Implications for Large-Scale Sea Level Change in the Turonian Western Interior Seaway: Evidence from the Codell Sandstone, Colorado*

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Abstract

The Codell Sandstone Member of the Carlile Shale is a complex stratigraphic succession preserved within and south of the Denver Basin. Evidence for large-scale basinward migration of the shoreline in the Turonian is interpreted from facies and isotope study of this unit. The Codell Sandstone Member is the terminal unit in the well-studied Greenhorn regressive hemicyclothem of Kauffman, and records an overall upward-shallowing depositional facies trend. This unit was revisited to determine the magnitude of sea level fall during this regressive event, and the extent of strandline migration associated with the fall. This was done through facies interpretation of key stratigraphic sections (outcrop and subsurface) and strontium analysis of the strata bracketing this interval. Outcrops and core studied were deposited near the axis of the Cretaceous Western Interior Seaway. Two distinct facies are interpreted within the Codell Sandstone Member: an upward–coarsening unit interpreted as distal lower shoreface facies at the base of the member and an estuarine facies association at the top of the member. The estuarine facies association is composed of complex relationships of bioturbated, heterolithic, channelized, and deltaic facies. The surface separating the lower shoreface facies and estuarine facies association is interpreted as a sequence boundary and the base of a 10-meter thick incised valley fill exposed near Pueblo, Colorado. $^{87}Sr/^{86}Sr$ ratio analyses from unaltered shell material show an isotopic excursion within the estuarine facies, which is attributed to freshwater input. Facies interpretation and isotopic analysis places the lowstand shoreline for the Codell Sandstone Member west of Pueblo, Colorado. The time equivalent shoreline for the highstand (lower shoreface) strata of the Codell Sandstone Member is placed between central Kansas and central Missouri, 700 to 1100 km east of the study area. Brackish-water strata of the incised valley fill would require a minimum of 700 km of lateral translation of the eastern margin of the Cretaceous Western Interior Seaway during deposition of the Codell Sandstone Member. This westward shift in the eastern shoreline resulted from a sea level fall that could have been as little as 30–60 meters. Such a significant seaward translation in shoreline position associated with a sea level fall of this magnitude suggests that the sea floor along the eastern margin of the Seaway was of low gradient over large distances.

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IMPLICATIONS FOR LARGE-SCALE SEA LEVEL CHANGE IN THE TURONIAN WESTERN INTERIOR SEAWAY: EVIDENCE FROM THE CODELL SANDSTONE, COLORADO

Matt Myers

Overview

- The Codell Sandstone Member has not been extensively studied since the mid 1980's to early 1990's
  - Krutak, 1970; Lowman, 1977; Pinel, 1977; Aulia, 1982; McLane, 1982; McLane, 1983; Pinel, 1983; Glenister and Kauffman, 1985; Caraway, 1990; Recent thesis by Lewis, 2013

- The Codell Sandstone Member is a complex, often heterolithic unit
  - Successions of physical sedimentary structures are rarely diagnostic of a particular facies

- Previous interpretations range from shoreface through beach deposits, a barrier island complex, and offshore marine bar
  - With some descriptions of tidal influence

Purpose

- Revisit the Codell Sandstone Member
  - The magnitude of sea level fall
  - The extent of strandline migration
  - Incomplete Greenhorn regressive event (Kauffman, 1969)

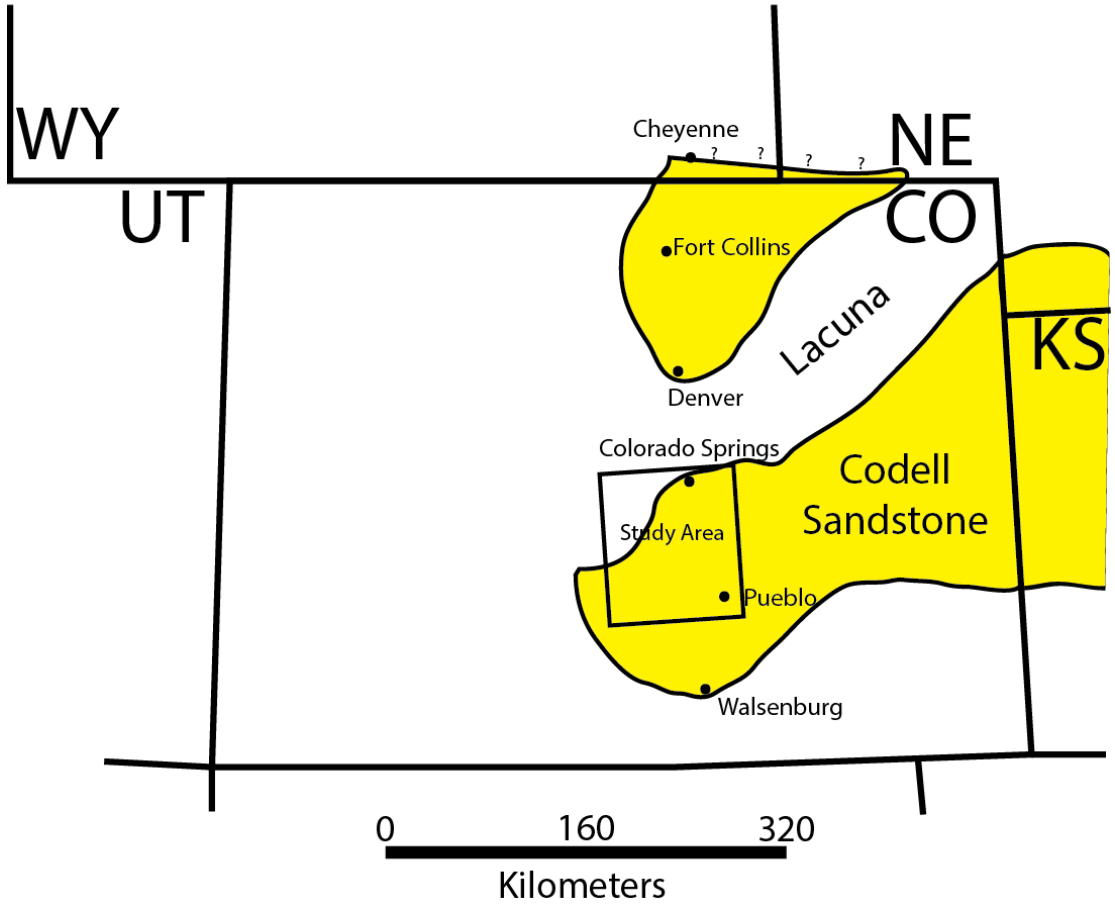
- Accomplished by
  - Facies interpretation of key stratigraphic sections (outcrop and subsurface)
  - Strontium isotope analysis

Paleogeography

~ 90 Ma map modified from Sageman and Arthur (1994) Williams and Stelck (1975)

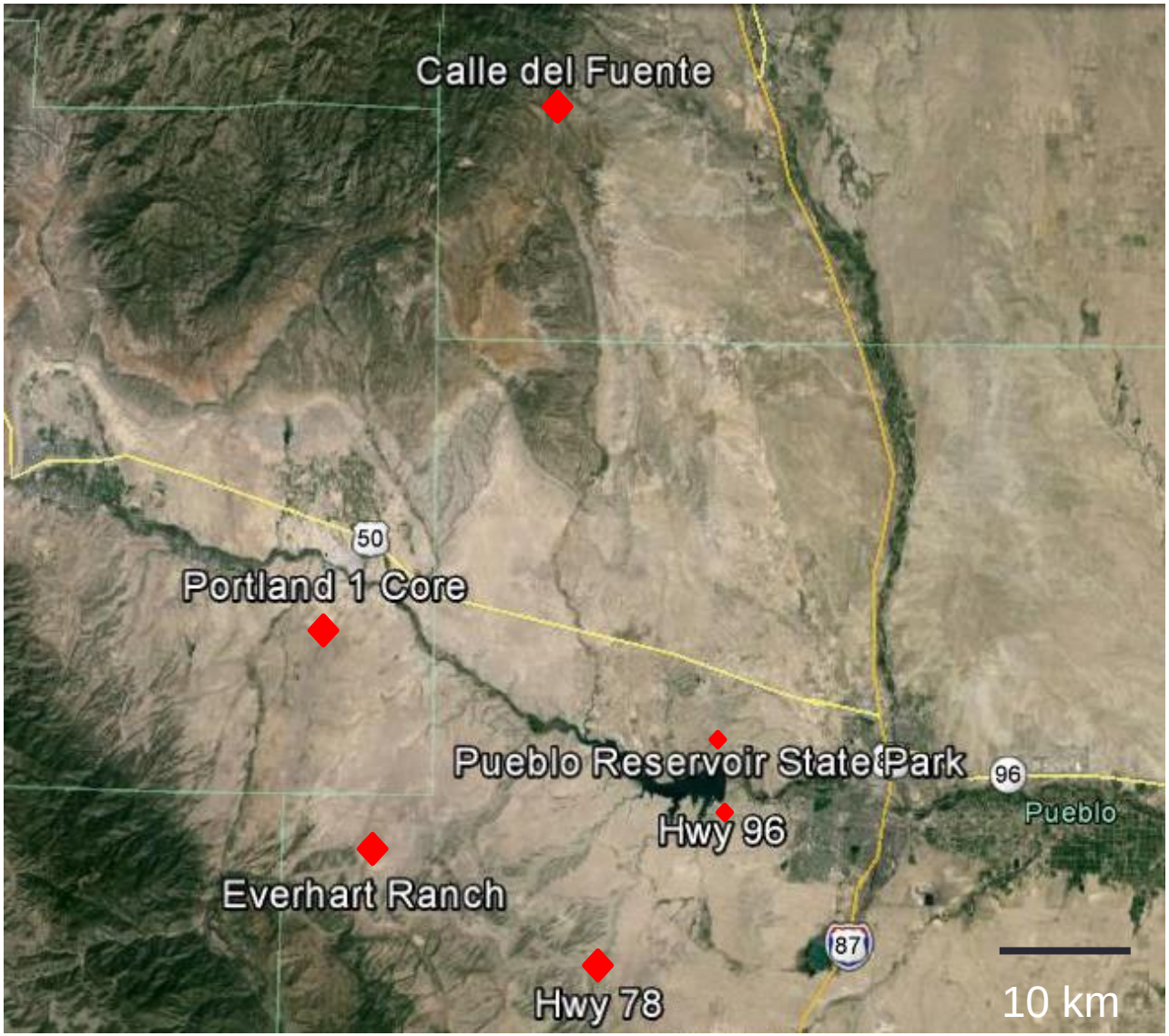
Lines represent the position of the Western Interior shoreline.

Paleogeography

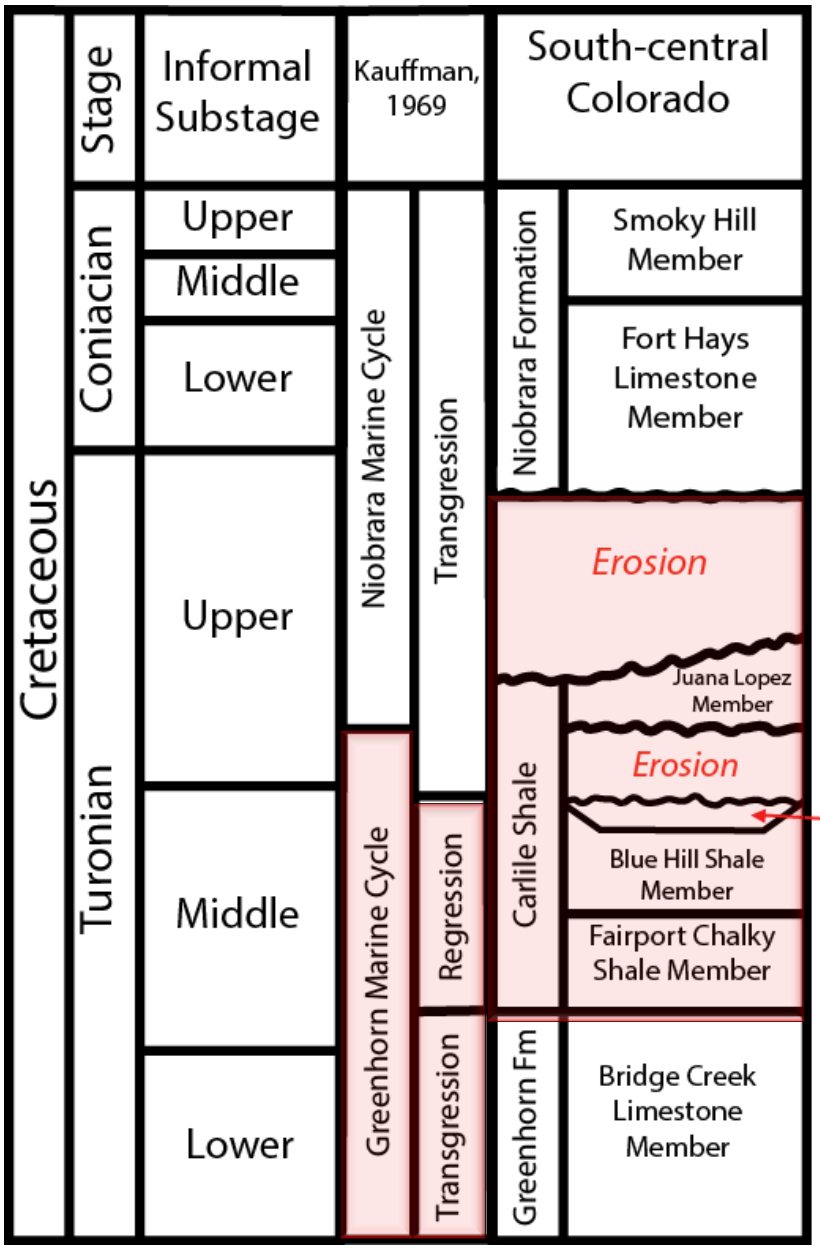


Modified from Merewether et al. (1983)

Paleogeography



Stratigraphy

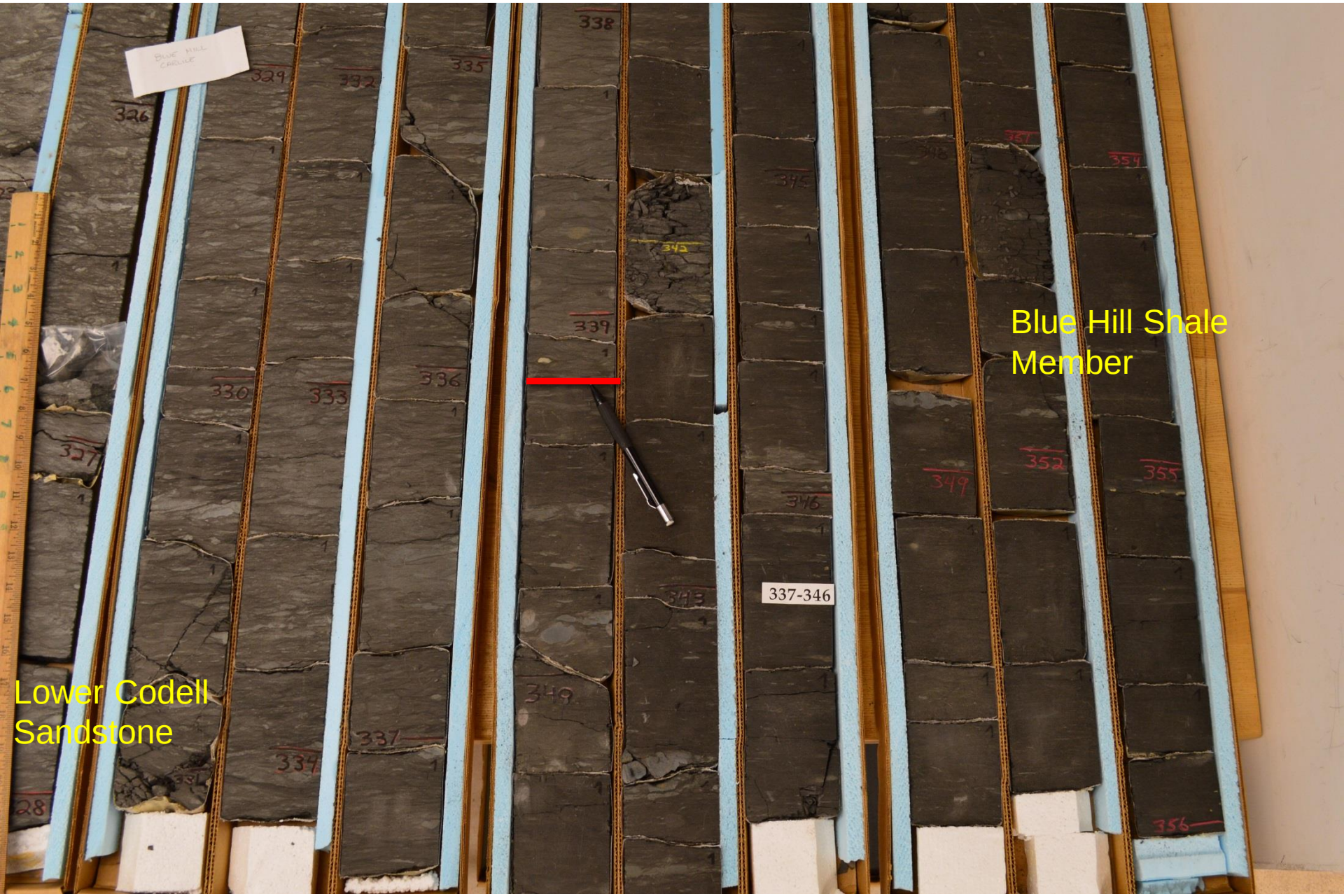


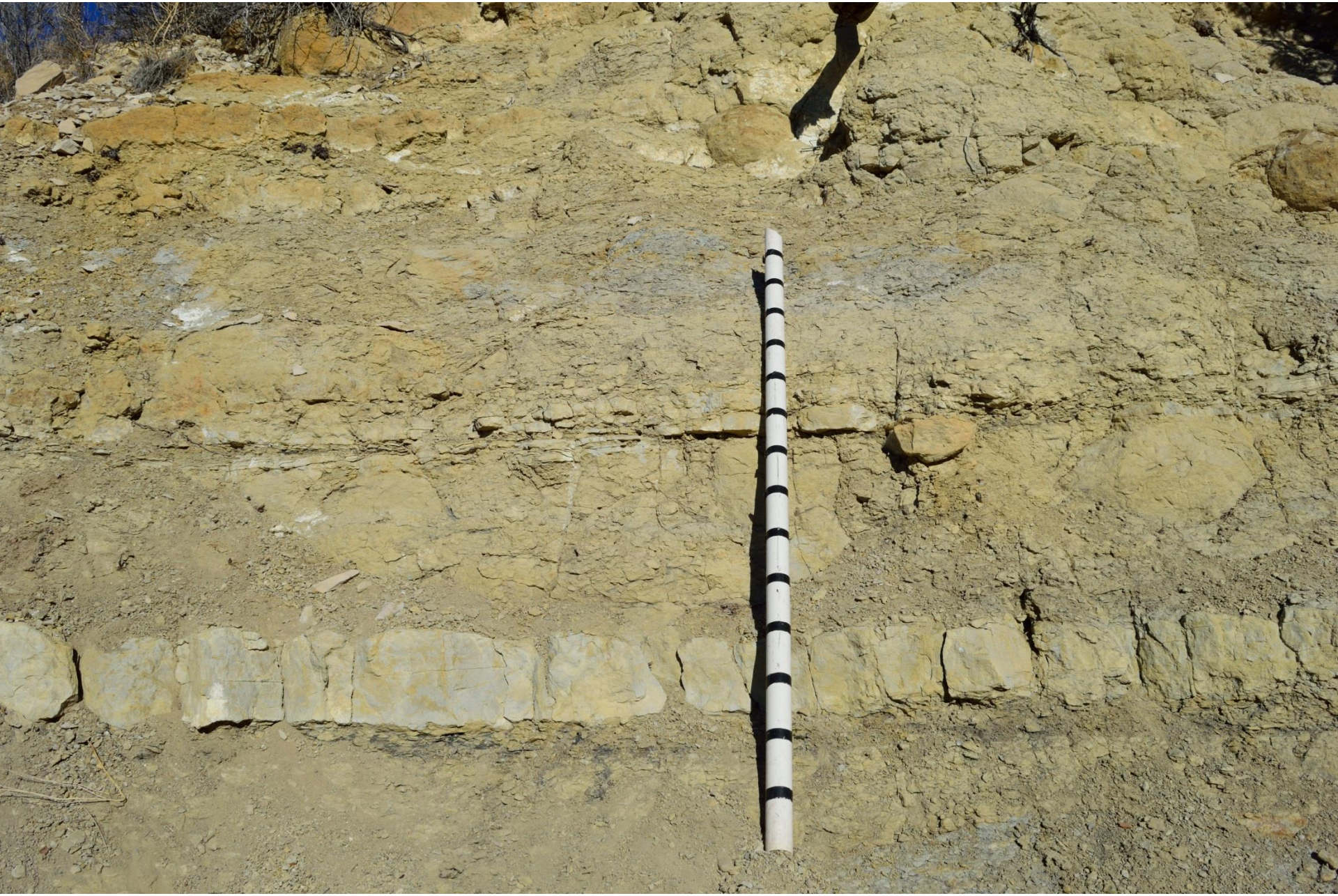
Modified from Merewether et al. (1983) and Kauffman (1969)

Facies

- **Facies 1 - Blue Hill Shale Member Facies**
  - Completely bioturbated (bioturbation index of 4-5)
  - Upper contact is gradational
  - Offshore interpretation

- **Facies 2 - Lower Codell Sandstone Member Facies**
  - Two upward-coarsening intervals
  - Hummocky cross stratification
  - Distal lower shoreface interpretation


Blue Hill Shale Member
Lower Codell Sandstone
337-346

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Facies

- **Facies 3 - Upper Codell Sandstone Member Facies**
  - Bioturbated Facies, Heterolithic Facies, Channelized Facies, and Upward-Coarsening Facies
  - Grouped due to their vertical relationship with one another

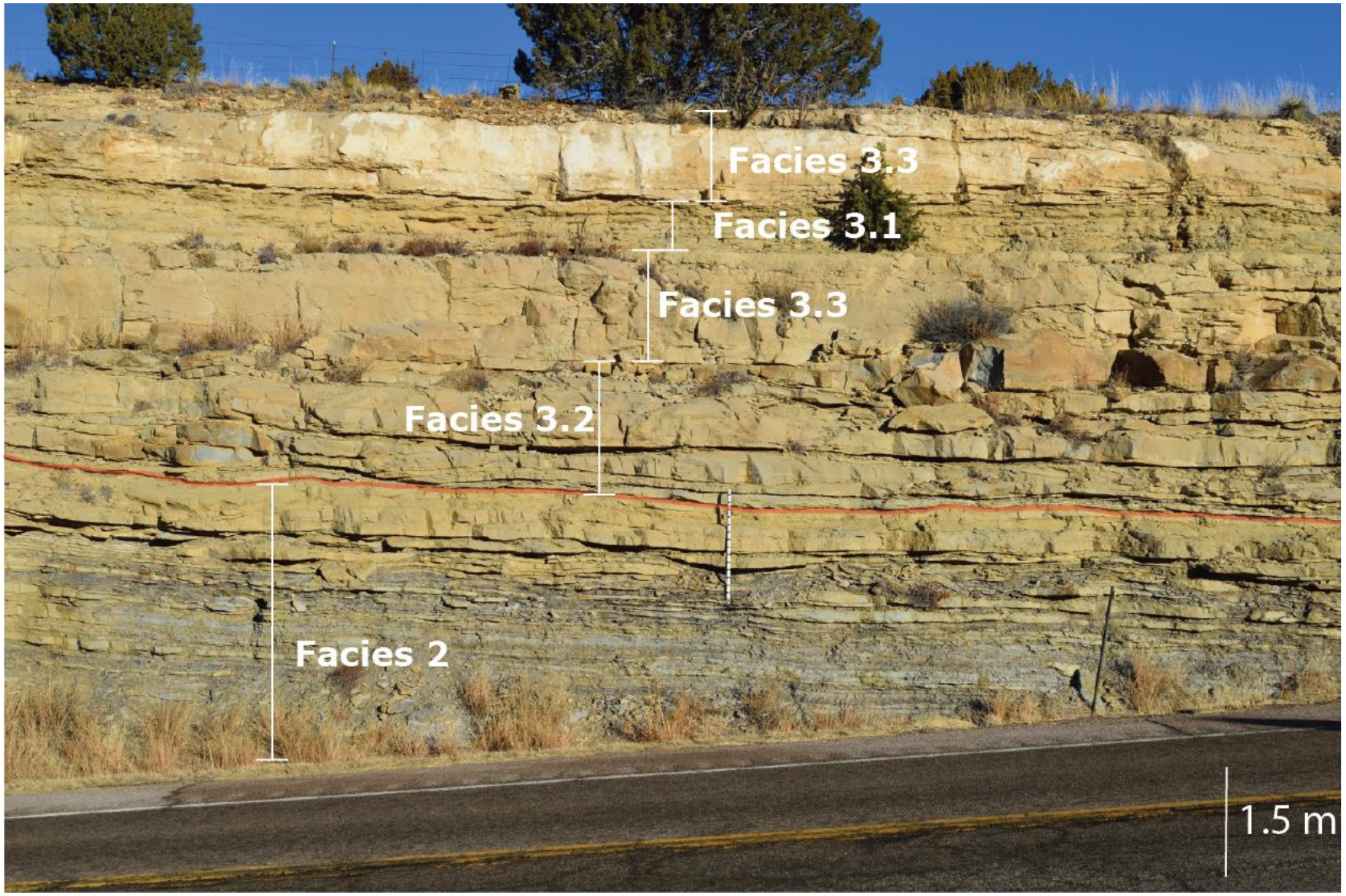
- ***Subfacies 3.1 - Bioturbated facies***
  - Heavily burrowed (bioturbation index of 3-4).
  - Low energy protected environment

- ***Subfacies 3.2 - Heterolithic facies***
  - Laterally variable in character across the outcrop
  - Locally heterolithic strata are inclined (< 5 degrees)
  - Tidally infulenced channel-fill deposits


Bioturbated
subfacies

Facies

Facies



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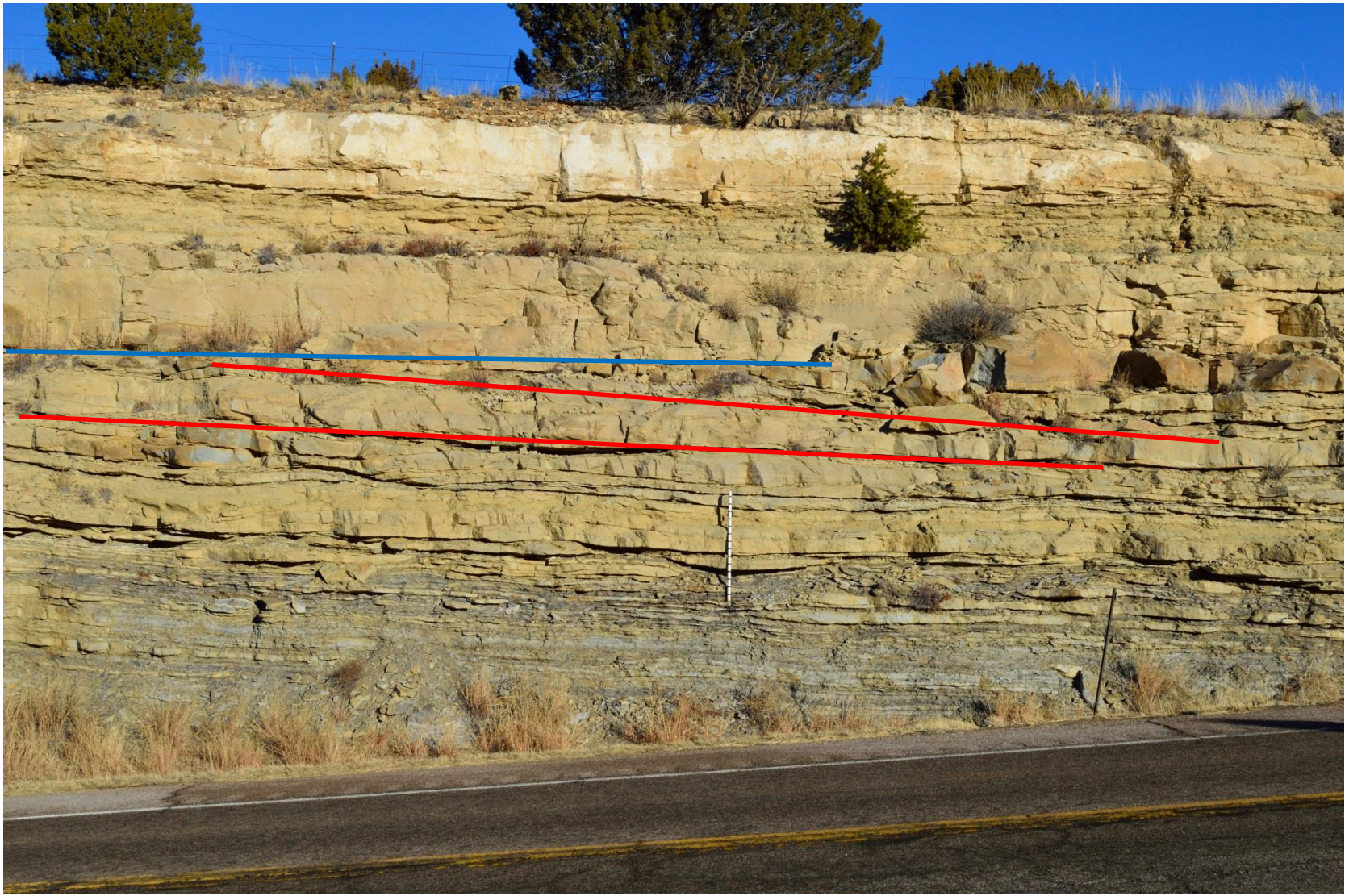
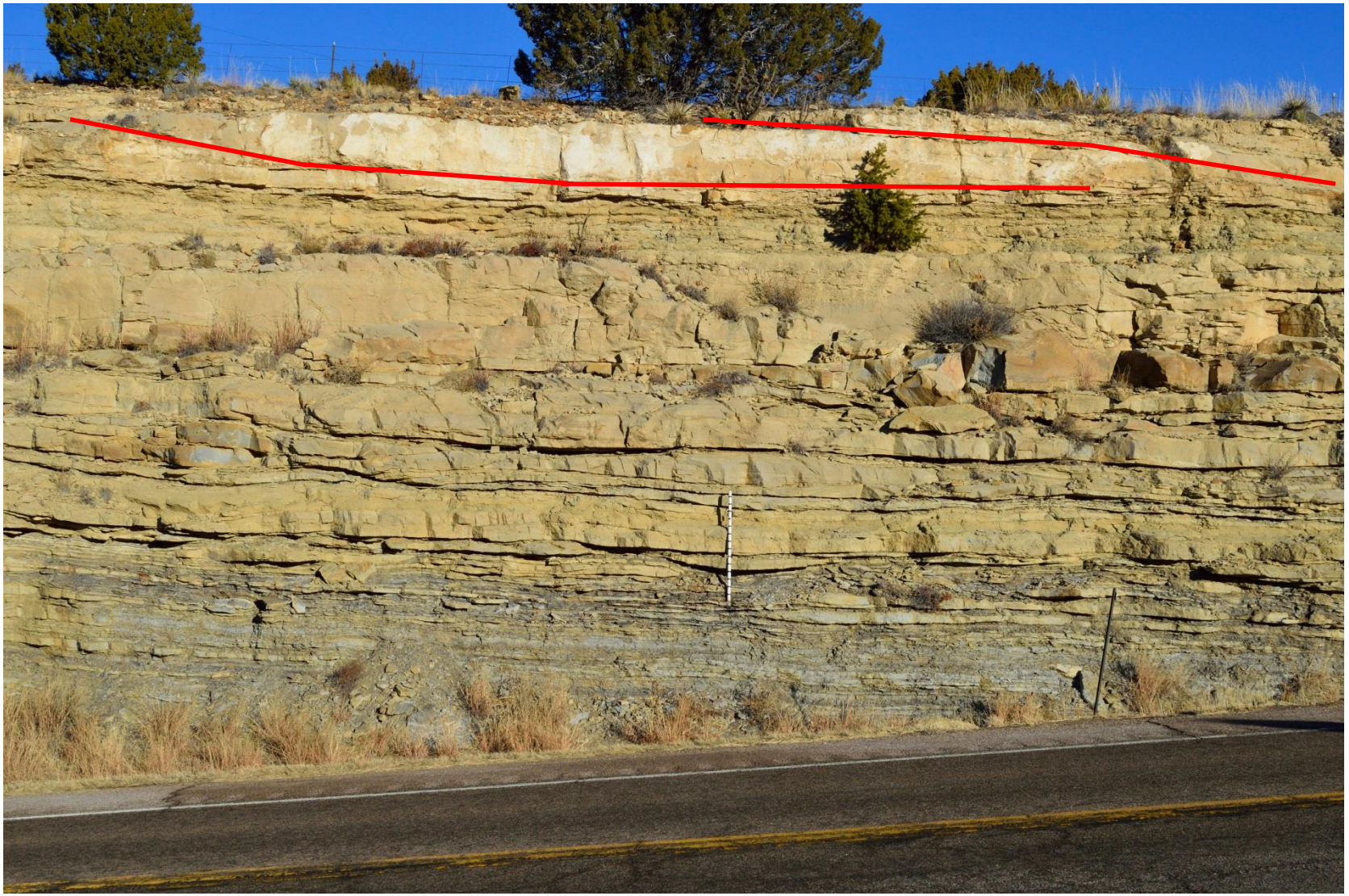


Facies

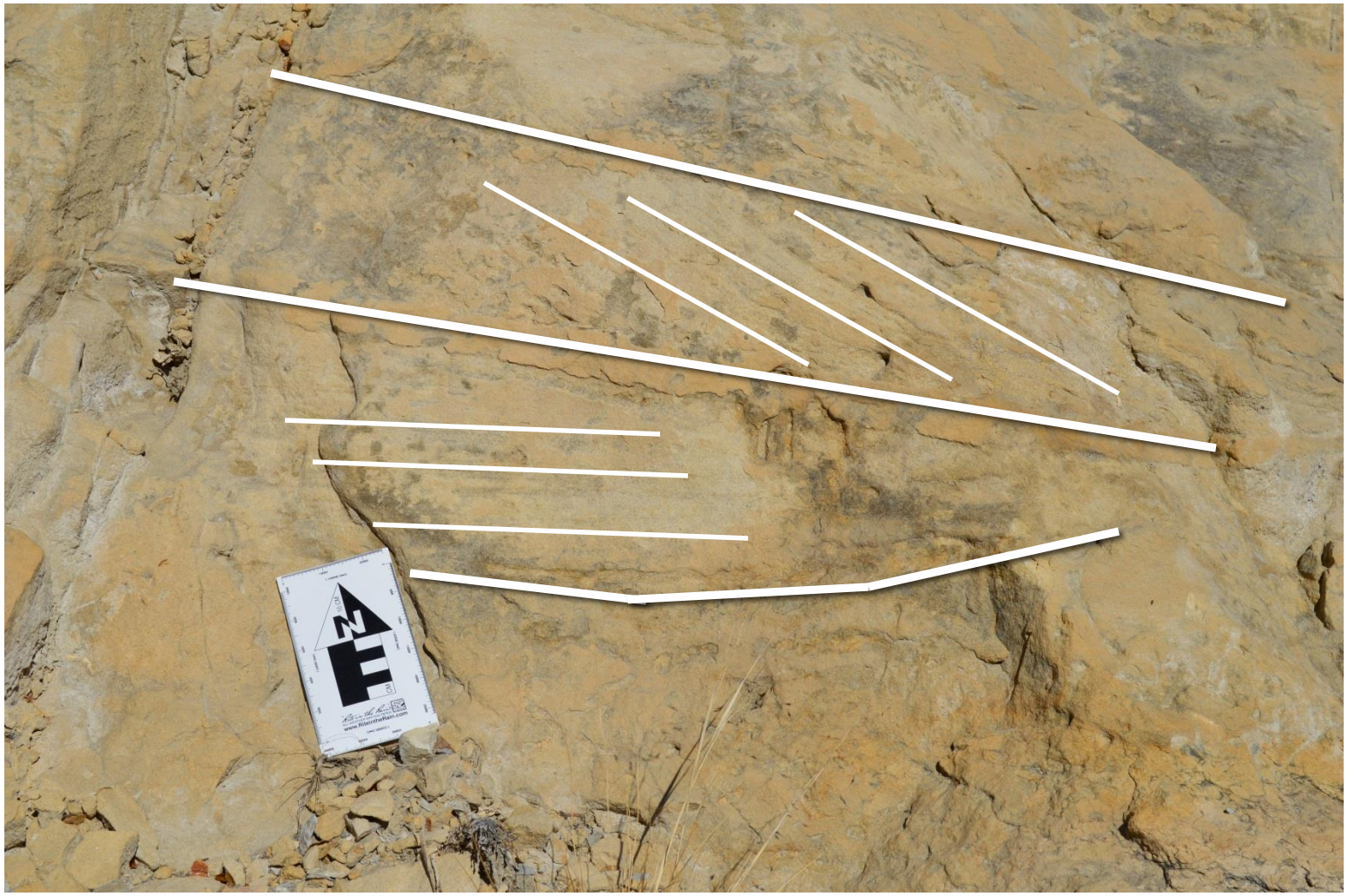
- ***Subfacies 3.3 - Channelized facies***
  - Complex compound stratification (range of depositional processes over short distances)
  - Internal scour and fill structures
  - Lateral shingling
  - Tidally influenced channel-fill interpretation

- ***Subfacies 3.4 – Upward-coarsening facies***
  - Upward-coarsening sandstone profile
  - Wedge-shaped cross stratified sandstone beds
  - Beds thicken upward
  - Deltaic environment

Facies



Facies



Facies

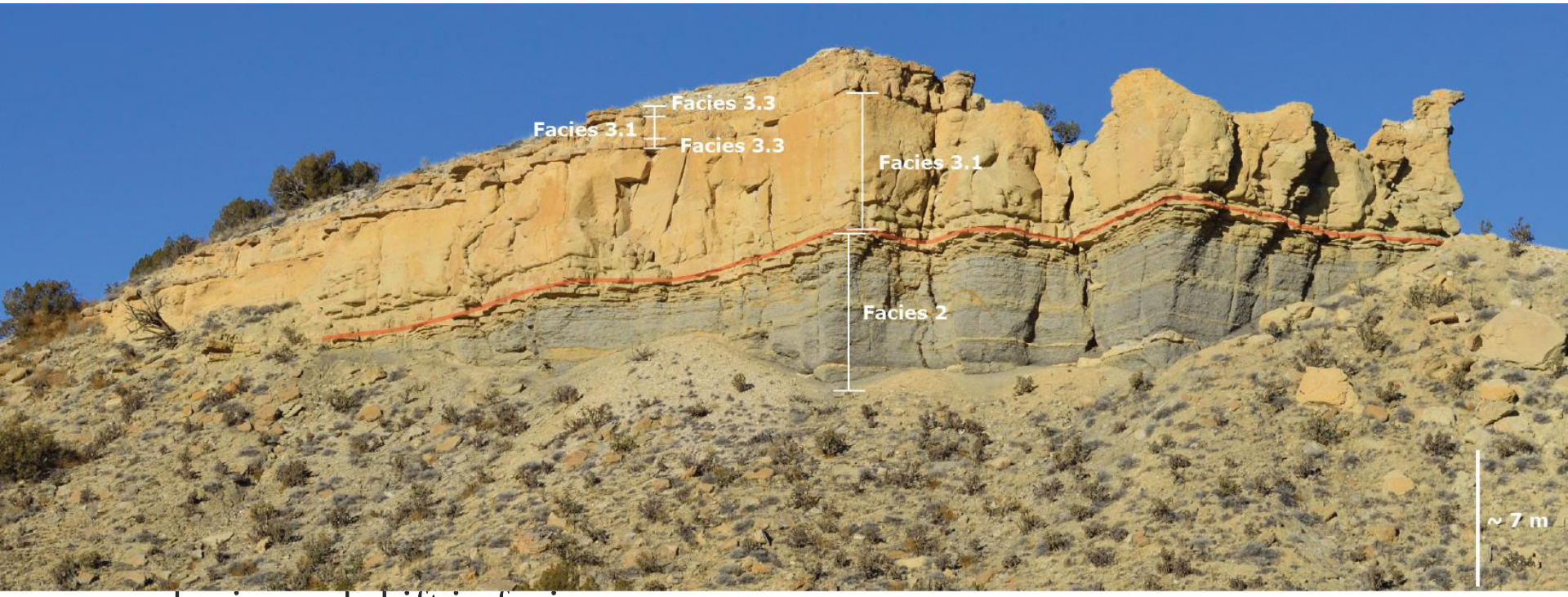
- **Facies 4 - Juana Lopez Member Facies**
  - Planar-tabular crossbeds up to 20-30 centimeters thick
  - Rip-up clasts and centimeter-scale abraded shell material
  - Transgressive barform showing 2-D megaripple migration
    - Lag

Stratigraphic Context

- Facies 3, with subfacies 3.1-3.4, preserves the complex interaction between tidal, channelized, low-energy, and deltaic facies, and represents a complicated depositional environment
  - Correlation of facies 3 and its relationship to the underlying facies 1 and 2 allows all facies to be placed in stratigraphic context
  - Estuarine depositional environment

- The lower contact of facies 3 is an erosional contact
  - Interpreted to define a regional surface of base-level fall resulting in a basinward shift in facies

Stratigraphic Context



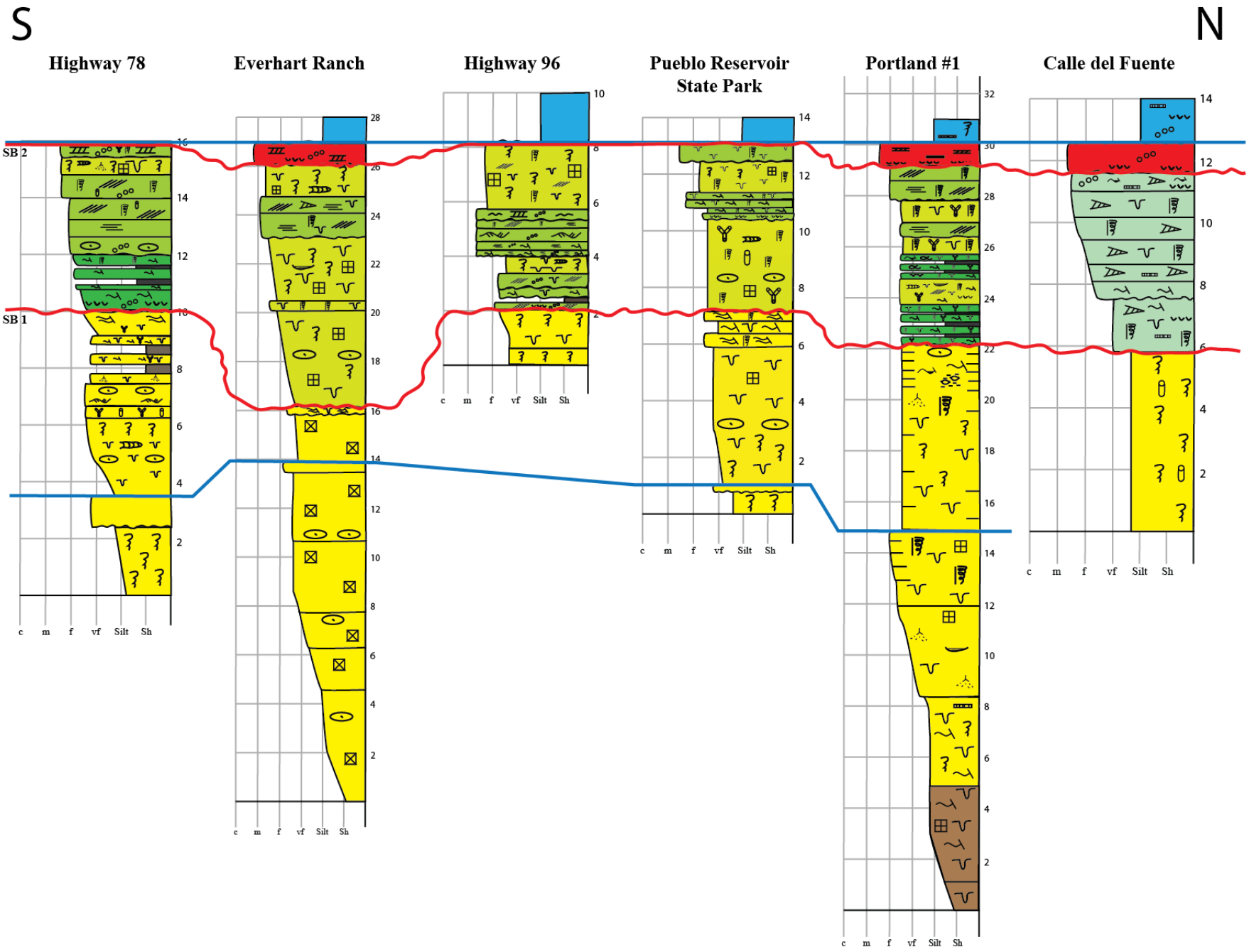
basinward shift in facies

Stratigraphic Context

- Truncated HCS beds are evidence of incision along the proposed sequence boundary

- The surface of incision marks the development of an incised valley
  - Incised valley fill is ~10 m
  - Recognized by the facies association of subfacies 3.1-3.4, overlying distal lower shoreface deposits (facies 2)

- Facies were correlated using the base of the Niobrara Formation as a datum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Highway 78
Everhart Ranch
Highway 96
Pueblo Reservoir State Park
Portland #1
Calle del Fuente
SB 2
SB 1
c m f vf Silt Sh

Strontium Isotopes

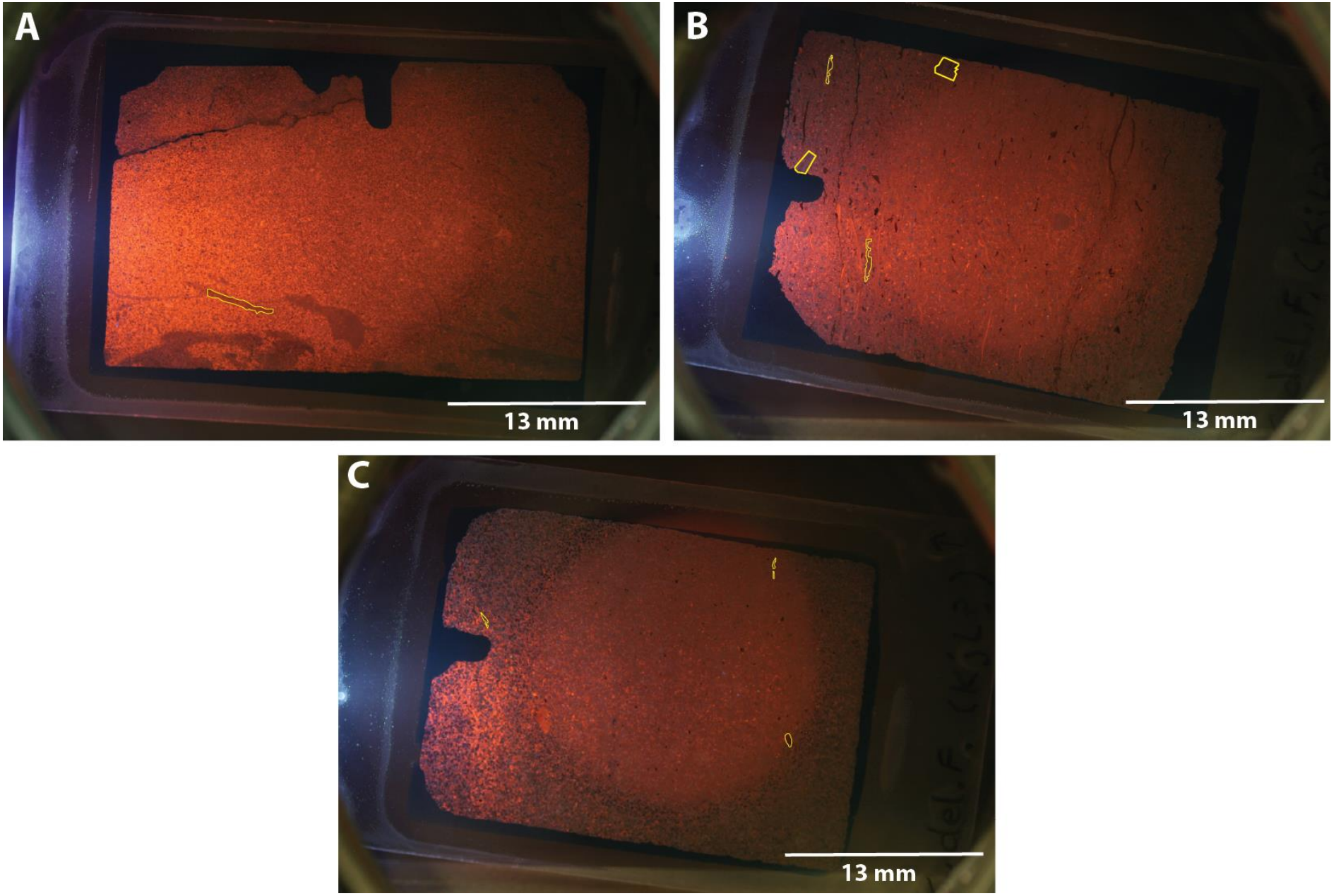
- Was the Codell Sandstone Member incised valley strata subject to freshwater input?
  - McArthur et al., 1994

- Sector 54 Thermal Ionization Mass Spectrometer (TIMS)

Cathodoluminescence

- Cathodoluminescence - degree of diagenetic alteration

- Dean and Arthur (1998) suggested that samples from this interval into the Niobrara Formation retain their original strontium values despite appearing diagenetically altered under cathodoluminescence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B
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C
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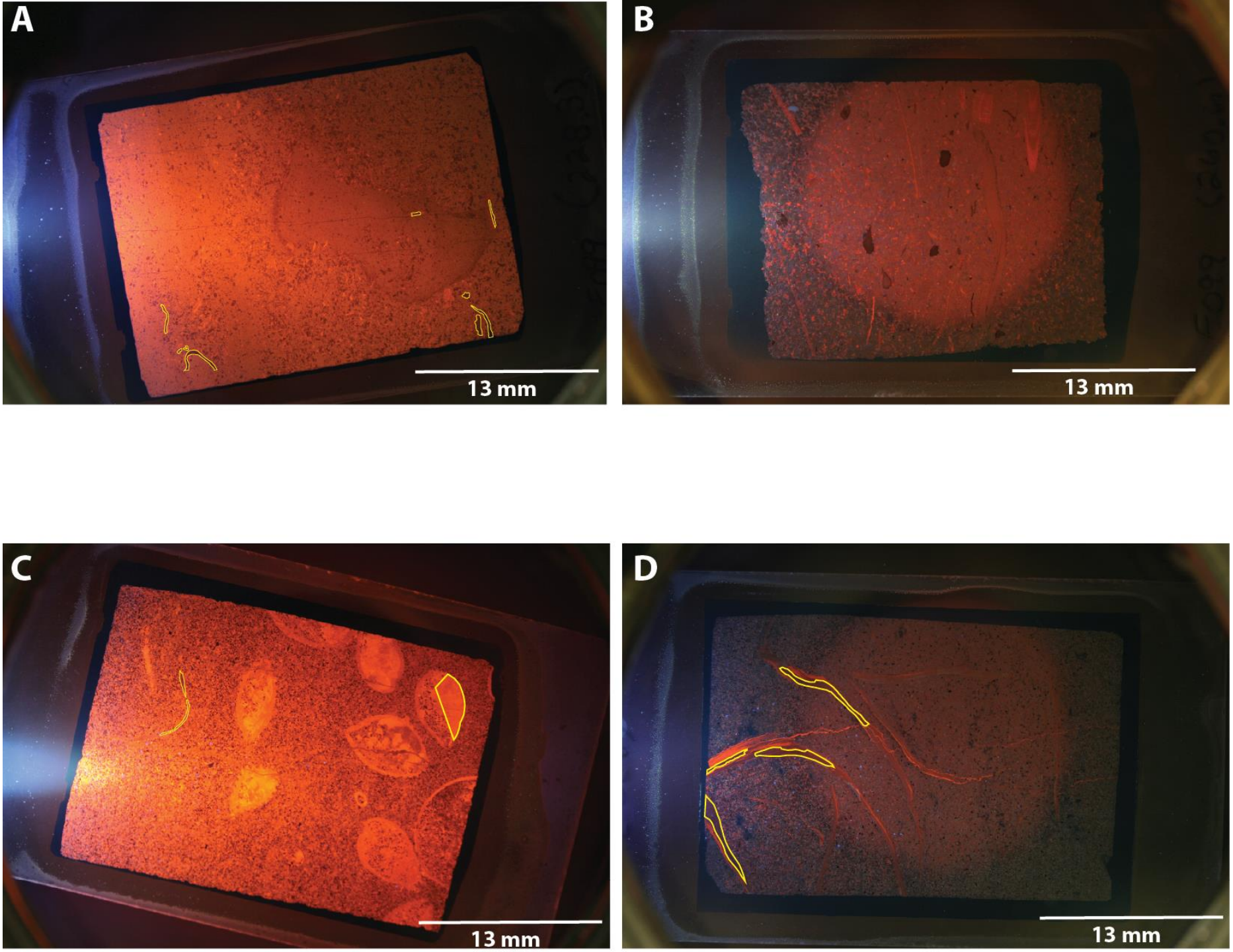
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B
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C
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D
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Strontium Isotopes

Normal marine values for this time frame, 90.98 Ma to 90.43 Ma, range from 0.707310 to 0.707288 (McArthur et al., 2001).

Sample Name	Facies	Material	Diagenetically Altered?	EXP AVG	Corrected
E099 279.7	3.2	*Inoceremus*	No	0.707427	0.707430
E099 276.8	3.1	Bivalve	Yes	0.708936**	0.708938**
E099 228.3 “A”	Niobrara	*Inoceremus*	No	0.707353	0.707356
E099 228.3 “B”	Niobrara	*Inoceremus*	No	0.707366	0.707369
E099 260.6	4	*Inoceremus*	Yes	0.707330	0.707333
K_{JL} 1	4	*Inoceremus*	No	0.707361	0.707364
K_{JL} 2	4	*Inoceremus*	No	0.707377	0.707379
K_C 1	3.4	Ino / Foram	No	0.707898*	0.707901*

Asterisk (*) indicates a brackish-water ratio while two asterisks (**) indicate a freshwater ratio.

Shoreline Migration

- Greenhorn hemicyclothem highstand (Lower Turonian)
  - Eastern shoreline of the KWIS located between central Missouri and the Kansas-Missouri border (Williams and Stelck, 1975)

- Following peak highstand conditions, deep water conditions prevailed in the study area
  - Fairport Chalky Shale Member

- Blue Hill Shale Member records a gradational shallowing in water depth and westward progradation of the eastern shoreline of the KWIS

Shoreline Migration

- Blue Hill Member and time equivalent strata are not preserved east of central Kansas

- The shallowest facies preserved in Kansas (of the Carlile Shale) is the Codell Sandstone Member
  - Interpreted as a distal lower shoreface deposit (Krutak, 1970)

- Marginal marine deposits with brackish- and freshwater strontium isotope values in the Pueblo area
  - Indicate a rapid westward shift in the eastern shoreline

- Interpreted to result from the sea level fall documented within the Codell Sandstone Member (sequence boundary 1)

Shoreline Migration

- The distance from the interpreted position of the Greenhorn highstand shoreline to the outcrops (lowstand shoreline) measured during this study is between 700 and 1100 kilometers
  - A sea level fall and shoreline shift of this nature suggests that a substantial portion of the regressive hemicyclothem is missing

- A low gradient seabed in association with progradation
  - Accounts for the laterally widespread facies as well as the vertical facies thicknesses seen in the Carlile Shale
  - Allows for large lateral shoreline migration during sea level changes

Sea Level Fall

- The Bridge Creek Member (Greenhorn Fm.) is indicative of maximum transgression (Kauffman et al., 1977)
- The Bridge Creek Member was deposited in water as little as 30-60 meters deep (Kauffman, 1967)
  - Suggesting that overlying members of the Carlile Shale were deposited in water shallower than 30-60 meters
- Sea level fall from the deposition of the Bridge Creek Member to the Codell Sandstone Member could have been as little as 30-60 meters
  - Sea level falls of 30 meters were probably common in the KWIS (Van Wagoner et al., 1991).
- This sea level fall is followed by a more substantial sea level fall at the base of the Juana Lopez Member (sequence boundary 2)
  - Sequence boundary 1 may be a precursor to this larger sea level fall

Conclusions

- The Codell Sandstone Member near Pueblo, Colorado is separated into two distinct facies
  - Estuarine facies overlie a sequence boundary and comprise an incised valley fill that is up to 10 meters thick
- The Carlile Shale records a 700 to 1100 kilometer westward migration of the eastern shoreline of the KWIS from early Middle Turonian to the end of the Middle Turnonian
- The majority of this shoreline translation occurred during the sea level fall recorded within the Codell Sandstone Member
- This shift occurred during a sea level fall that could have been as little as 30-60 meters
  - The sea floor had a low gradient over large distances
  - A significant portion of the Greenhorn regressive hemicyclothem is missing

Acknowledgments

- University of Kansas Department of Geology
- Devon Energy Corporation
- Dr. Kamola
  - Committee
- Wife and Family
- Marathon Oil Corporation
- USGS

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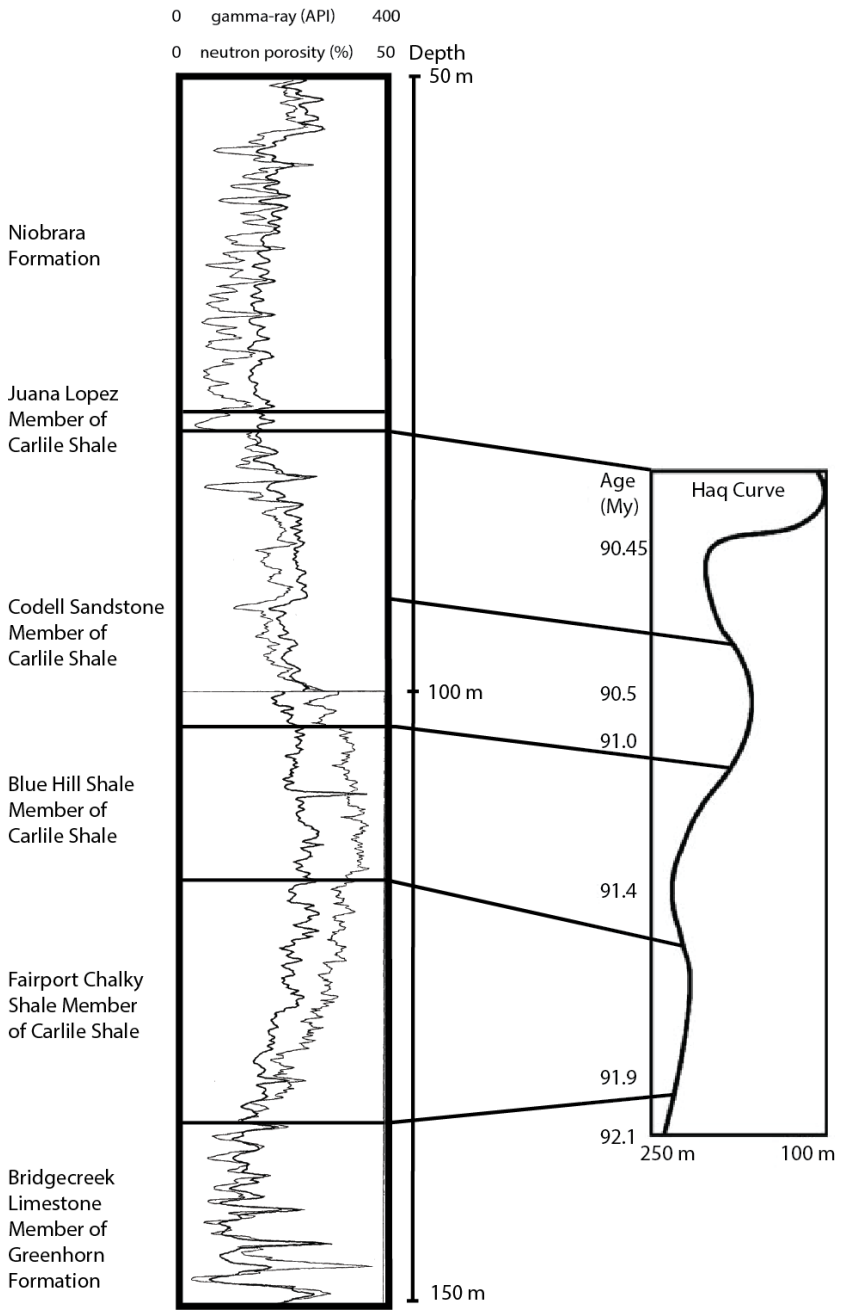
QUESTIONS

Sea Level



Haq and others (1987) sea level curve was modified from a similar correlation interpreted by White and Arthur (2005)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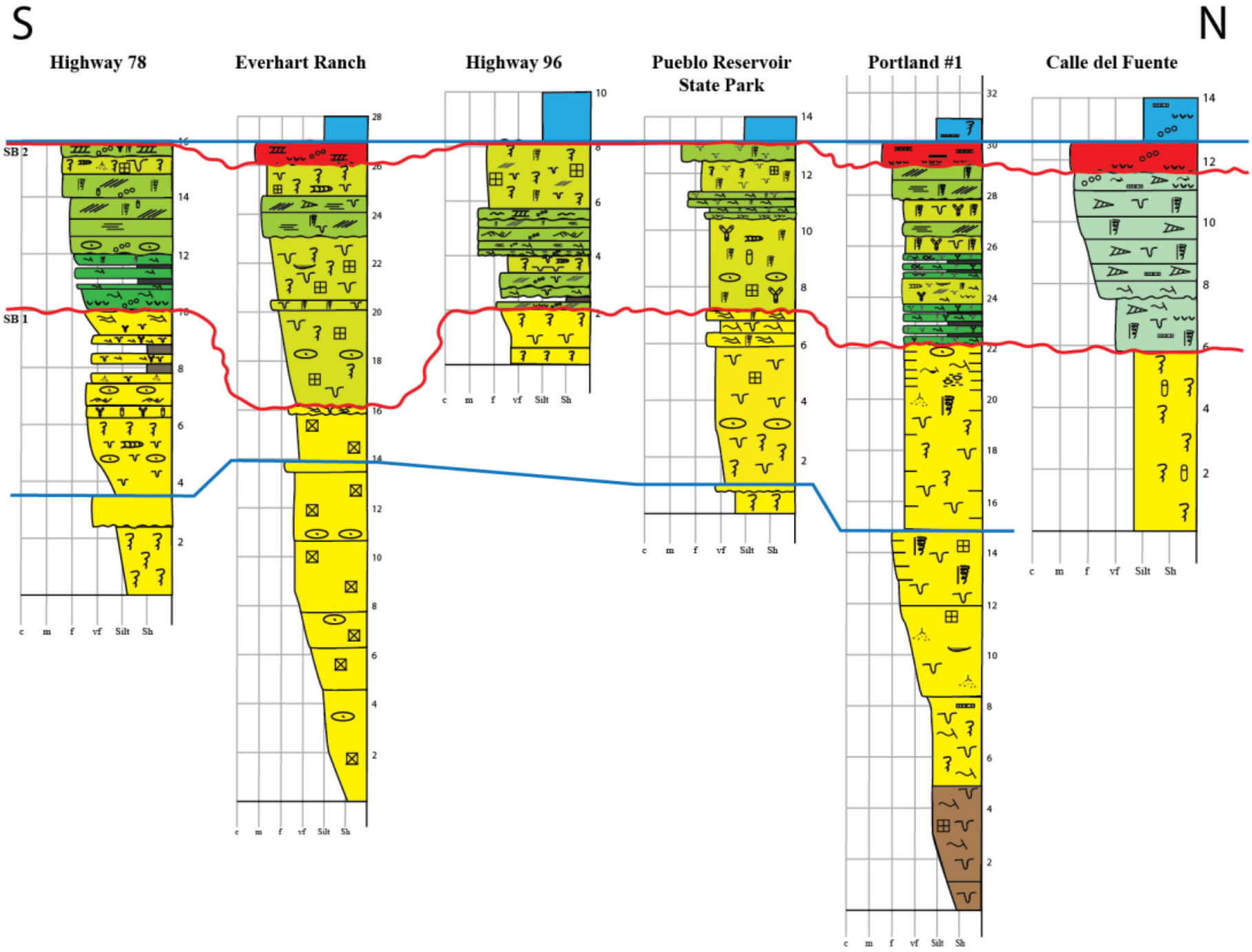
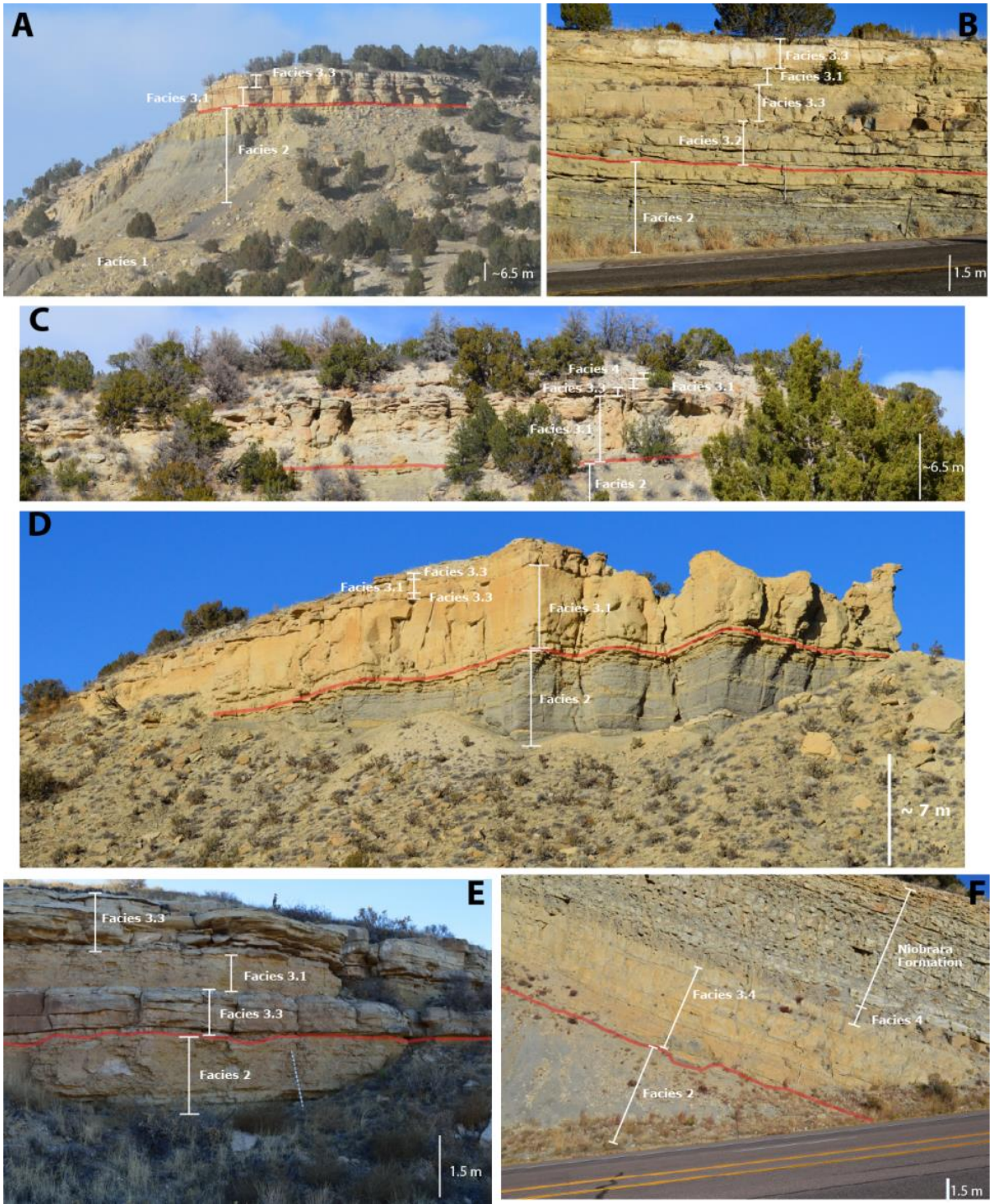

S
N
Highway 78
Everhart Ranch
Highway 96
Pueblo Reservoir State Park
Portland #1
Calle del Fuente
SB 2
SB 1
c m f vf Silt Sh


A
Facies 3.3
Facies 3.1
Facies 2
Facies 1
~6.5 m
B
Facies 3.3
Facies 3.1
Facies 3.3
Facies 3.2
Facies 2
1.5 m
C
Facies 4
Facies 3.4
Facies 3.1
Facies 3.1
Facies 2
~6.5 m
D
Facies 3.3
Facies 3.1
Facies 3.3
Facies 3.1
Facies 2
~ 7 m
E
Facies 3.3
Facies 3.1
Facies 3.3
Facies 2
1.5 m
F
Niobrara Formation
Facies 3.4
Facies 4
Facies 2
1.5 m