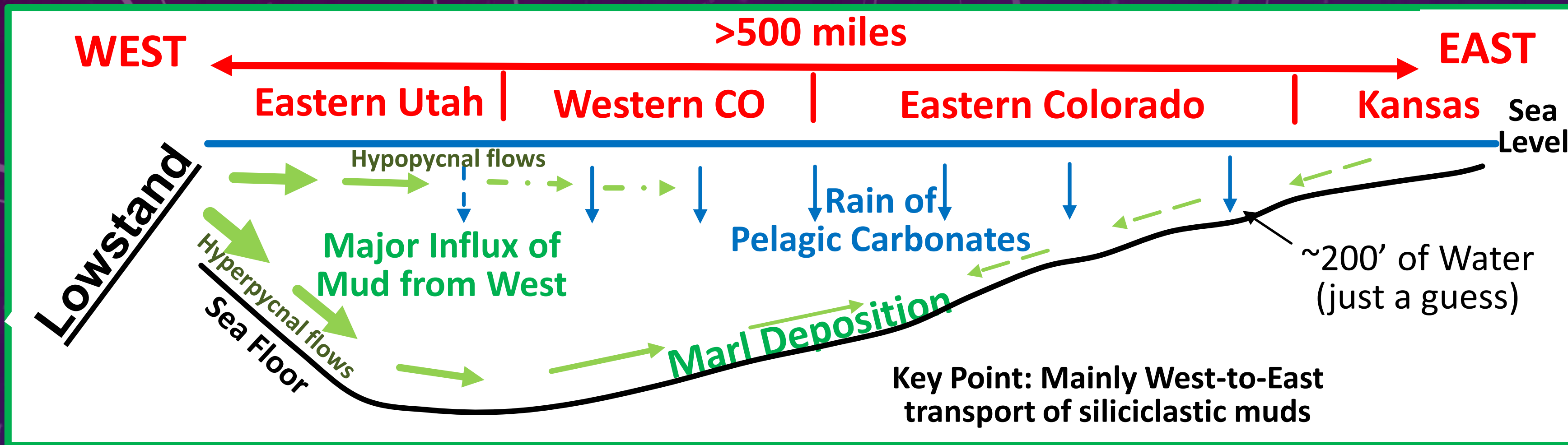
Transgressions and Regressions explain the “chalk” and “marl” Benches

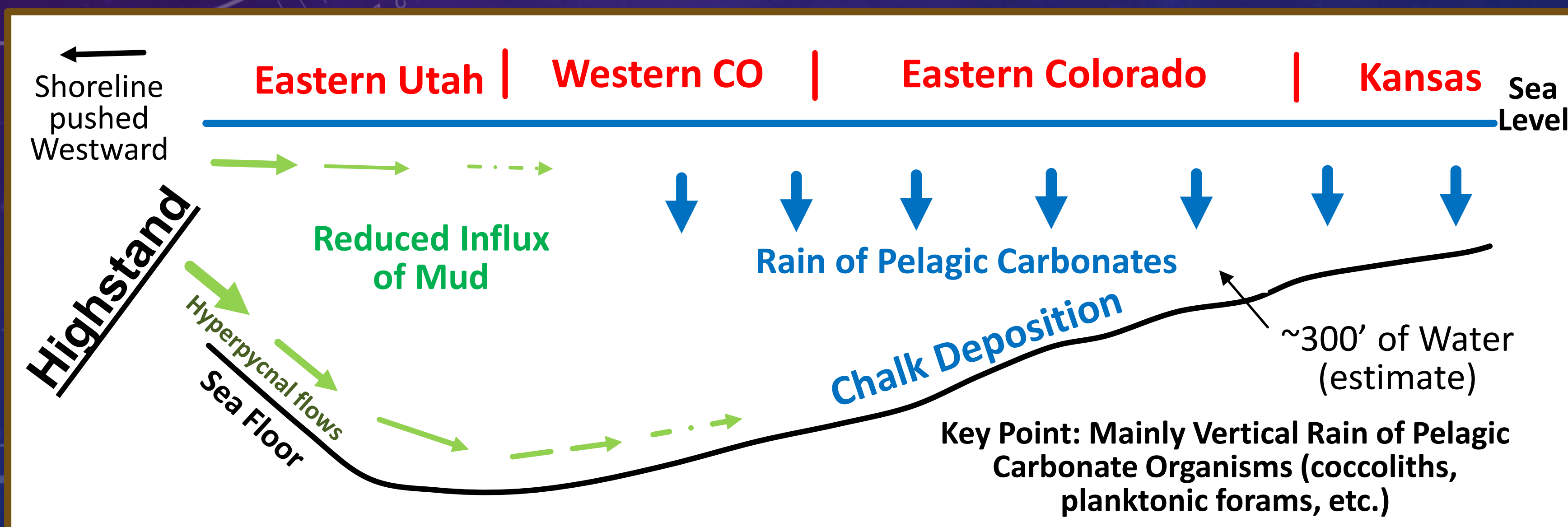
Approximate Absolute Ages at right suggest the Niobrara represents ~6.6 MY of Deposition

=8.3% of the 79-million-year Cretaceous Period



Schematic Model for Chalk vs. Marl Deposition in the Western Interior Seaway during Niobrara Time

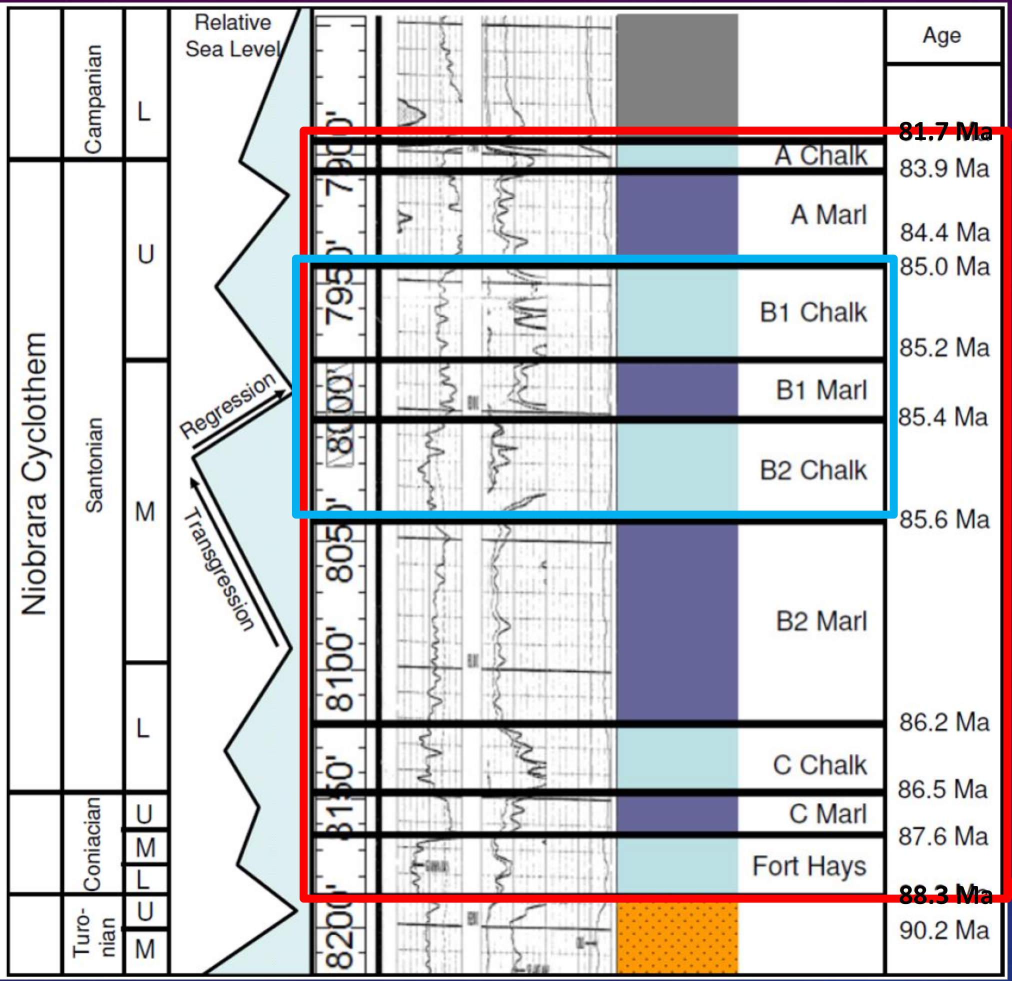




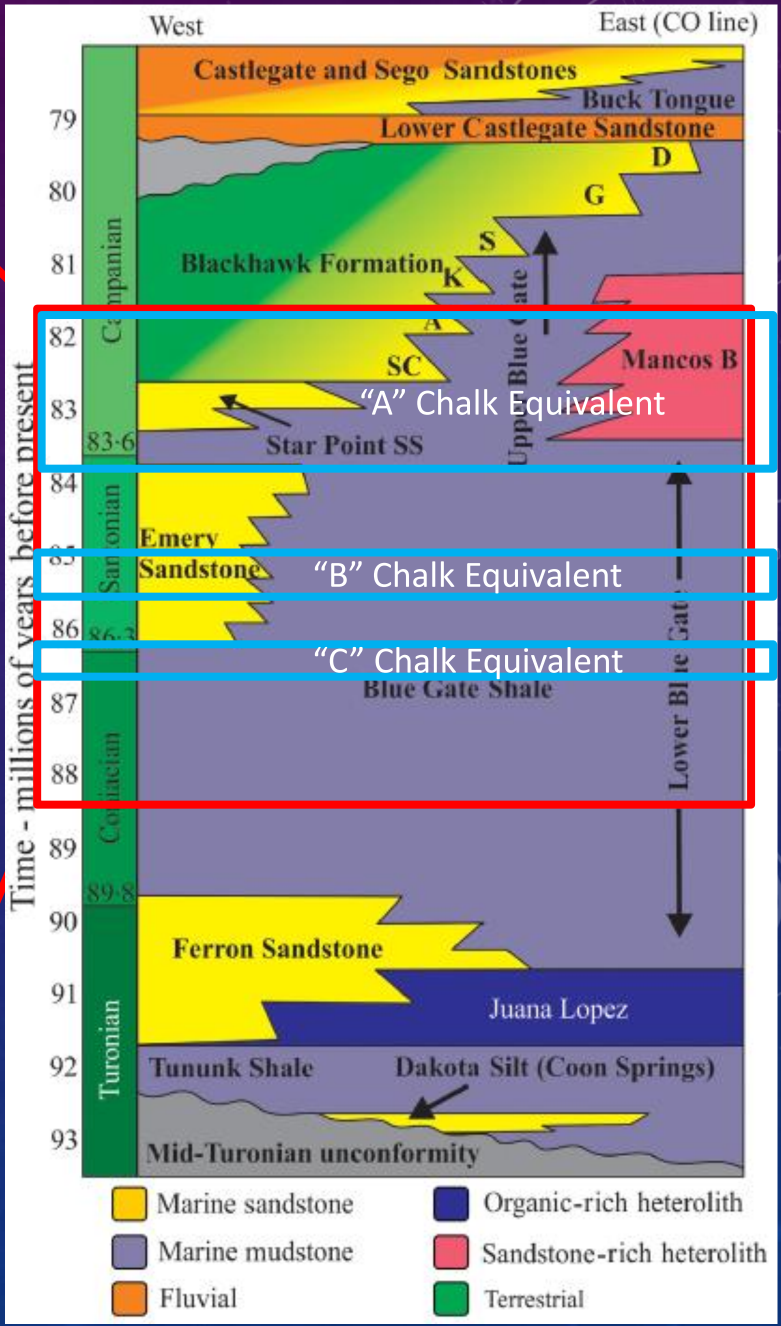
Interpreted from Models for Niobrara Deposition by Kauffman and others

Vertical Exaggeration >2500X

Well in Wattenberg Field, Weld County, Colorado with ages from the Niobrara Stratotype near Pueblo, CO



Absolute ages based on Argon ages from bentonites by Obradovich (1993) tied to ammonite biozones of Cobban (1993), and molluscan biozones of Kauffman et al. (1993)



From Birgenheier et al., 2017

Some figures in our 1998 paper illustrate an Alternative Control on Chalk vs. Marl Deposition:

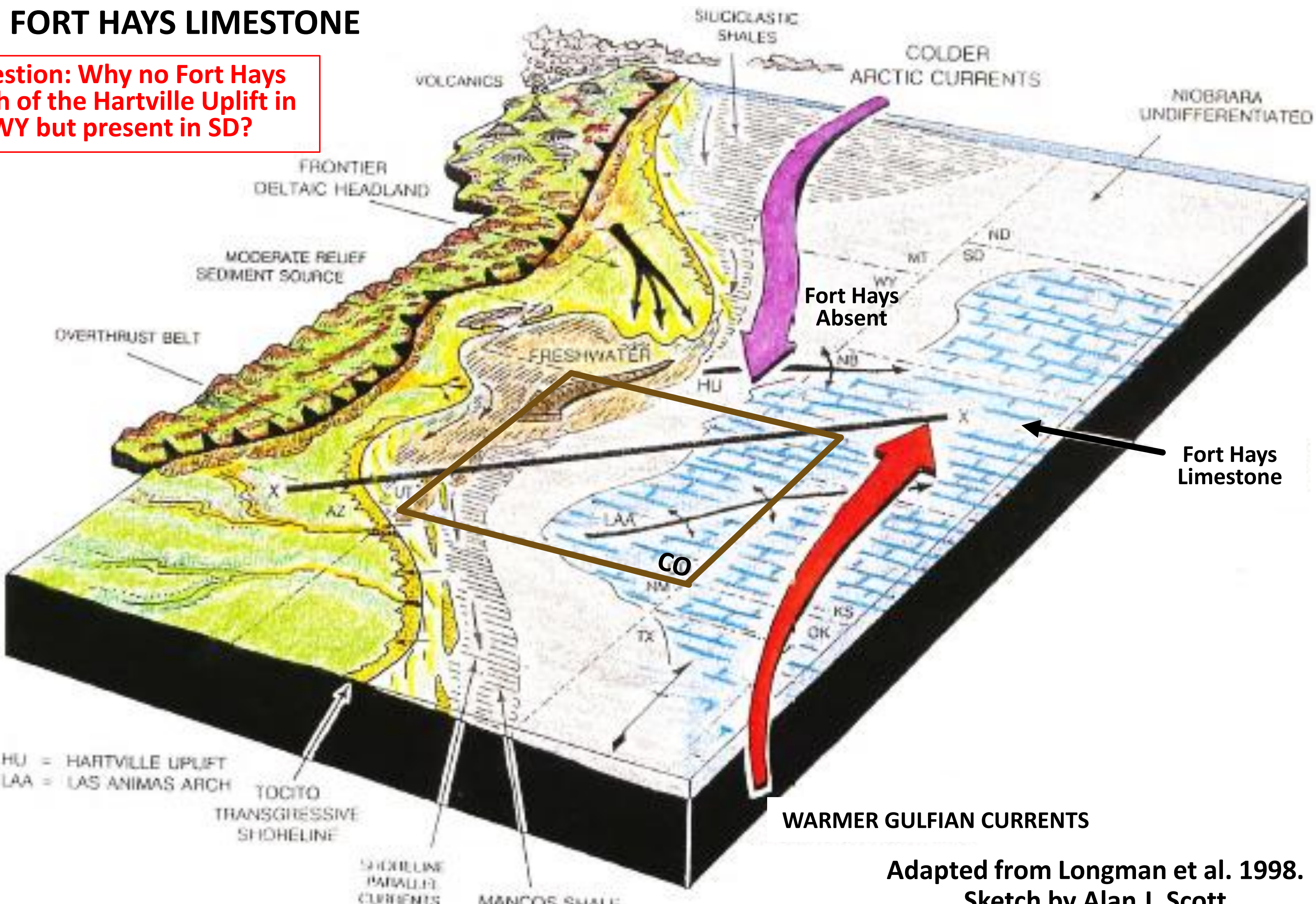
Current Flow Directions in the Seaway

Diagram for Current Flow and Fort Hays "Waters" in the Western Interior Seaway

PALEOENVIRONMENTAL SETTING OF EARLY NIOBRARA FORT HAYS LIMESTONE

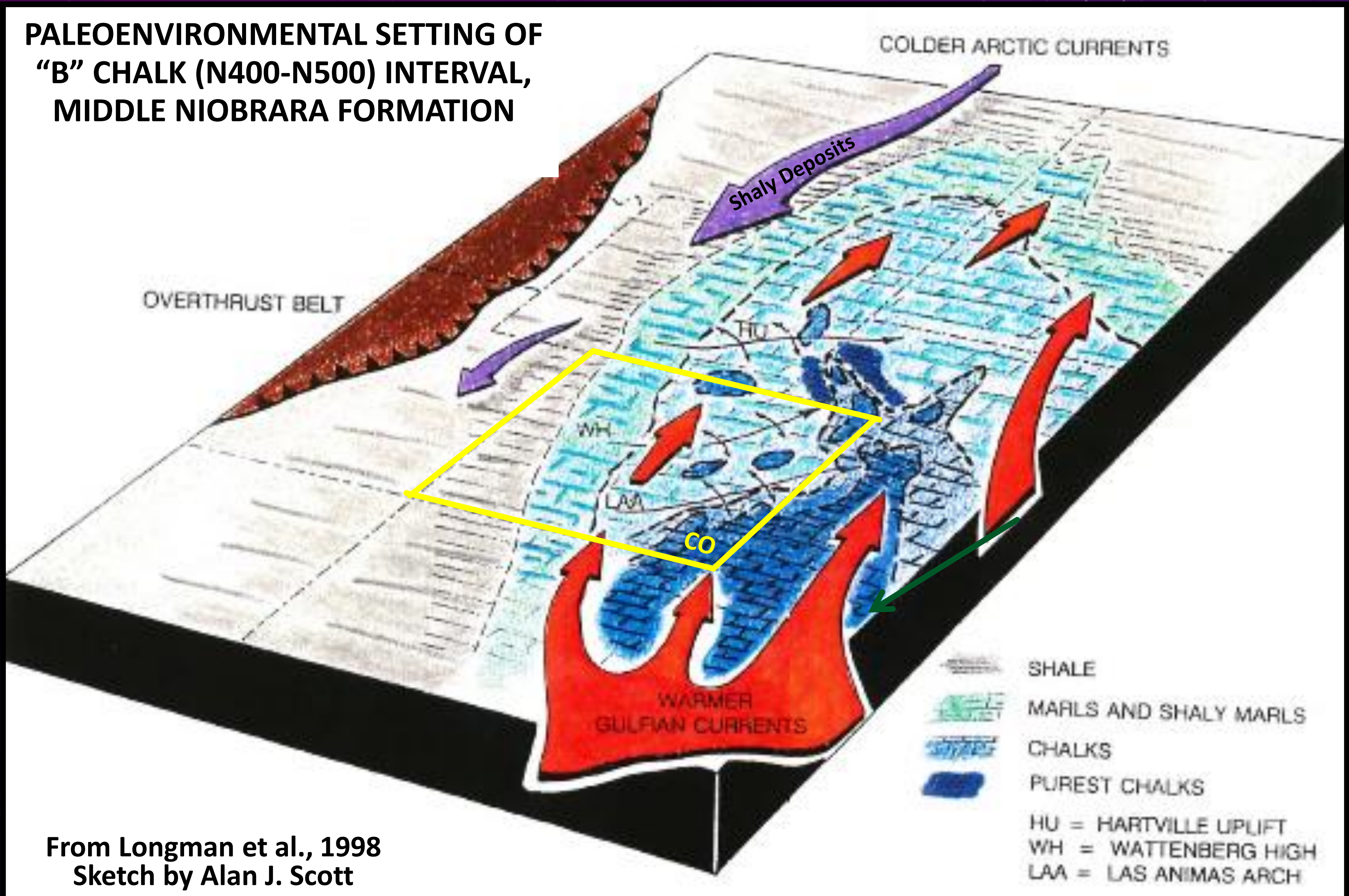
Question: Why no Fort Hays north of the Hartville Uplift in WY but present in SD?

Diagram is the result of a "Brain-Storming" session on Fort Hays Deposition

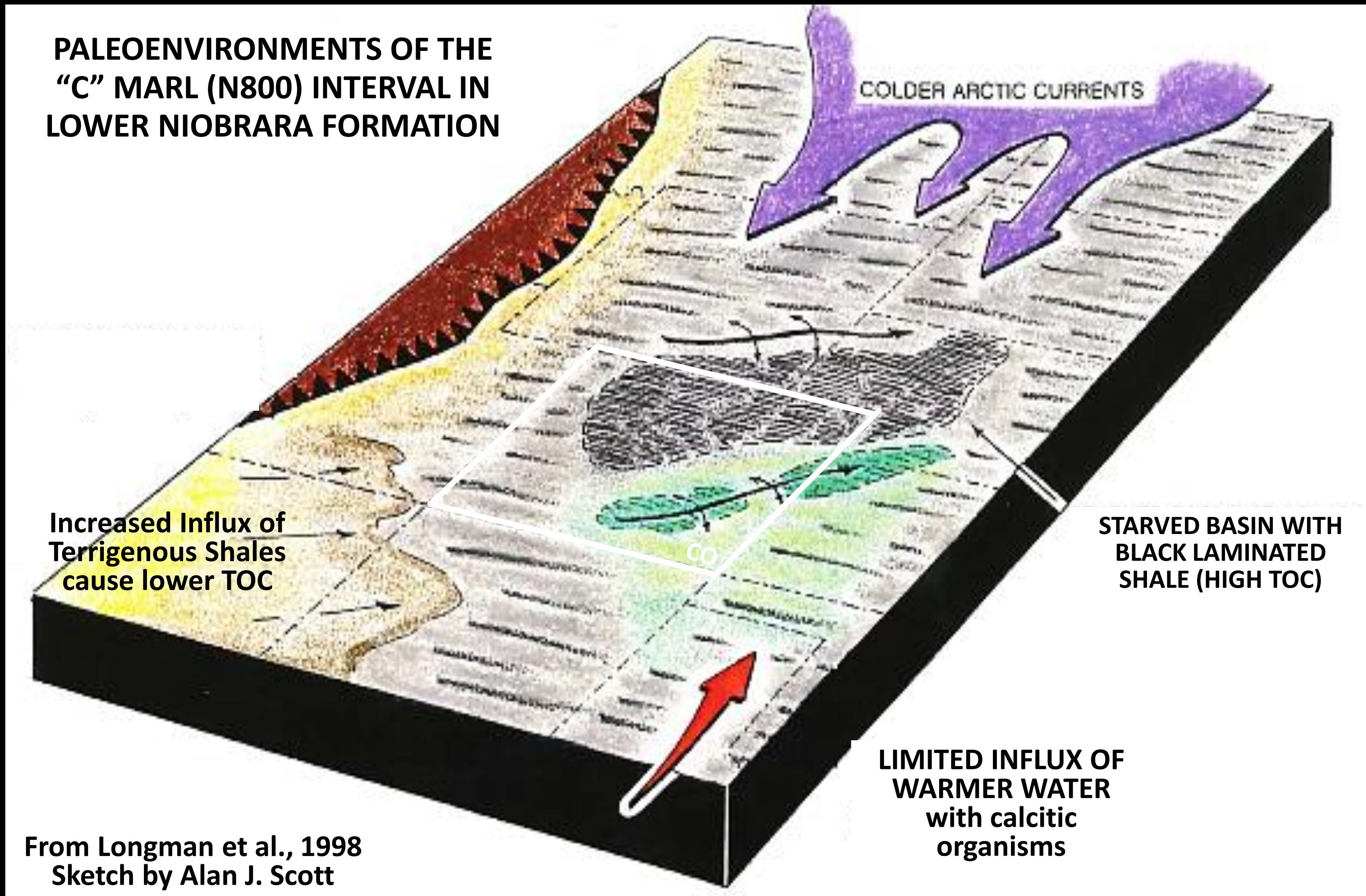


Adapted from Longman et al. 1998.
Sketch by Alan J. Scott

Diagram for Current Flow during Middle Niobrara "B" Chalk Deposition in the Western Interior Seaway



Where are the Best Hydrocarbon Source Rocks in the Niobrara?



From Longman et al., 1998
Sketch by Alan J. Scott

WHAT HAS HAPPENED WITH THE NIOBRARA SINCE 1998?

1. Quality of Niobrara Hydrocarbon Source Rocks Recognized

2. The Niobrara became a primary focus of exploration and horizontal drilling in much of the Rocky Mountain Region

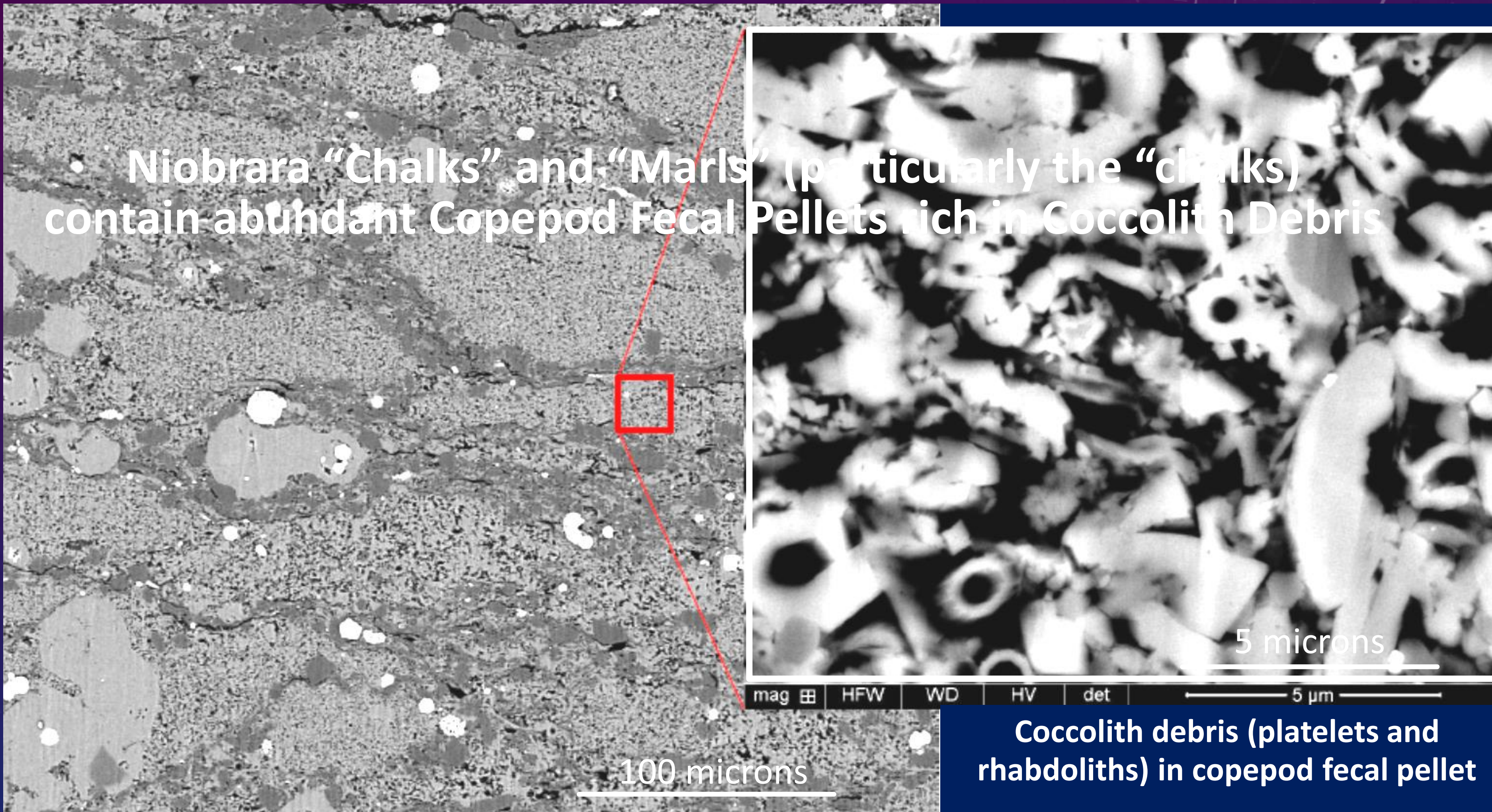
3. Hundreds of Niobrara horizontal wells have been drilled in Colorado, Wyoming, and to a lesser extent New Mexico

4. Hundreds of millions of barrels of oil have been produced

5. Dozens of “Sweet Spot” reservoirs have been identified but the reservoirs are not “blanket-like

6. >700 Niobrara abstracts, papers, theses, & dissertations published

To Answer the Question: "What is the Primary Control on Niobrara Deposition," let's look at the Rocks in Detail



- Niobrara "Chalks" and "Marls" (particularly the "chalks) contain abundant Copepod Fecal Pellets rich in Coccolith Debris

Coccolith debris (platelets and rhabdoliths) in copepod fecal pellet

Pyrite Framboids (white) in argillaceous matrix (dark) between compacted copepod fecal pellets

SEM images of the Niobrara Chalk from Deacon and Lieber, 2013 ACE

1. Simple: The Niobrara is Composed of "Chalks" and "Marls"

2. More Complex

Pelagic "ooze" of Coccoliths, Copepod Fecal Pellets, Planktonic Forams, and Organic "Snow" Settling Vertically through the Water Column "Chalk"

interbedded with

Hemipelagic Marine Sediments of Terrigenous, Volcanogenic, and Neritic origin that have undergone Lateral Transport (e.g., silt, clay, ash) "Marl"

3. Still More Complex

Burrowed Chalks/Marls	Bioturbated Chalk (coccolith biomicrite and coccolith-rich fecal pellets)
	Bioturbated Marly Chalk
	Bioturbated Chalky Marl
	Burrowed Slightly Chalky Marl
Laminated Chalks/Marls	Laminated, Burrowed Chalk-Marly Chalk
	Laminated, Burrowed Chalky Marl
	Laminated Chalky Marl (and rare thin marly chalk)

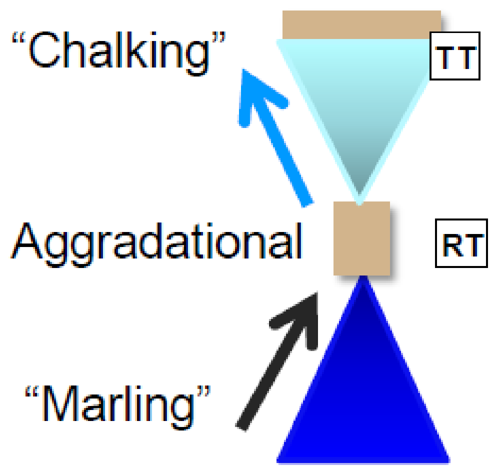
Alternating Beds: Burrowed/Laminated	Interbedded Bioturbated/Laminated Marly Chalk
	Bioclastic Alternating Bioturbated/Laminated Marly Chalk
	Alternating Bioturbated/Laminated Marly Chalk
	Alternating Bioturbated/Laminated Chalky Marl
"Crinkly"-Laminated Chalks/Marls	Crinkly-Lam Bedded Chalk and Marly Chalk
	Alternating Crinkly-laminated/bioturbated Marly Chalk and Chalky Marl
	(Lump with above) Alternating – Crinkly-Laminated Burrowed Marly Chalk

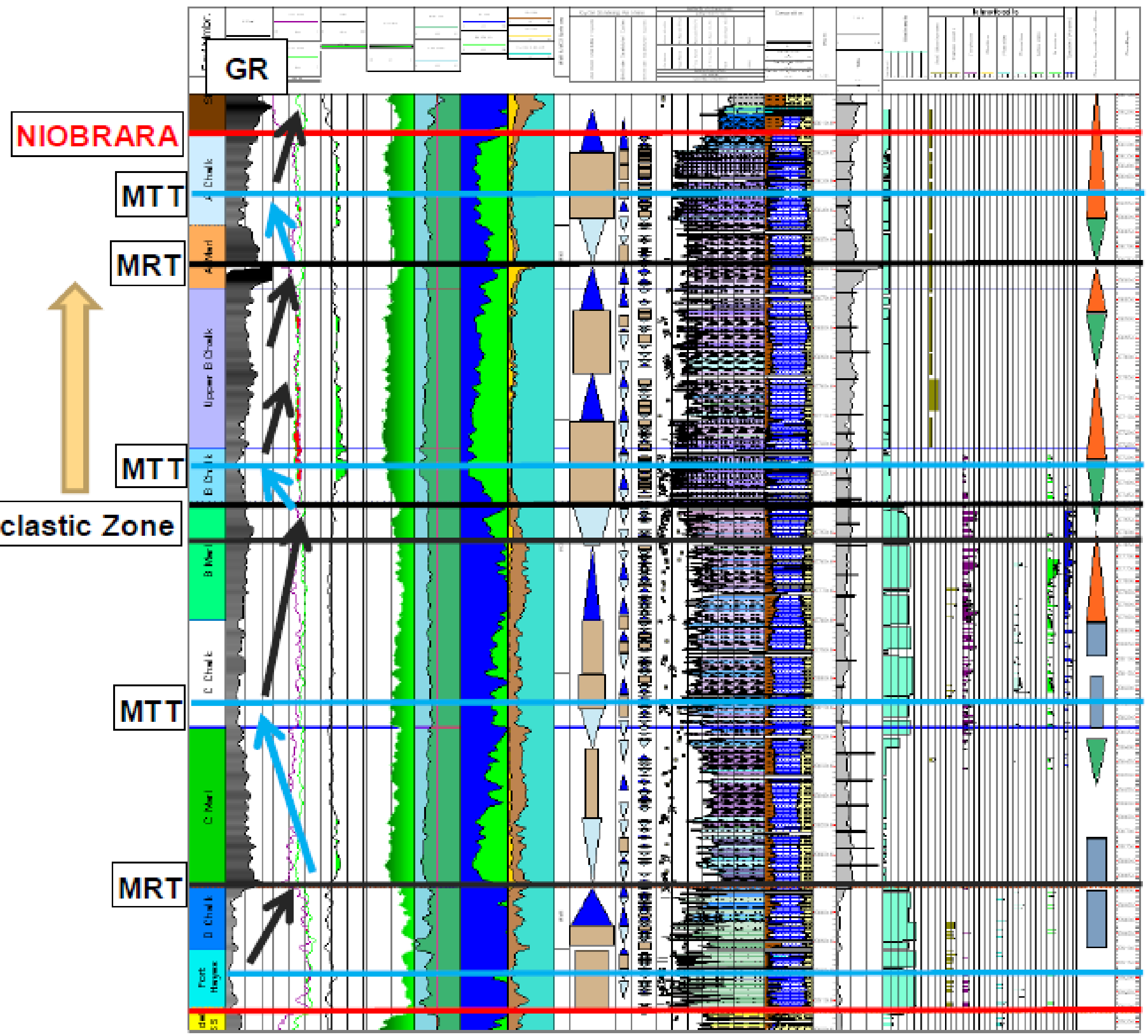
The more closely you look, the more complex the Niobrara!

18 Niobrara Facies were distinguished in cores by Deacon et al., 2013 ACE

A Detailed Core Description Summarizing Niobrara Sequences

Niobrara Depositional Sequence Summary



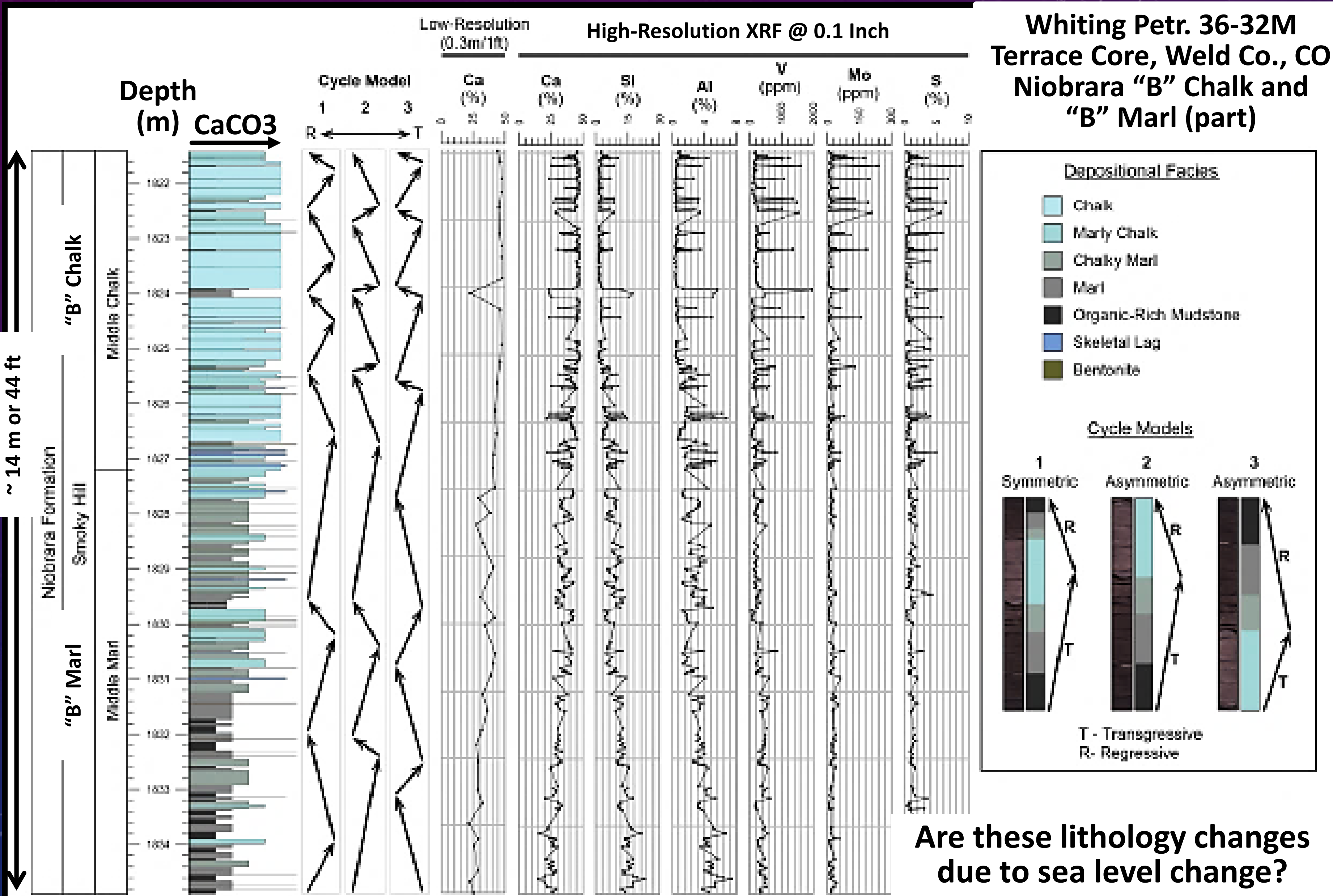


TT: Transgressive, open circulation
- Chalk-rich, dry cycle
- Low TOC
- Biotic processes dominate (CO3 productivity, microbial, burrowing)

RT: Regressive, restricted circulation
- Clay-rich
- Terrigenous Influx, wet cycle
- High TOC

From Deacon and Lieber, 2013 ACE

Note the level of interbedding seen with XRF in this Niobrara core!



Whiting Petr. 36-32M Terrace Core, Weld Co., CO Niobrara "B" Chalk and "B" Marl (part)

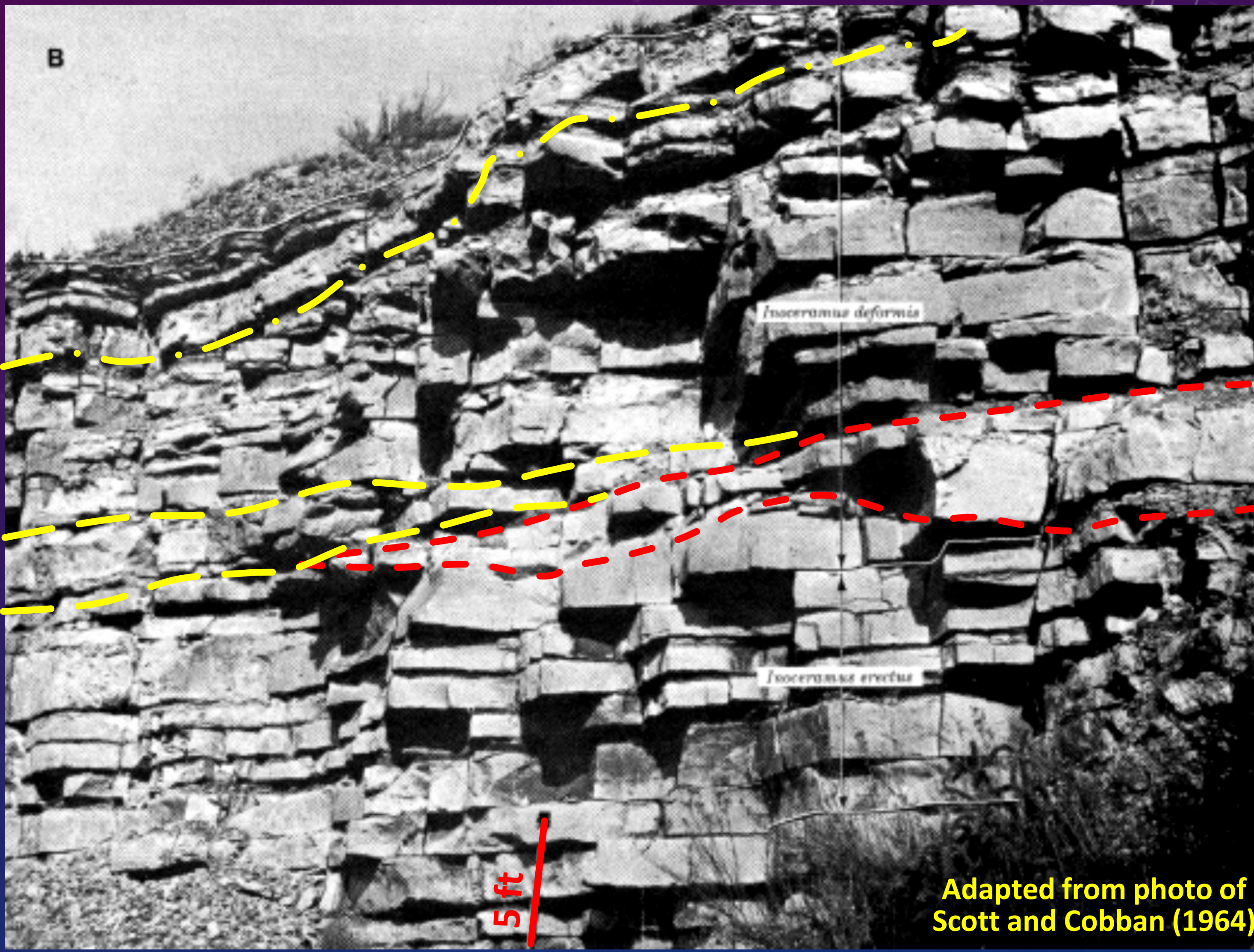
Are these lithology changes due to sea level change?

From Nakamura, 2015 CSM Thesis

Blanket-Like Limestone/Marl Couplets in the Fort Hays Member near Pueblo (SE NE Sec. 32, T20S, R65W) result from Climate Cycles

These limestone/marl couplets have been interpreted as the result of Milankovitch cycles for decades, not as the product of sea level fluctuations. Photo from Scott and Cobban (1964)

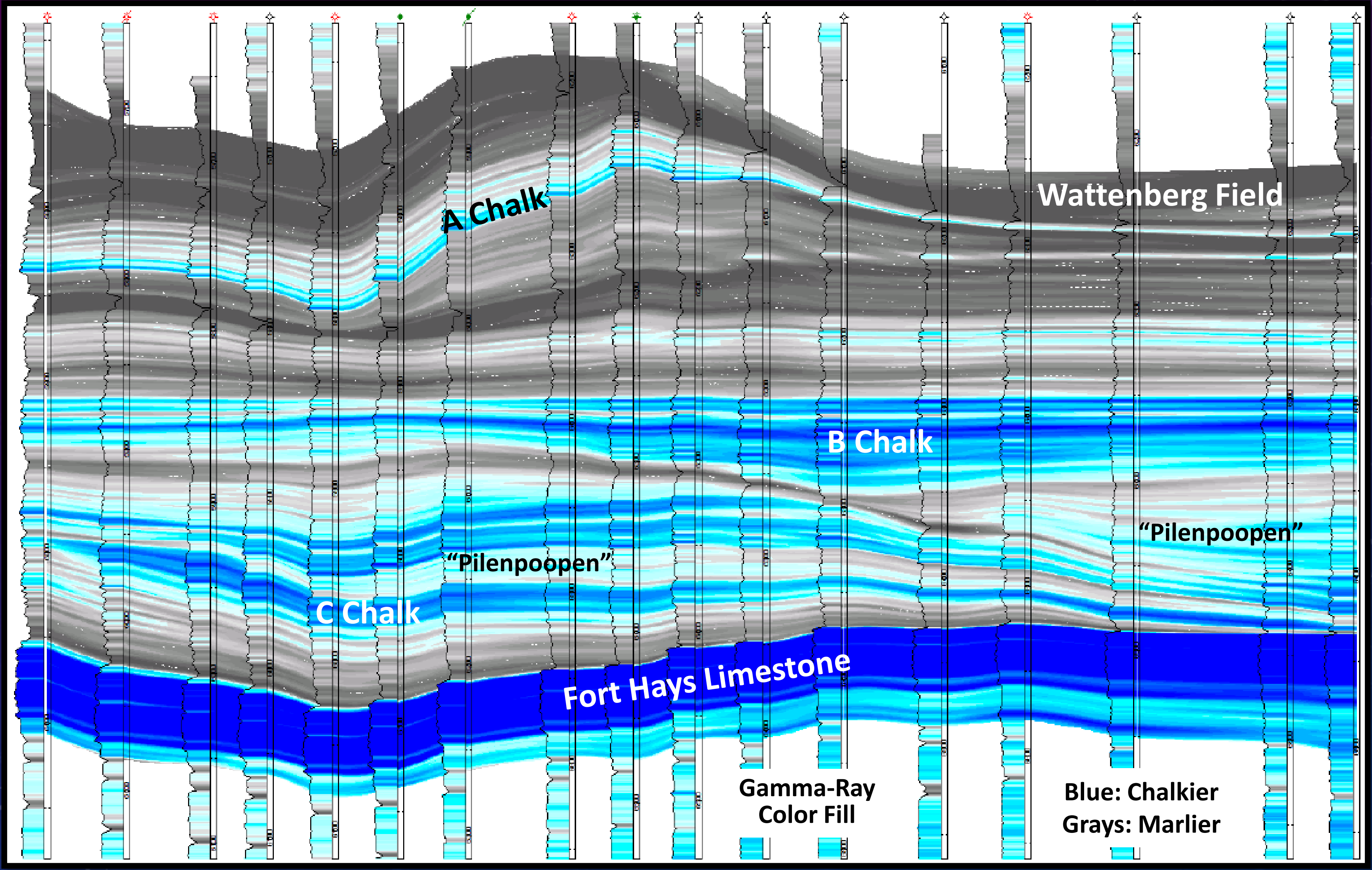
But are they really Blanket-Like? Note the Channel Scours!



Adapted from photo of
Scott and Cobban (1964)

With these scours, the limestone/marl couplets are not purely the result of Milankovitch cycles, nor are they the product of sea level fluctuations.

New Software provides a New Way to Examine Correlations within the Niobrara: Does this 30-Mile Cross-Section Reflect a Sea-Level Control on Deposition?



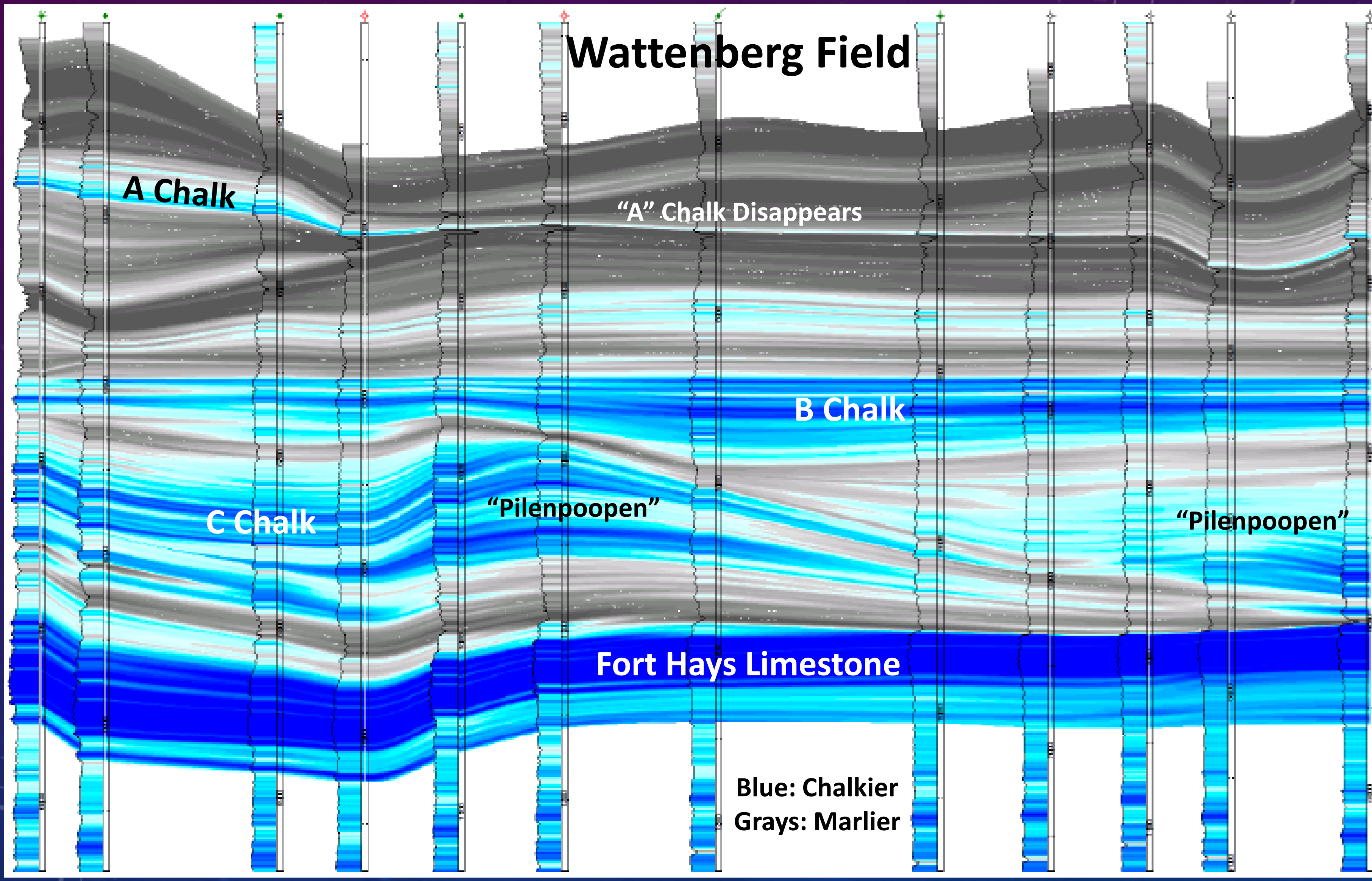
Datum: Top of "B" Chalk

From Cumella (2017) RMS-SEPM Lunch Talk, Orion Skinner Tops

A 25-mile long northern Denver Basin Stratigraphic Cross-Section of the Niobrara Formation Using Color-filled Gamma-ray Logs

SW

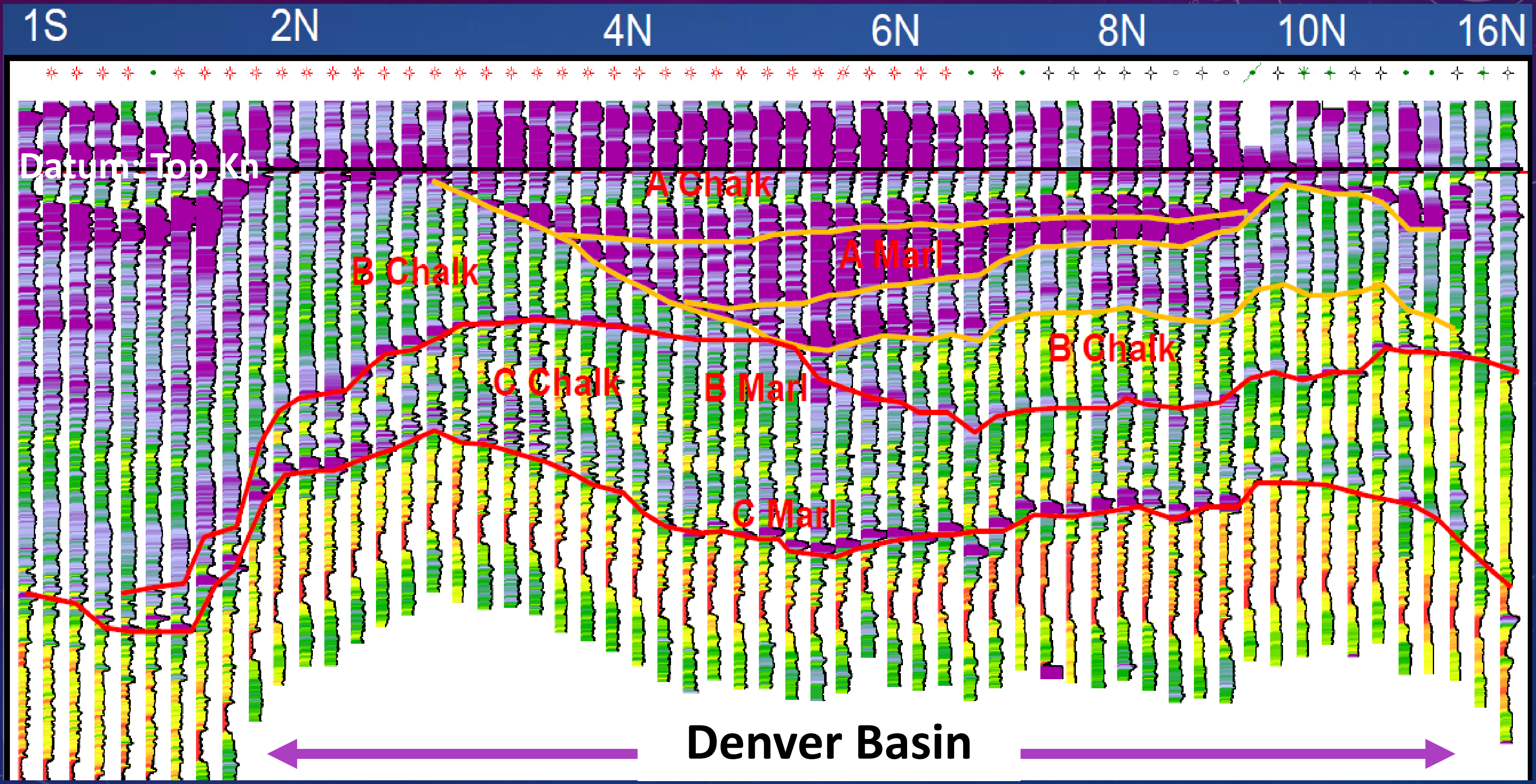
NE



Datum: Top of "B" Chalk

From Cumella (2017) RMS-SEPM Lunch Talk

Another argument against eustatic sea-level fluctuations is shown in this 100-mile long South-to-North Color-filled Gamma-Ray Log Cross-section of the Niobrara Formation



Not Layer-Cake Deposition at all!

From Deacon & McDonough, 2018 ACE

These cross sections suggest that Niobrara deposition was not sea-level driven.

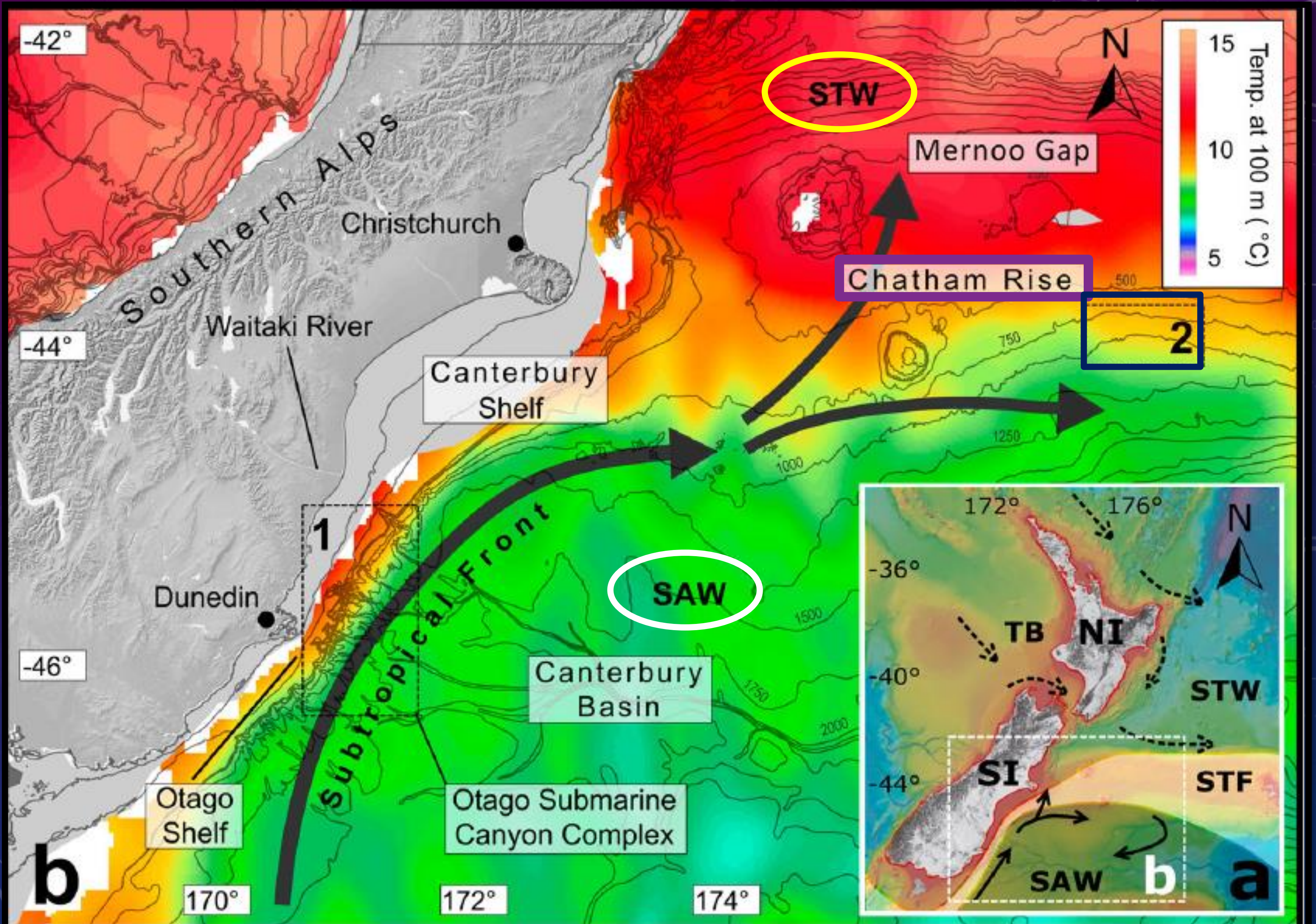
What's Going On?

Let's Look at Possible Modern Analogs for the Western Interior Seaway . . .

One is on the opposite side of the Globe off New Zealand's South Island

A Possible Modern Analog can be found on the Chatham Rise Southeast Of New Zealand's South Island (Area #2)

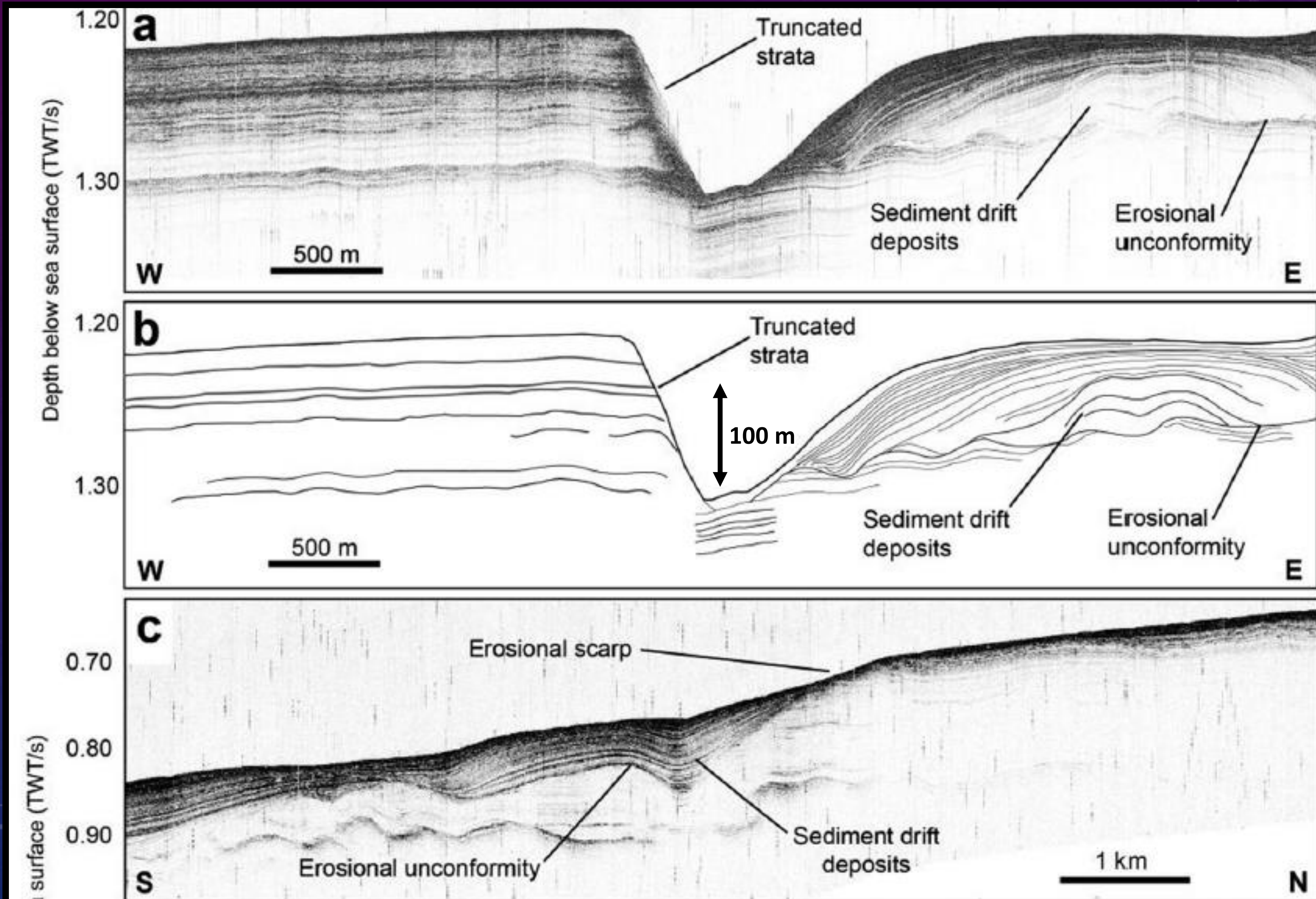
STW = Subtropical Warm Nutrient-Poor Waters



SAW = Subantarctic Cool Nutrient-Rich Waters

From Hillman et al., 2018, NZ J. Geology

On the Chatham Rise, Bottom Currents Scour Soft Hemipelagic Calcareous Oozes to form Asymmetrical "Depressions" 6 to 12 Km Long and 50 to 150 meters deep at depths of 500 to 900 meters



Seismic Profile

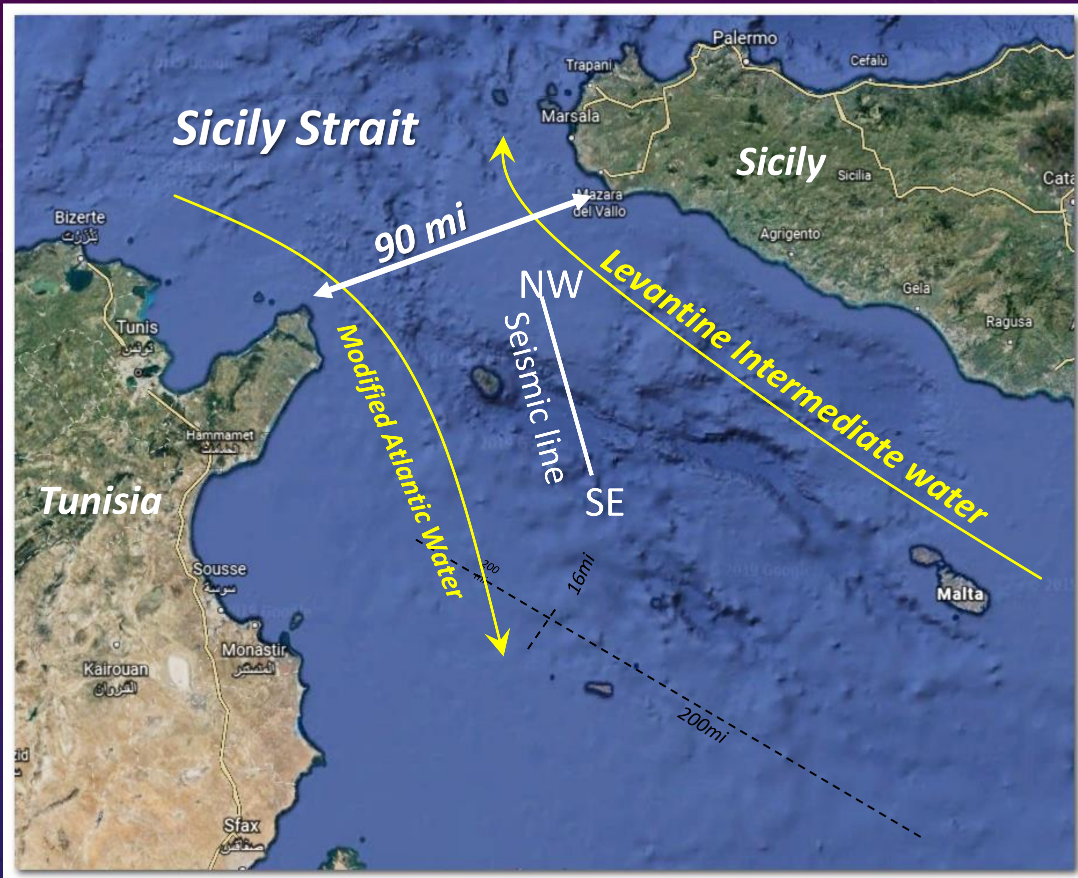
Inter-pretation

A Second Seismic Profile

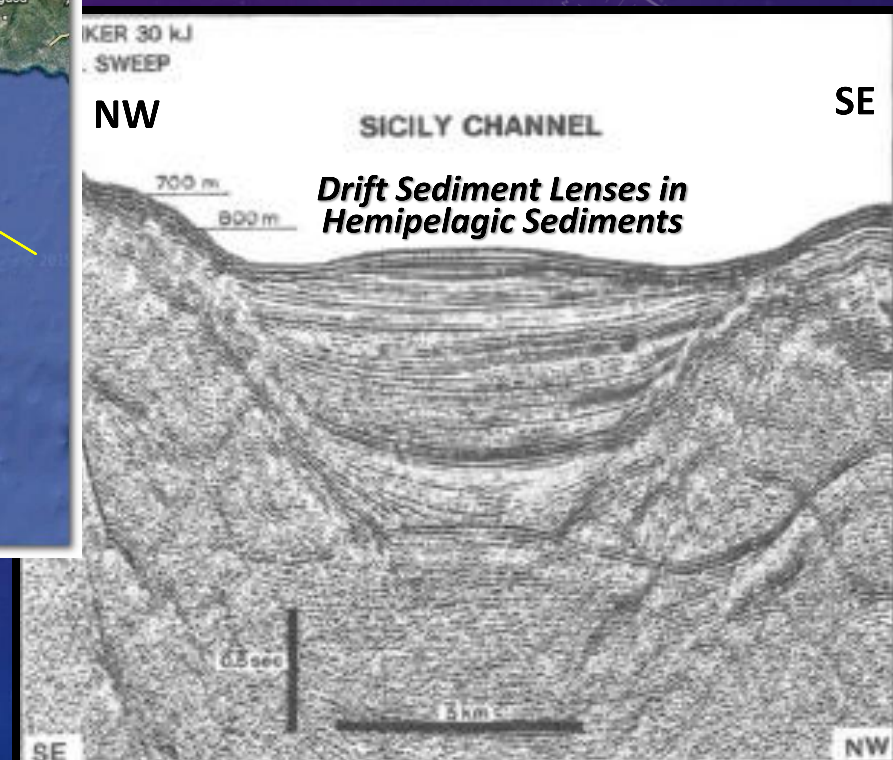
Large Volumes of Sediment are Current-Transported!

From Hillman et al., 2018, NZ J. Geology

Another Example of Submarine Current-Driven Scour & Sediment Deposition in the Mediterranean: The Sicily Strait



Water depths: 700 to 1000 m
Channel Scour ~200 miles long
Drift deposits >300 feet thick



Conclusion: Deep currents redistribute pelagic and hemipelagic sediments!

Marani M, et al., 1993, Sediment drifts and erosional surfaces in the central Mediterranean: seismic evidence of bottom-current activity: Sediment Geol. 82:207–220. doi:10.1016/0037-0738(93)90122-L

We propose that a similar interplay of "cool" Arctic currents and "warm" Gulfian currents in the Western Interior Seaway better explains the distribution of "chalks" vs. "marls" in the Niobrara than Transgressive/Regressive Sea-Level Changes

This deep-marine current hypothesis best explains the Niobrara **"Scour and Drift" features in the Denver Basin.**

It also explains features such as the Sage Breaks Channel and absence of the Fort Hays in the PRB

It explains the "Pilenpoopen" complexity of the "C" Chalk

It may explain the abrupt termination of the Niobrara into the carbonate-poor Sharon Springs/Pierre/Mancos

Conclusions

1. Much of our basic understanding of the Niobrara from 20+ years ago remains intact.
2. However, deposition of "Chalks" vs. "Marls" in the Niobrara was at best only slightly influenced by sea-level fluctuations and/or sequence stratigraphy
3. A more important control was current flow to the north or south within the Western Interior Seaway
4. Where warm Gulfian current flow predominated, chalk-rich, organic-poor, reservoir rocks formed
5. Where cooler Arctic currents predominated, organic-rich hydrocarbon-source marls accumulated
6. Swirling/mixed currents contributed to interfingering of marls and chalks on a scale of feet/inches or less.
7. Major ocean currents carved large sea-floor channels

5000X

5000X

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We hope this talk has offered new insights into Niobrara deposition.

Thank you for listening.

Any Questions?