Unconventional Oil Exploration in Wyoming Using Regional Chronostratigraphic Correlation*

Ranie M. Lynds[1], Joshua S. Slattery[2], and Rachel N. Toner[1]

Search and Discovery Article #80655 (2018)**
Posted December 3, 2018

*Adapted from oral presentation given at AAPG 2018 AAPG Annual Convention and Exhibition, Salt Lake City, Utah, May 20-23, 2018
 DOI:10.1306/80655Lynds2018

[1]Wyoming State Geological Survey, Laramie, WY, United States (ranie.lynds@wyo.gov)
[2]University of South Florida, Tampa, FL, United States

Abstract

For more than a decade, the formal definition of an "unconventional" oil reservoir has proven elusive and variable, prompting adoption of a working definition throughout much of Wyoming: a reservoir in which production is improved through horizontal drilling and enhanced stimulation techniques. Practically speaking, Wyoming's unconventional oil reservoirs consist of horizontal wells with lengthy laterals and large multi-stage completions. Technically speaking, Wyoming's unconventional oil reservoirs are low permeability sandstones and siltstones that were deposited in marine to transitional marine settings of the Western Interior Foreland Basin (WIFB) during the Late Cretaceous and are now part of the Laramide Powder River and Denver basins. Seven of Wyoming's top ten oil-producing formations were deposited as part of the WIFB, and account for 59% of 2016 production. Reservoir facies are commonly highly bioturbated with pore space occlusion caused by clays and multi-phase porosity and permeability development. These reservoirs were produced historically with conventional vertical wells, yet recent unconventional exploration of these same reservoirs prompted a significant increase in production from each well drilled.

To assess potential correlative unconventional strata for equivalent depositional conditions, including time and environment of deposition, we correlated 25 Upper Cretaceous sections in Wyoming to U.S. Western Interior biostratigraphic zonation (molluscan, palynostratigraphic, and land vertebrate), radiometric age control, and polarity chrons. Results demonstrate that (1) second-order sea level cycle maximum flooding surfaces occur at approximately 10 to 18 Myr intervals, (2) the bulk of Wyoming's current unconventional oil production occurs as part of two different retrogradational transgressive sequence sets deposited in shallow marine environments during the upper Turonian and middle Campanian, which account for 29% and 9% of 2016 oil production, respectively, (3) the larger Niobrara play is part of the Coniacian to Santonian highstand sequence set, with 5% of 2016 oil production, and (4) exploration of unconventional plays in other basins may benefit from consideration of the regional chrono-stratigraphic setting. This correlation provides a statewide baseline for future assessment of Laramide basin-specific hydrocarbon systems.

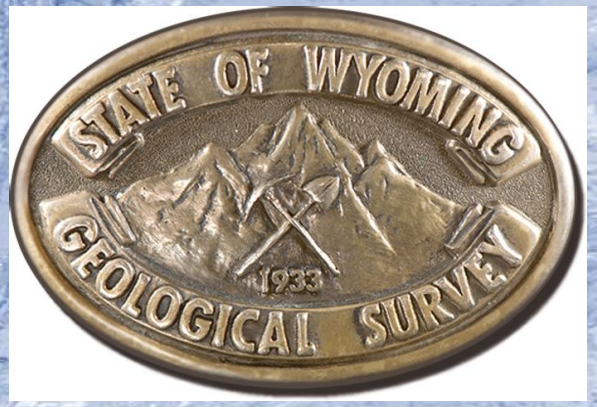
References Cited

wogcc.wyo.gov, 2018, Wyoming Oil & Gas Conservation Commission. Website accessed November 2018.

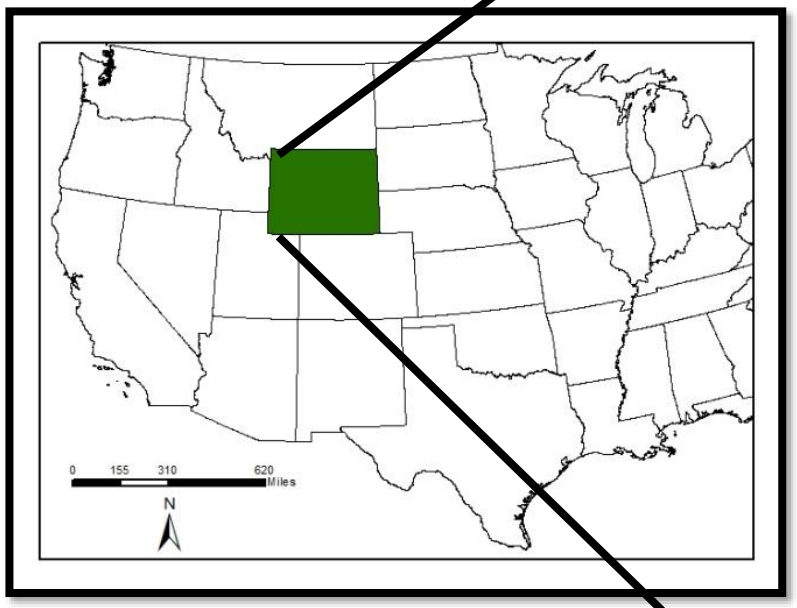
Slattery, J.S., W.A. Cobban, K.C. McKinney, P.J. Harries, and A.L. Sandness, 2015, Early Cretaceous to Paleocene Paleogeography of the Western Interior Seaway: The Interaction of Eustasy and Tectonism: Wyoming Geological Association Guidebook, p. 22-60.

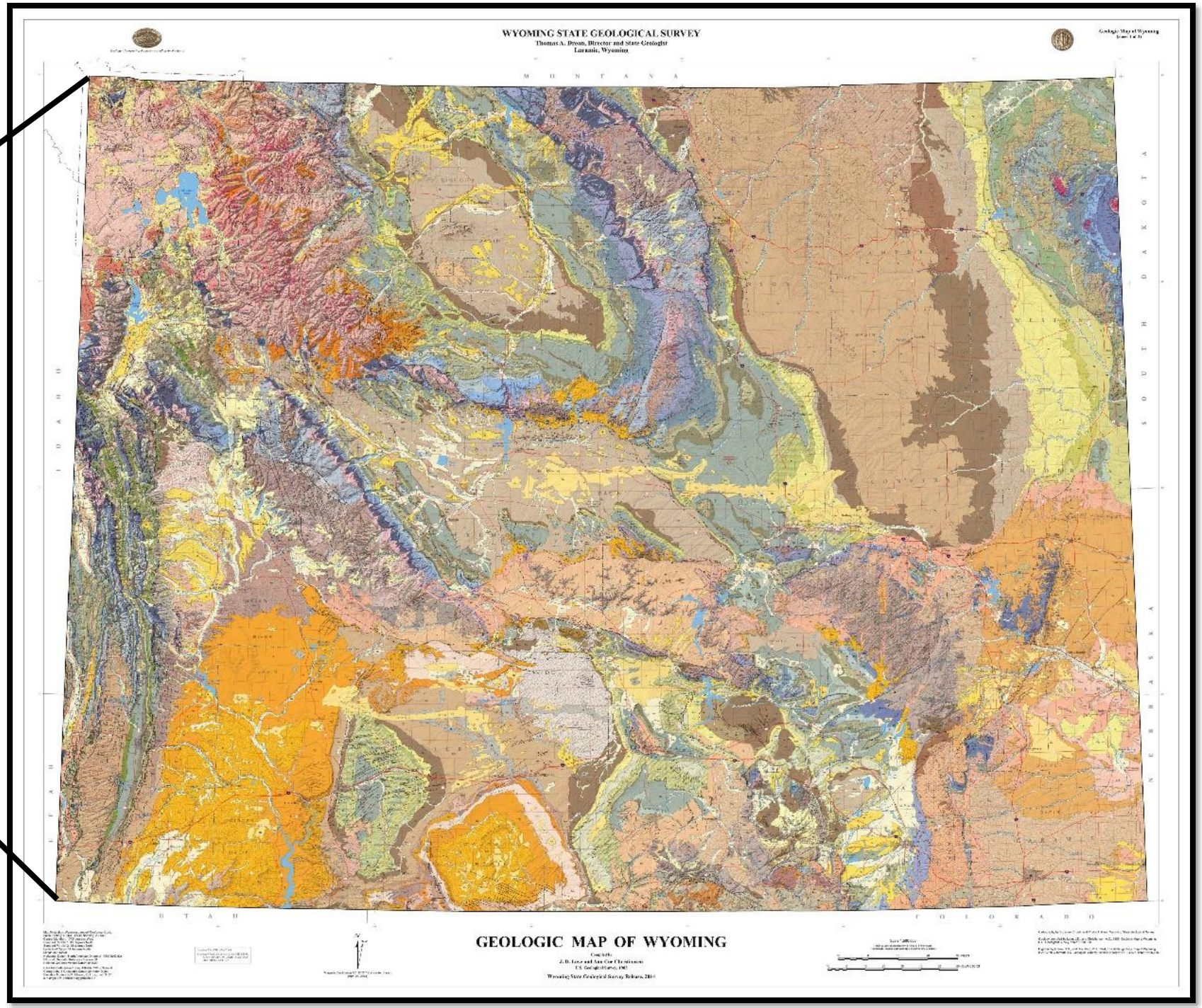
Unconventional Oil Exploration in Wyoming Using Regional Chronostratigraphic Correlation

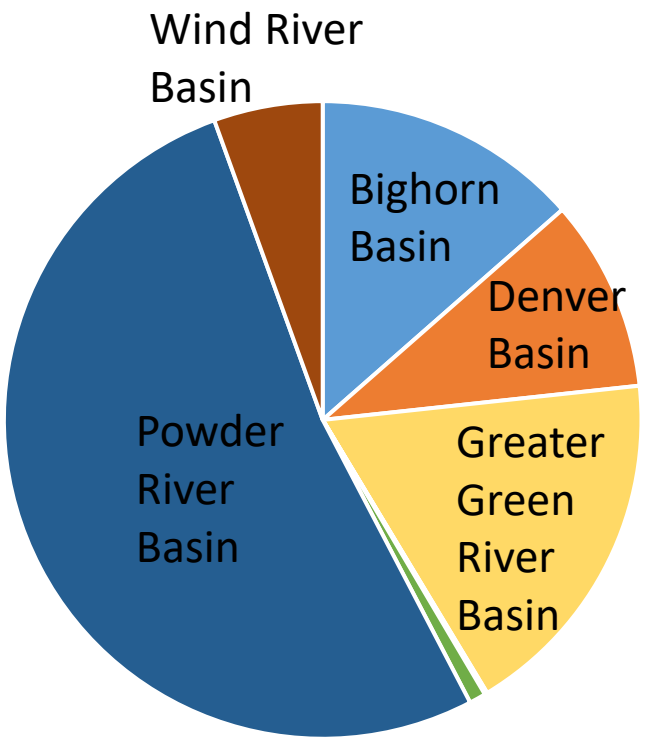
Ranie M. Lynds, Joshua S. Slattery, and Rachel N. Toner



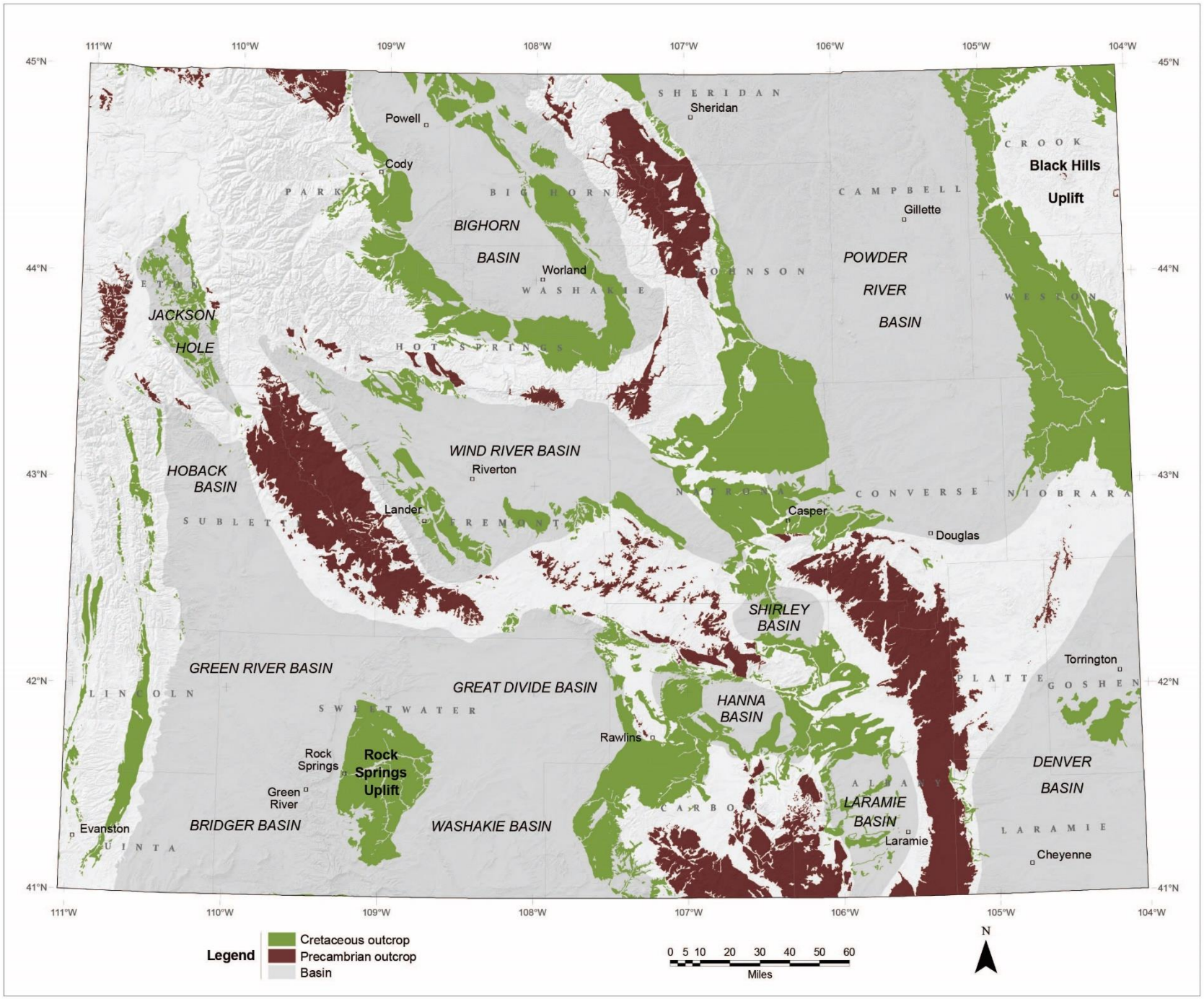
Wyoming

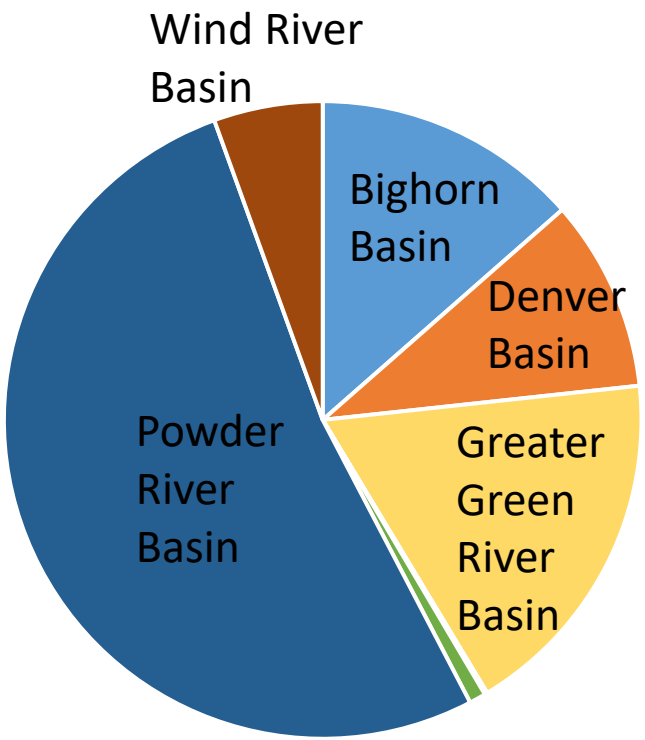

0 155 310 620
Miles
N


WYOMING STATE GEOLOGICAL SURVEY
Thomas A. Drean, Director and State Geologist
Laramie, Wyoming
MONTANA
IDAHO
SOUTH DAKOTA
NEBRASKA
UTAH
COLORADO
GEOLOGIC MAP OF WYOMING

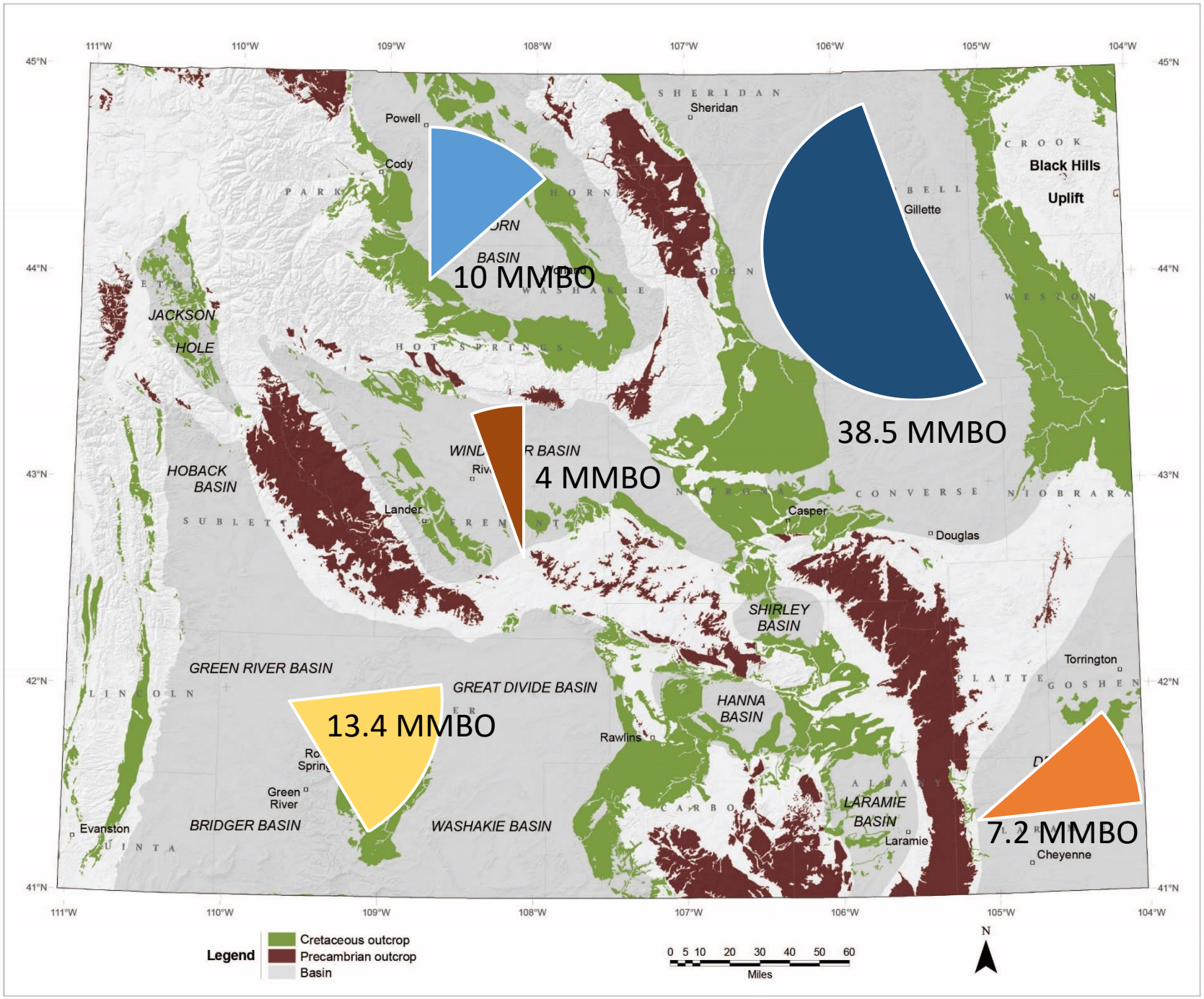


2017 WY Oil Production
73.9 MMBO

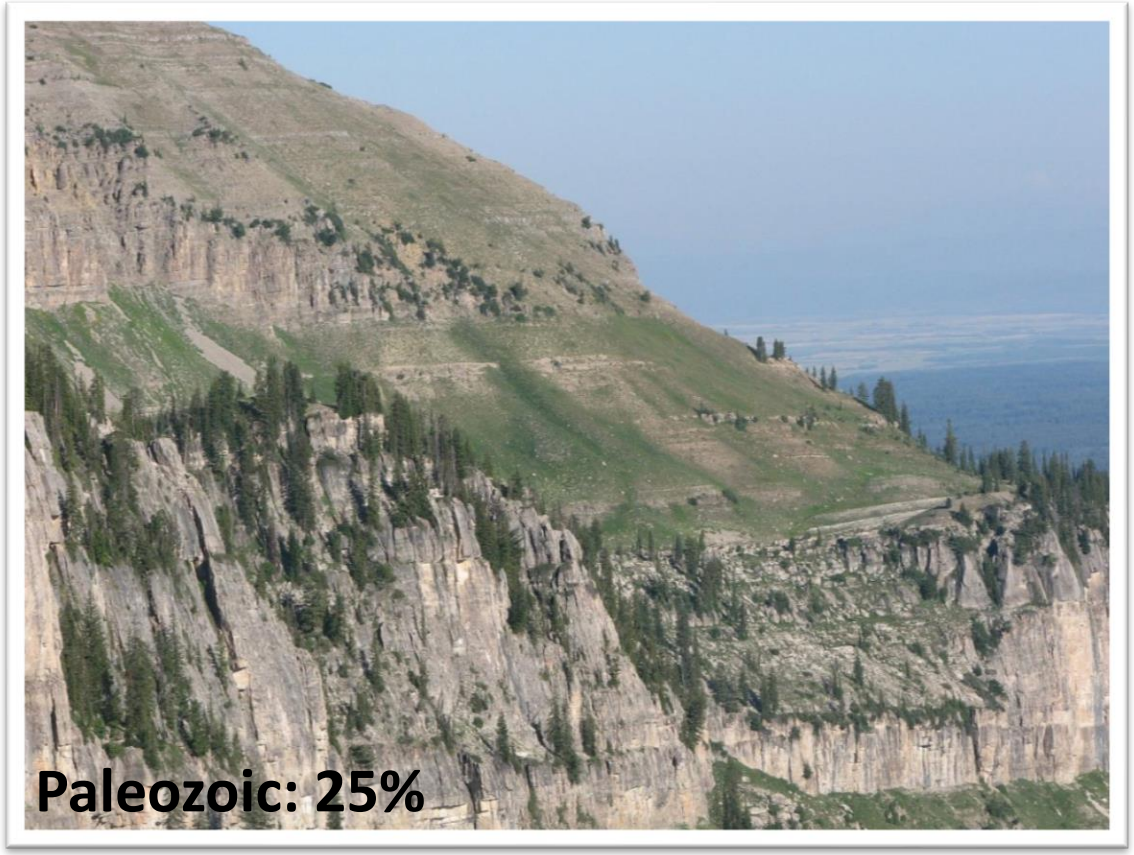




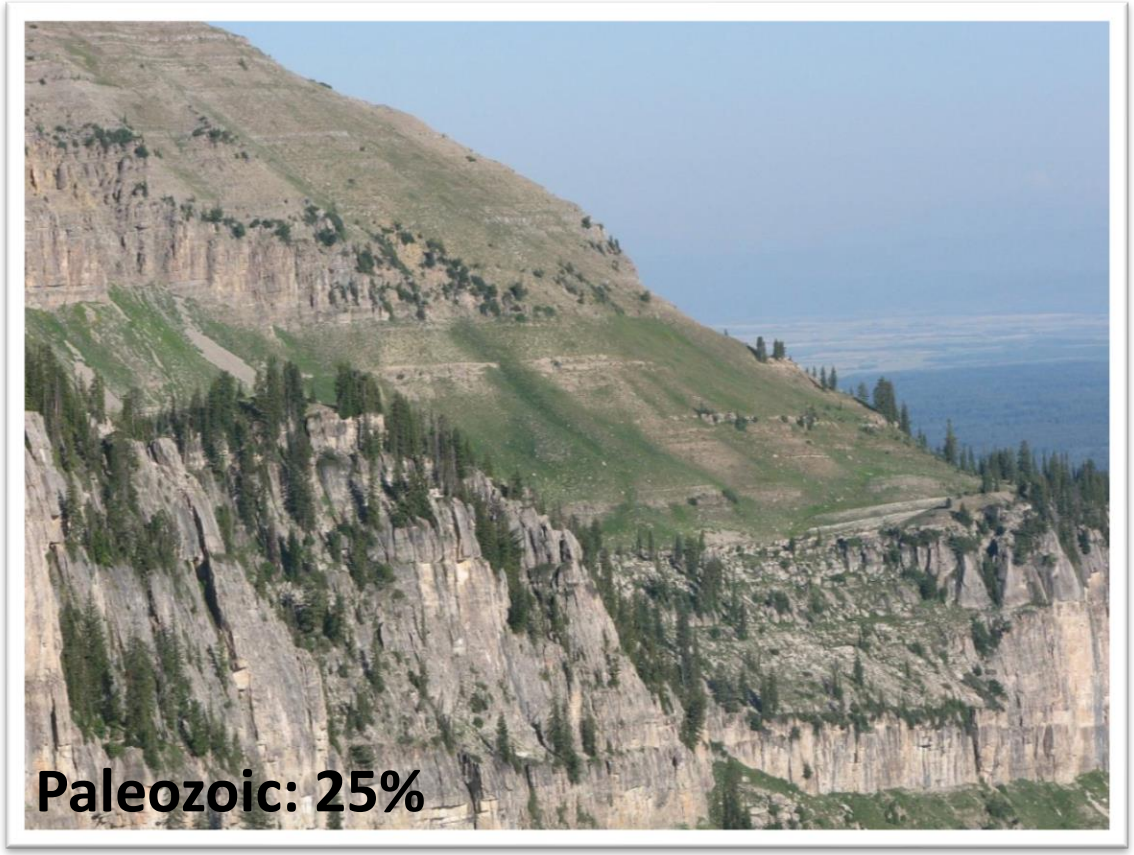
2017 WY Oil Production
73.9 MMBO



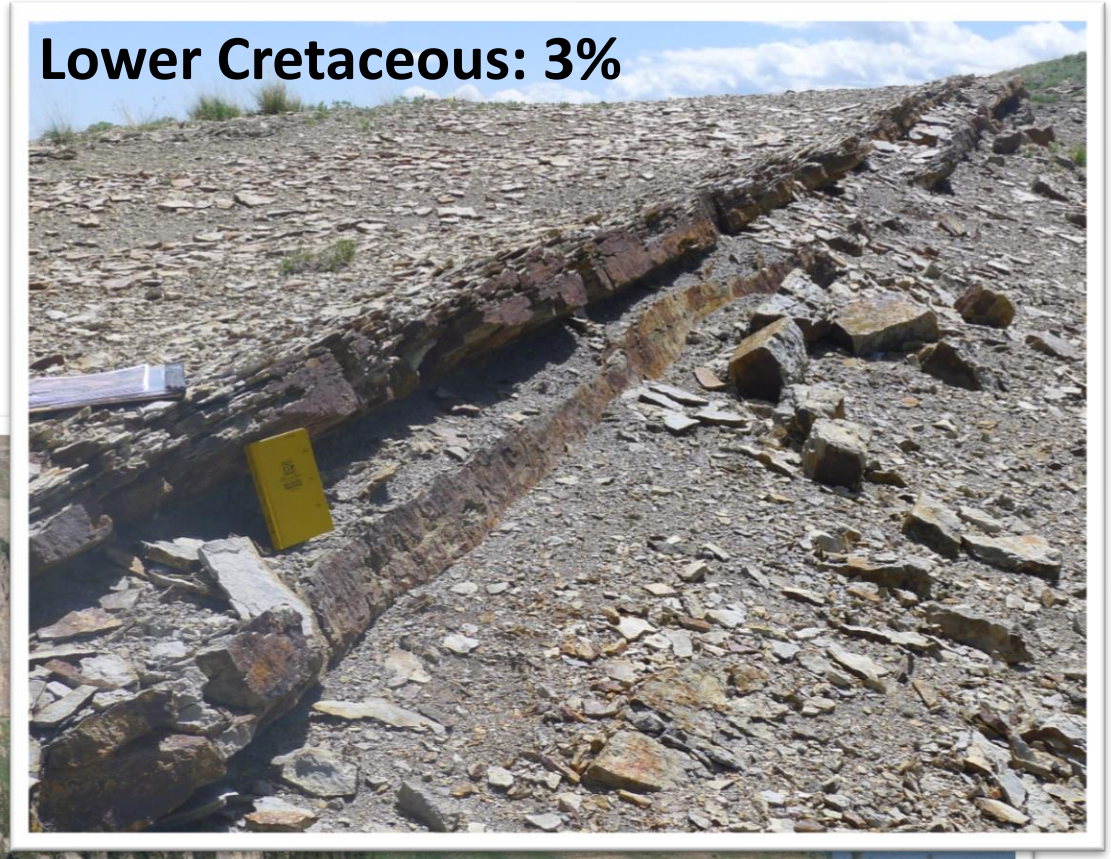
2017 WY Oil Production by Age

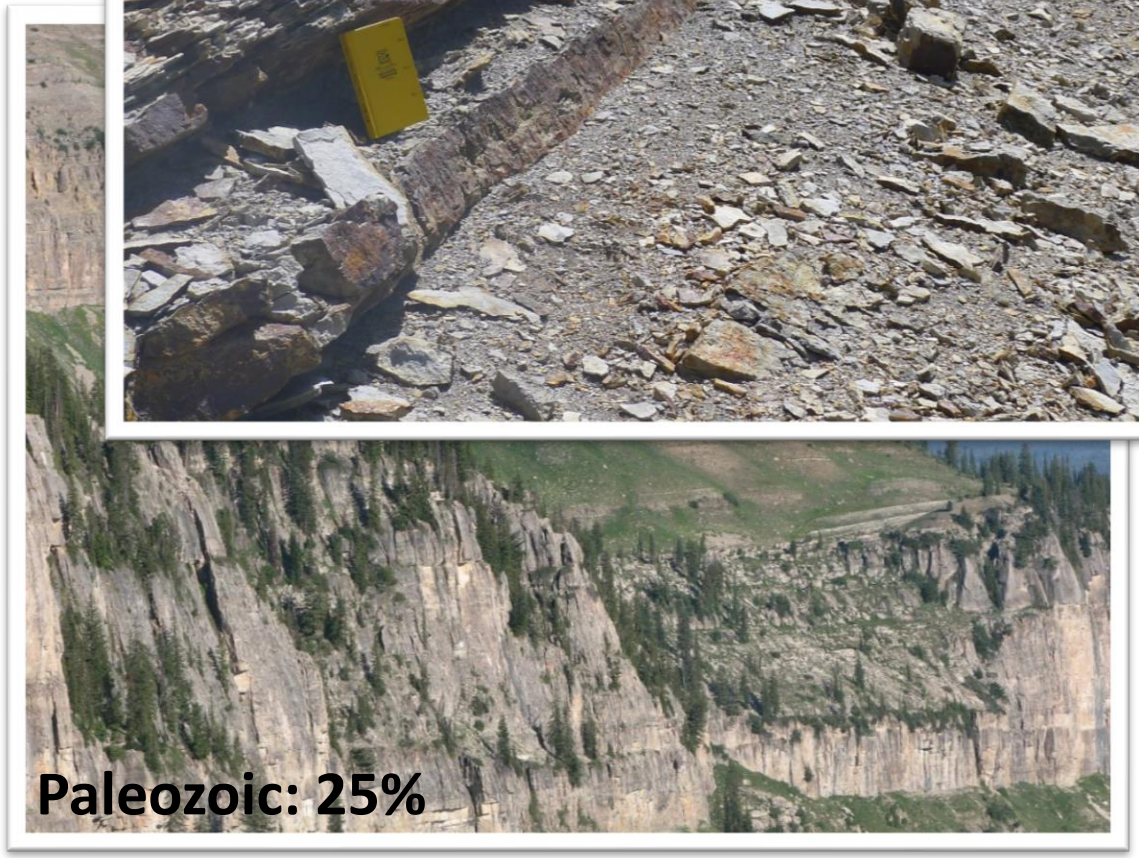


2017 WY Oil Production by Age

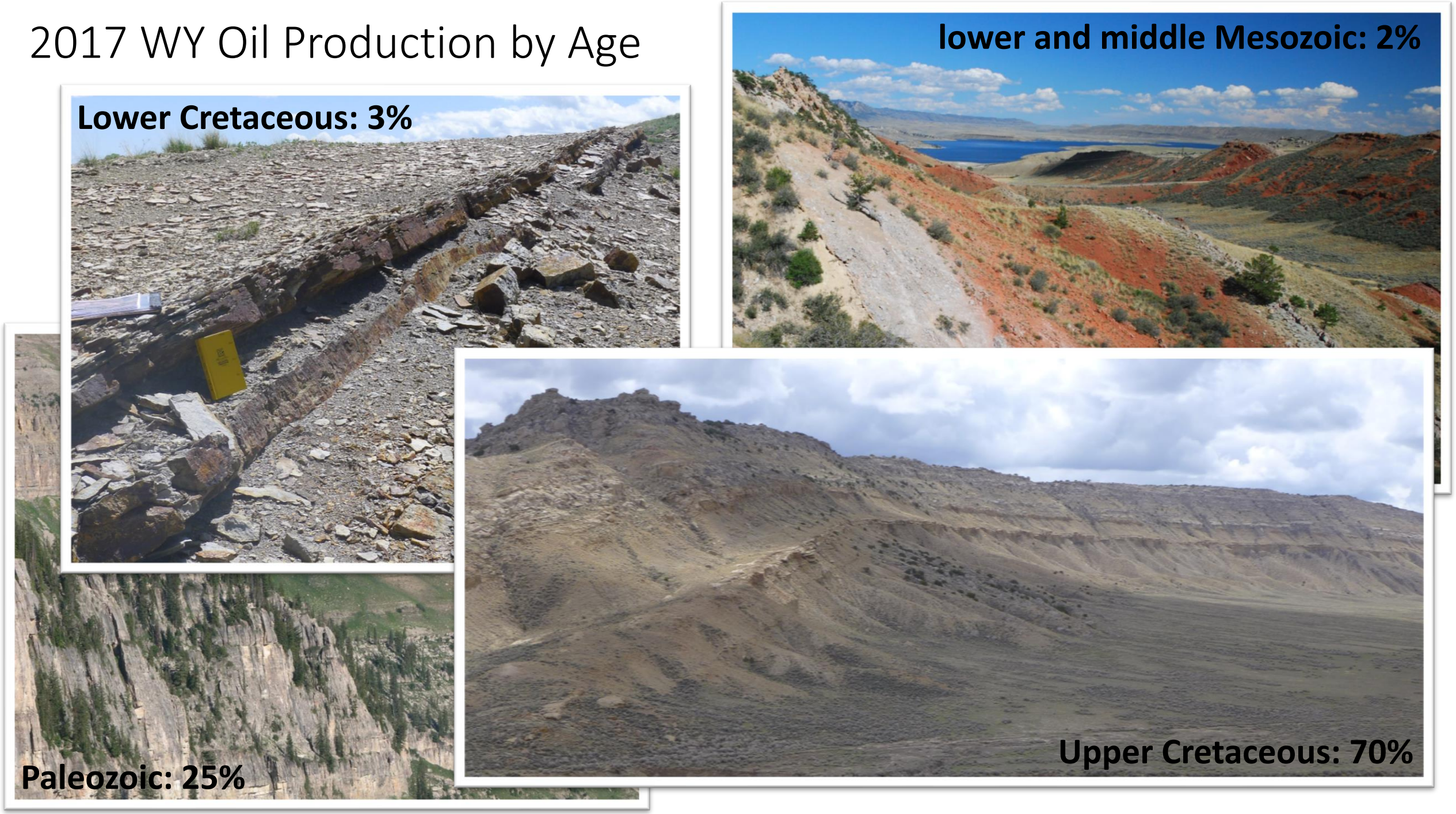


2017 WY Oil Production by Age





2017 WY Oil Production by Age

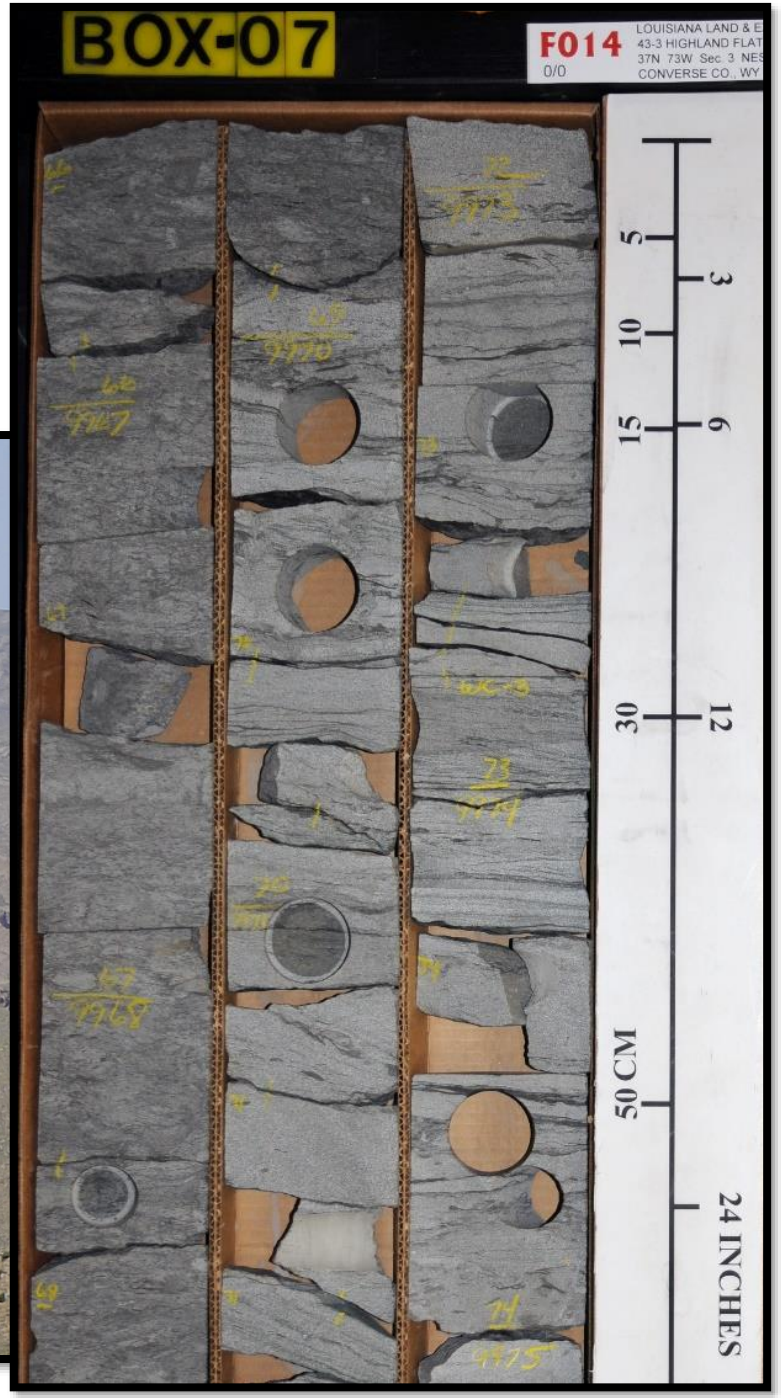


Wyoming Unconventionals

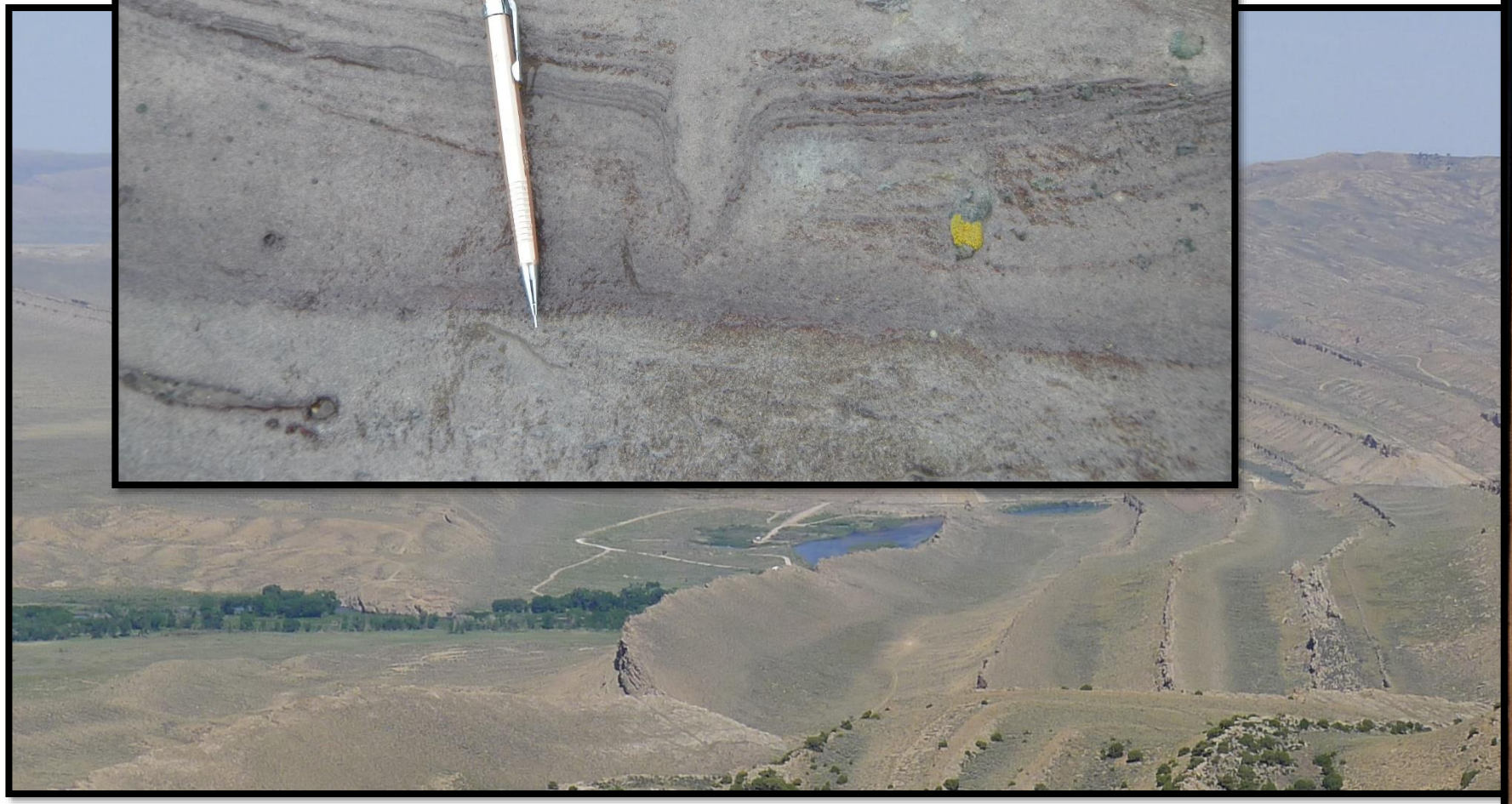
a.k.a. tight sand and siltstones

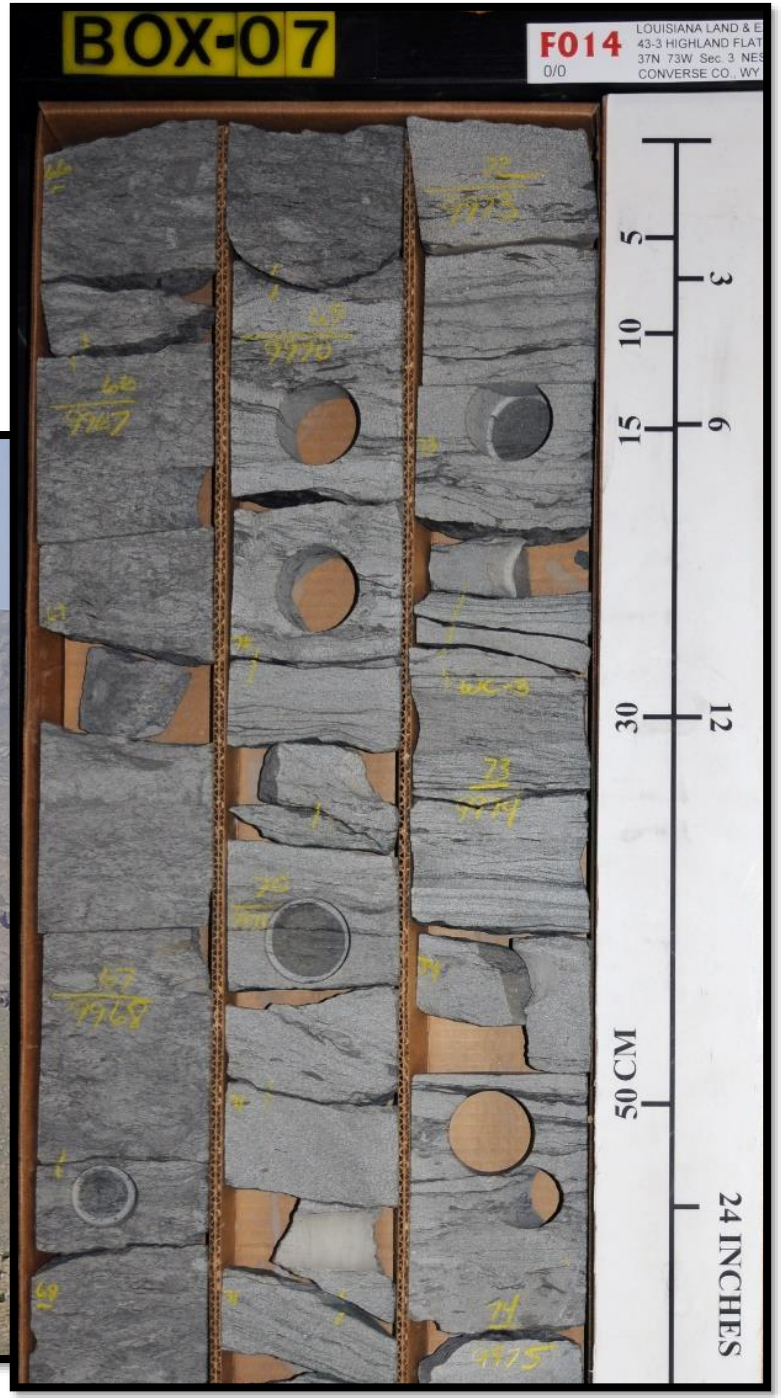
Wyoming Unconventionals

a.k.a. tight sand and siltstones



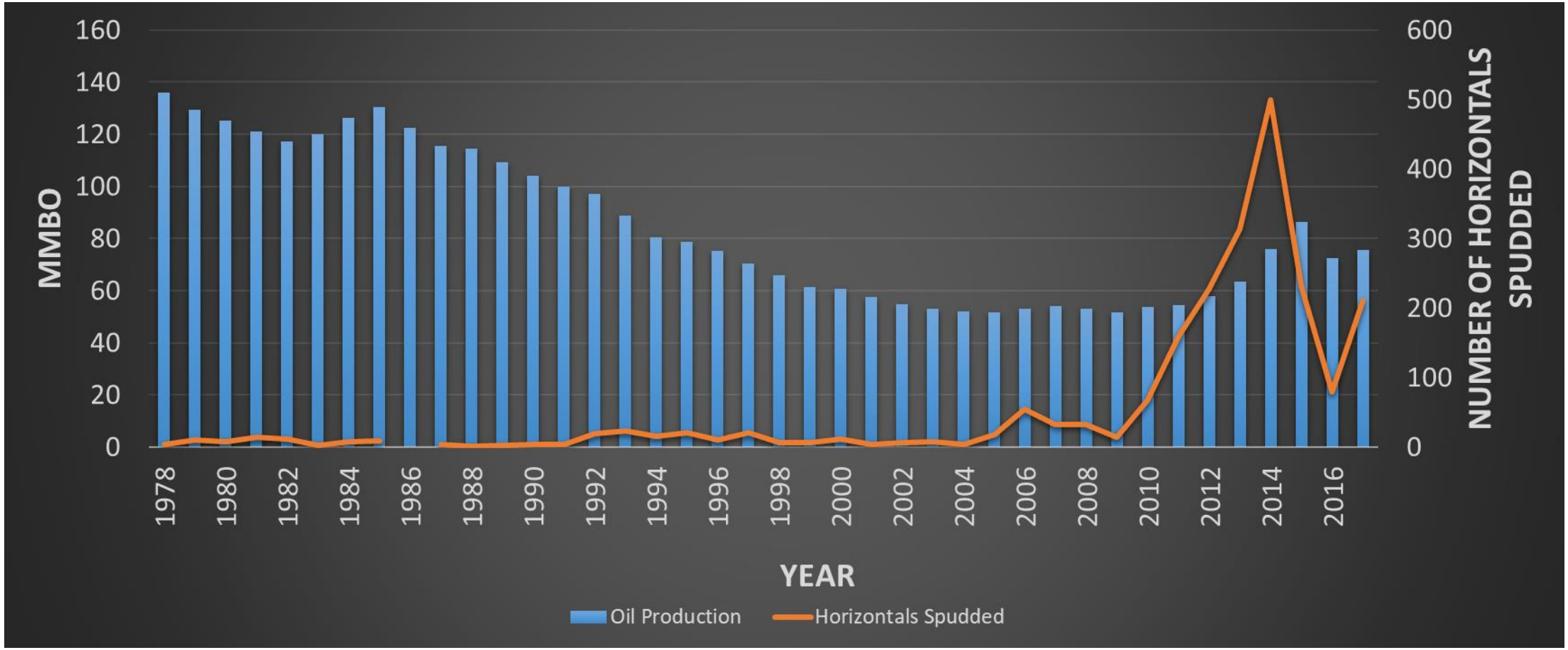
Core: geology.crc.usgs.gov/crc/, API 49-009-22400, Sussex Sandstone





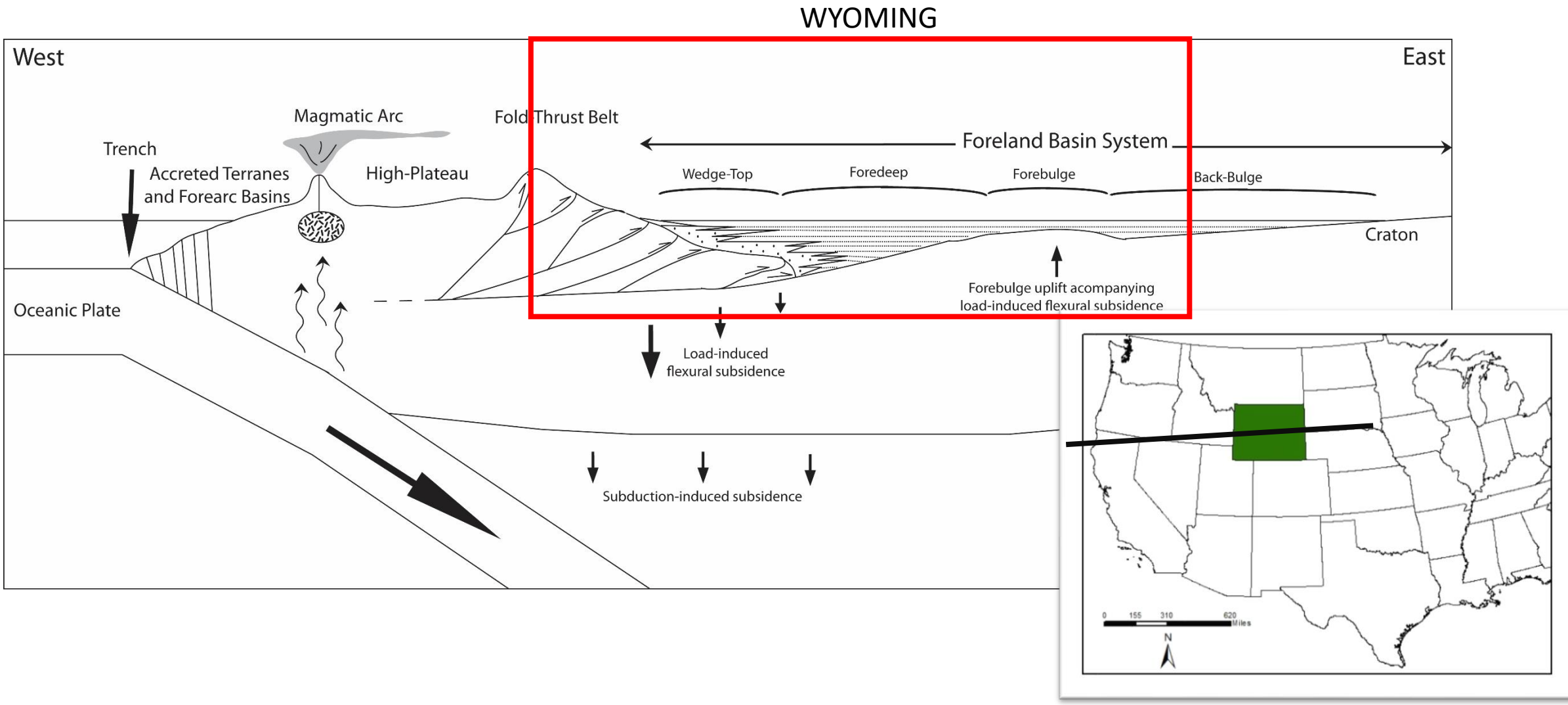
Core: geology.crc.usgs.gov/crc/, API 49-009-22400, Sussex Sandstone

Wyoming Unconventionals



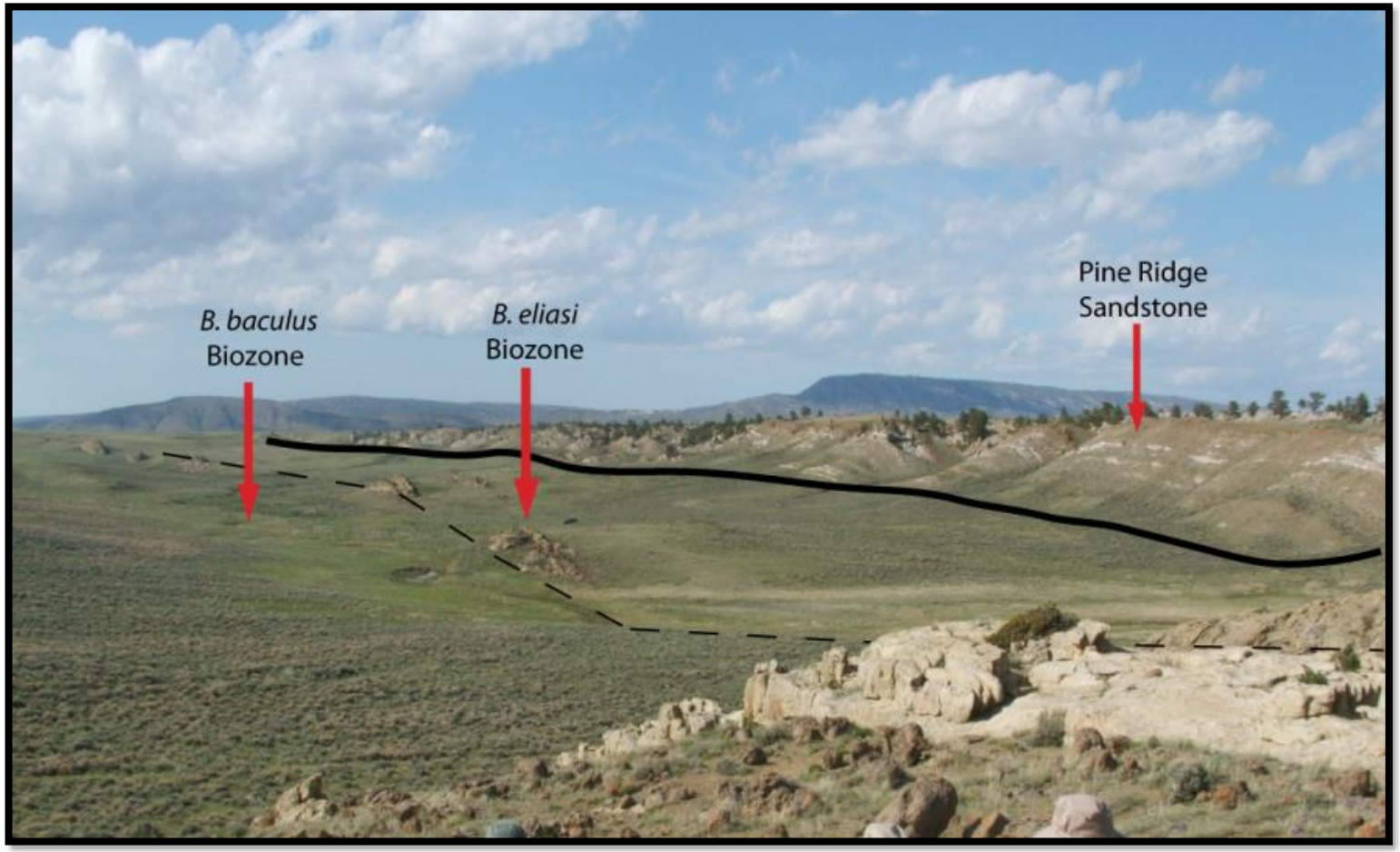
wogcc.wyo.gov, 2018

Western Interior Seaway (WIS) Paleogeography



WIS Chronostratigraphy

- Lithostratigraphy
- Biostratigraphy
- Radiometric dates
- Magnetostratigraphy



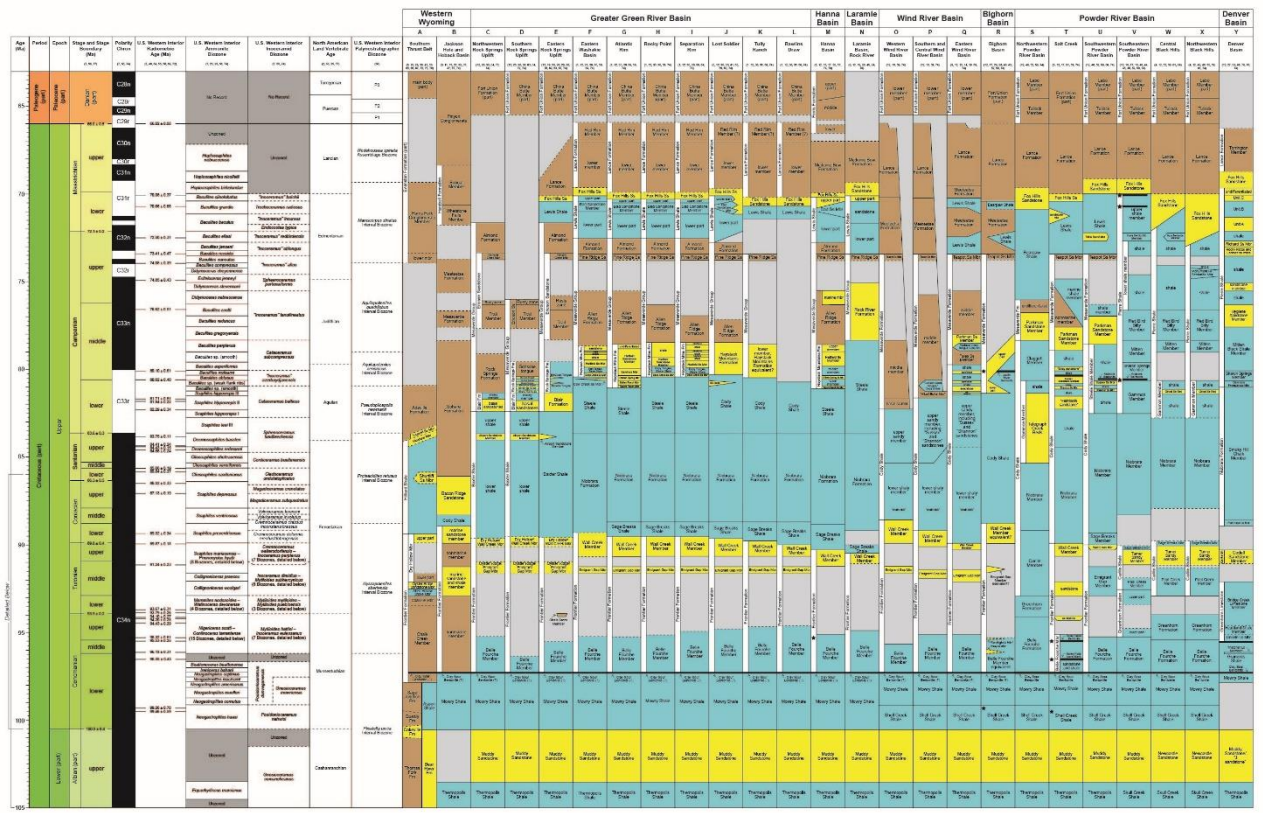
WYOMING STATE GEOLOGICAL SURVEY
Thomas A. Drean
Director and State Geologist
Laramie, Wyoming

Interpreting the past, providing for the future

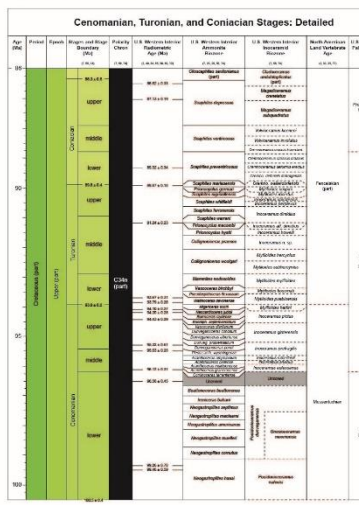
CORRELATION OF THE UPPER CRETACEOUS STRATA OF WYOMING

by
Ranie M. Lynds and Joshua S. Slattery
2017

Open File Report 2017-3
Stratigraphic Chart
Upper Cretaceous
Wyoming



Cenomanian, Turonian, and Coniacian Stages: Detailed



CORRELATION CHART EXPLANATION

—	Certain age boundary	Fm	Formation
- - -	Uncertain or unsupported age boundary	Mbr	Member
▬	Bentonite—Named when known	Ss	Sandstone
▨	Missing or condensed section	Ls	Limestone
?	Uncertain formation name	Sh	Shale
" "	Unofficial formation or member name	Bent	Bentonite
🟫	Terrestrial and transitional marine depositional environment (generalized)		
🟨	Nearshore to transitional marine depositional environments (generalized)		
🟦	Offshore depositional environment (generalized)		
★	Approximate location of radiometric age sample		

ADDITIONAL INFORMATION

The approximate location of each stratigraphic column is shown with the corresponding letter on the map.

References used to determine formation ages for each column are listed as numbers below the generalized column name and correspond to the numbered references.

Wyoming's stratigraphic nomenclature can be inconsistent, especially near the borders with surrounding states. The nomenclature used in this chart is from Love and others (1993) in locations where multiple terminologies are used.

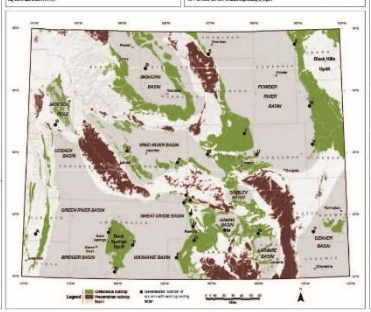
Morris and others (2007) proposed raising the rank of the Pierre Shale from formational to group level and consequently raised its members to formational status. To maintain consistency with previously published literature on the Pierre Shale, this chart retains the former nomenclature following Love and others (1993).

ACKNOWLEDGMENTS

[illegible]

REQUEST FROM AUTHORS

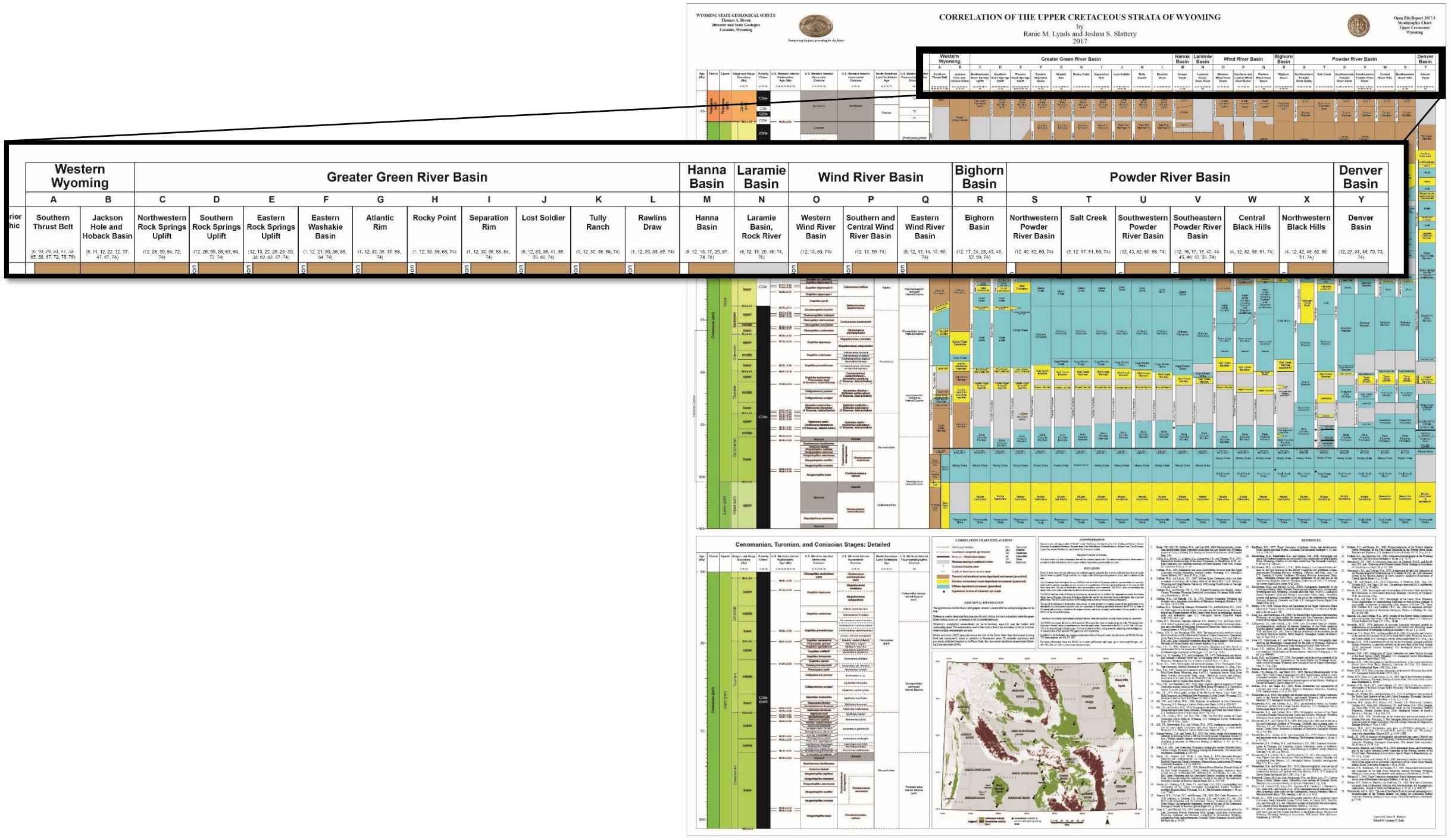
[illegible]

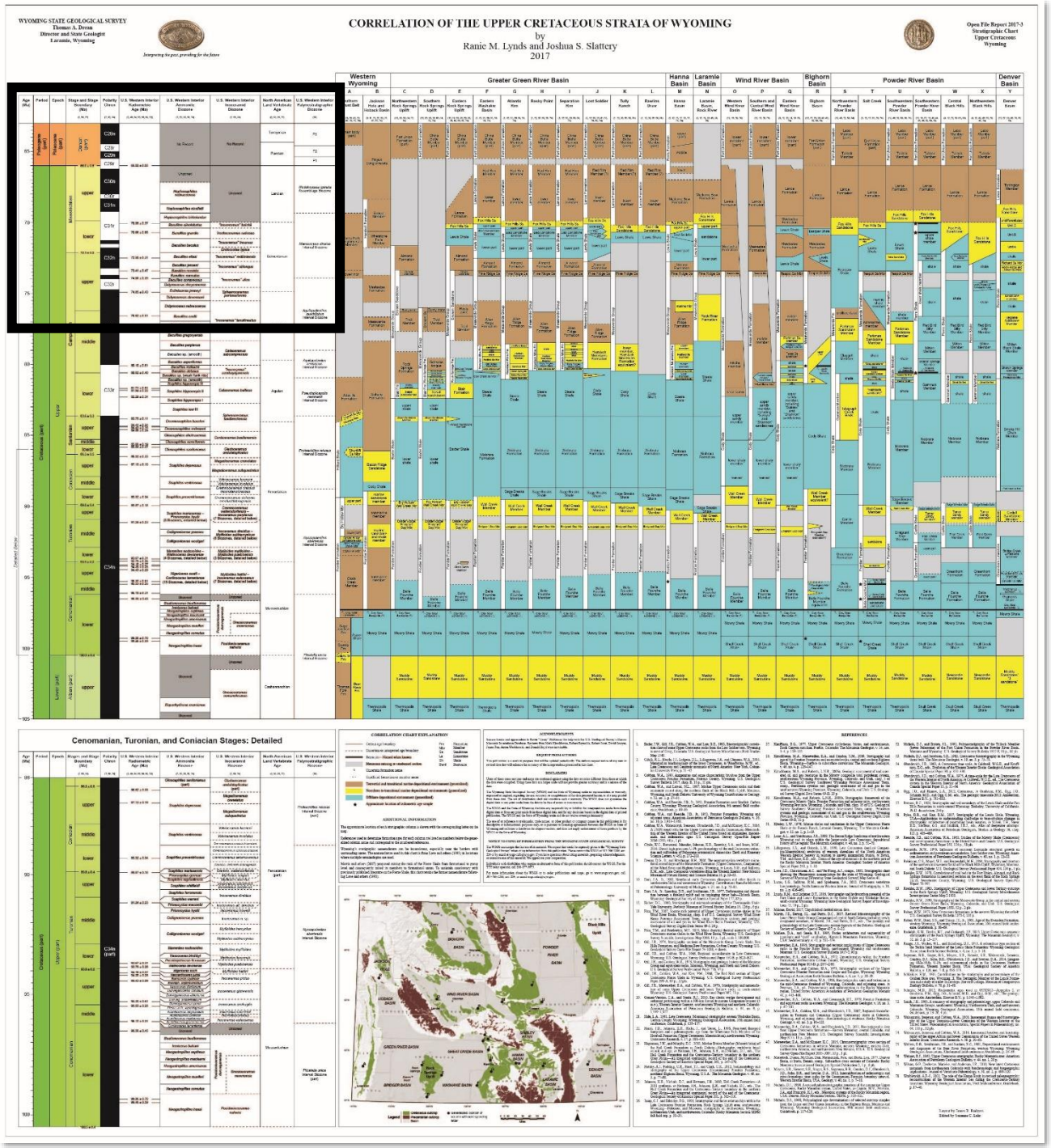


REFERENCES

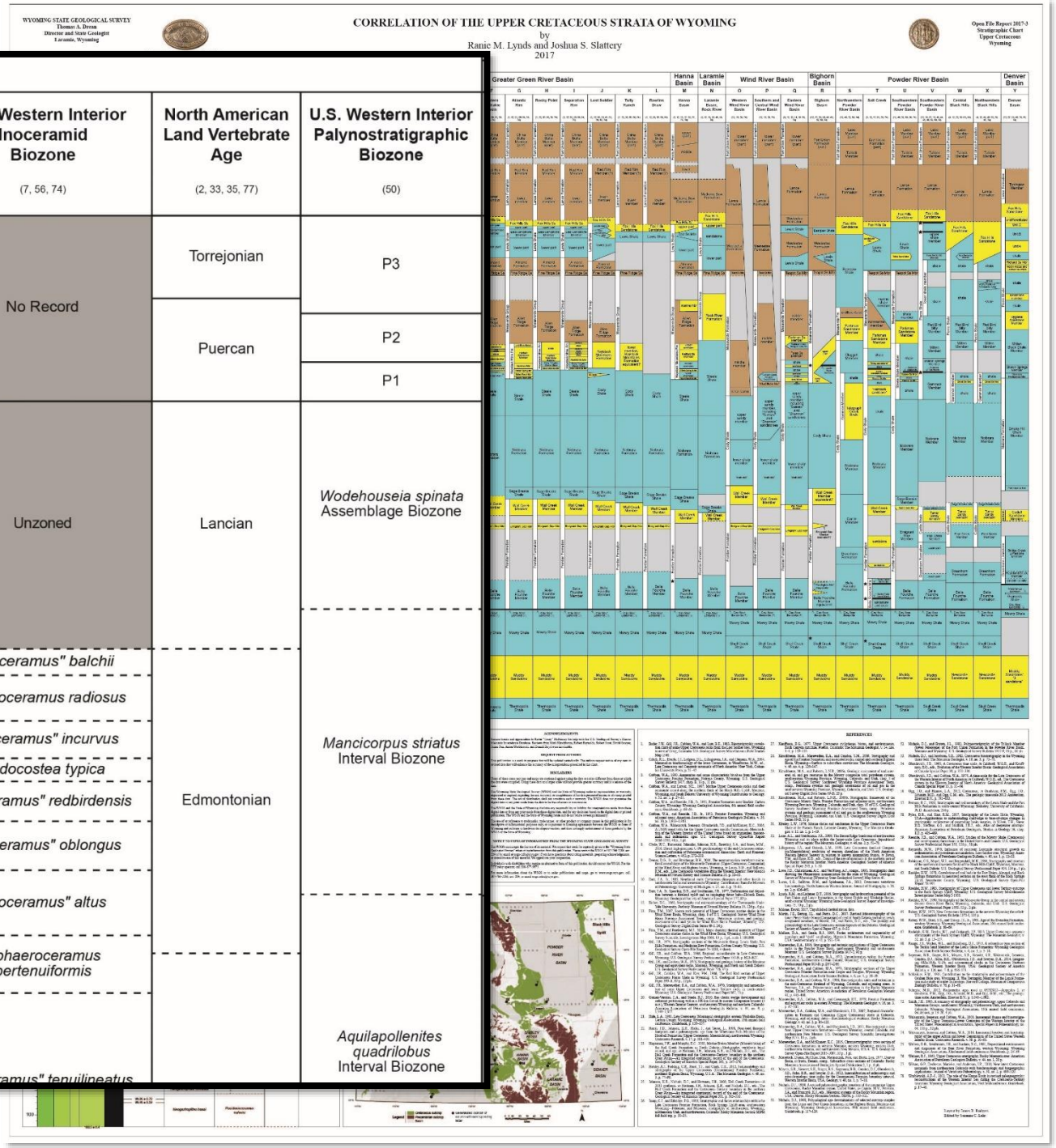
[illegible]

Layout by James R. Rodgers
Edited by Suzanne C. Luhr


WYOMING STATE GEOLOGICAL SURVEY
Thomas A. Drean
Director and State Geologist
Laramie, Wyoming
CORRELATION OF THE UPPER CRETACEOUS STRATA OF WYOMING
by
Ranie M. Lynds and Joshua S. Slattery
2017
Open File Report 2017-3
Stratigraphic Chart
Upper Cretaceous
Wyoming
Western Wyoming
Greater Green River Basin
Hanna Basin
Laramie Basin
Wind River Basin
Bighorn Basin
Powder River Basin
Denver Basin
A Southern Thrust Belt
B Jackson Hole and Hoback Basin
C Northwestern Rock Springs Uplift
D Southern Rock Springs Uplift
E Eastern Rock Springs Uplift
F Eastern Washakie Basin
G Atlantic Rim
H Rocky Point
I Separation Rim
J Lost Soldier
K Tully Ranch
L Rawlins Draw
M Hanna Basin
N Laramie Basin, Rock River
O Western Wind River Basin
P Southern and Central Wind River Basin
Q Eastern Wind River Basin
R Bighorn Basin
S Northwestern Powder River Basin
T Salt Creek
U Southwestern Powder River Basin
V Southeastern Powder River Basin
W Central Black Hills
X Northwestern Black Hills
Y Denver Basin
Cenomanian, Turonian, and Coniacian Stages: Detailed

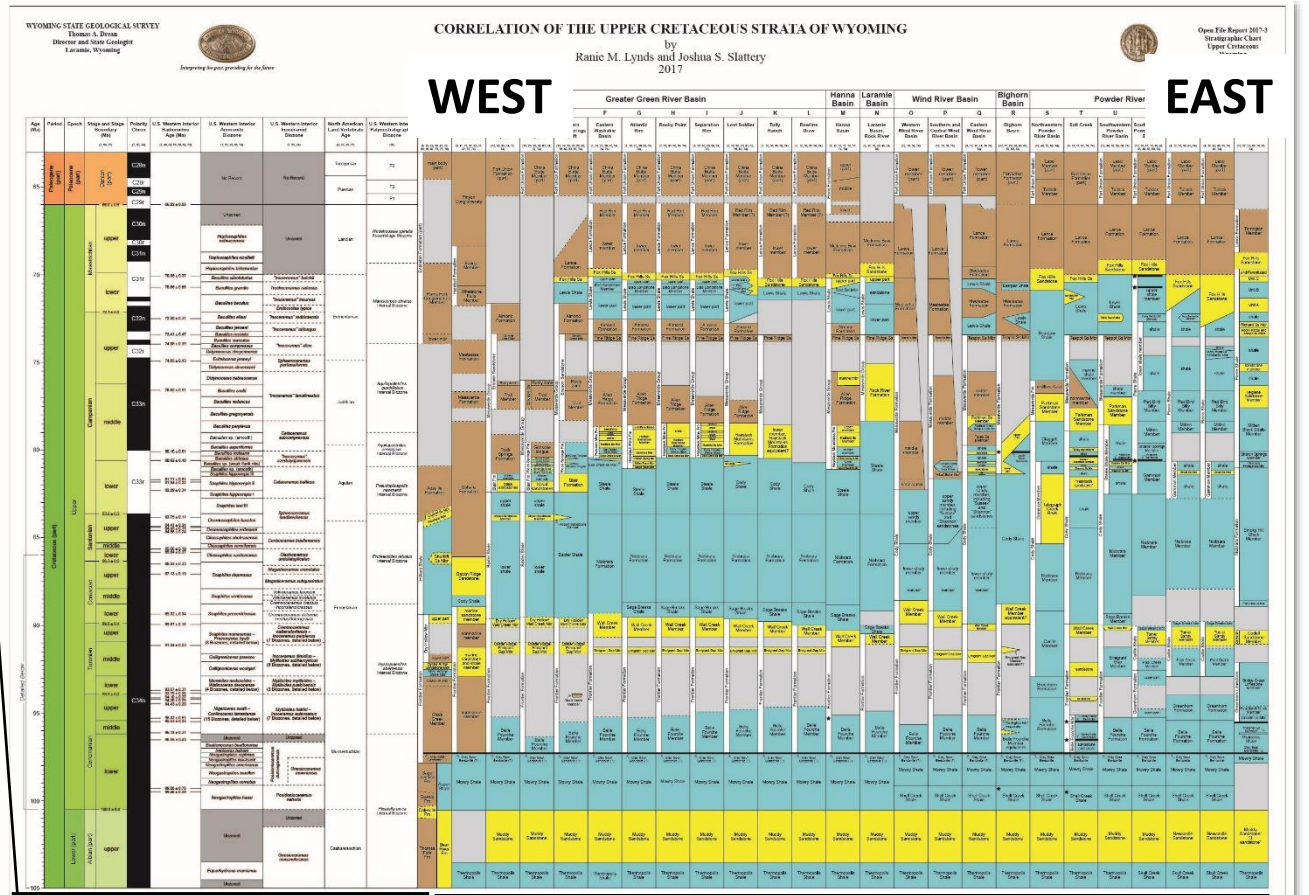

WYOMING STATE GEOLOGICAL SURVEY
Thomas A. Drean
Director and State Geologist
Laramie, Wyoming
Interpreting the past, providing for the future
CORRELATION OF THE UPPER CRETACEOUS STRATA OF WYOMING
by
Ranie M. Lynds and Joshua S. Slattery
2017
Open File Report 2017-3
Stratigraphic Chart
Upper Cretaceous
Wyoming
Western Wyoming
Greater Green River Basin
Hanna Basin
Laramie Basin
Wind River Basin
Bighorn Basin
Powder River Basin
Denver Basin
Cenomanian, Turonian, and Coniacian Stages: Detailed
CORRELATION CHART EXPLANATION
ACKNOWLEDGMENTS
REFERENCES

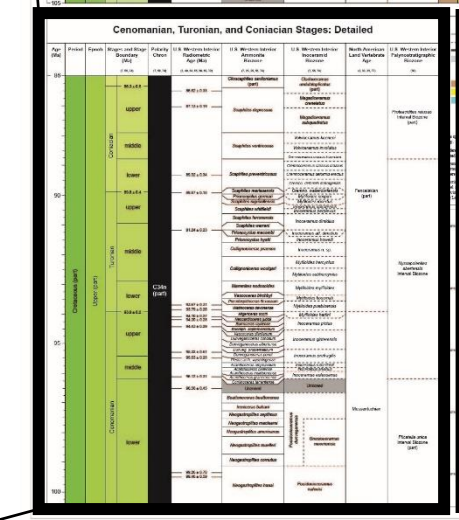
Age (Ma)	Period	Epoch	Stage and Stage Boundary (Ma) (7, 56, 77)	Polarity Chron (7, 56, 74)	U.S. Western Interior Radiometric Age (Ma) (8, 49, 54, 55, 56, 69, 72)	U.S. Western Interior Ammonite Biozone (7, 23, 25, 56, 74)	U.S. Western Interior Inoceramid Biozone (7, 56, 74)	North American Land Vertebrate Age (2, 33, 35, 77)	U.S. Western Interior Palynostratigraphic Biozone (50)
	Paleogene (part)	Paleocene (part)	Danian (part)	C28n		No Record	No Record	Torrejonian	P3
				C28r				Puercan	P2
65				C29n					P1
				C29r					
			66.0 ± 0.5		66.02 ± 0.08				
	Maastrichtian		upper	C30n		Unzoned			
						Hoploscaphites nebrascensis	Unzoned	Lancian	*Wodehouseia spinata* Assemblage Biozone
				C30r					
				C31n					
						Hoploscaphites nicolletii			
						Hoploscaphites birkelundae			
70				C31r	70.08 ± 0.37	*Baculites clinolobatus*	"Inoceramus" balchii		
			lower		70.66 ± 0.66	*Baculites grandis*	*Trochoceramus radiosus*		
						Baculites baculus	"Inoceramus" incurvus		*Mancicorpus striatus* Interval Biozone
							Endocostea typica		
			72.1 ± 0.2	C32n	72.50 ± 0.31	*Baculites eliasi*	"Inoceramus" redbirdensis	Edmontonian	
						Baculites jenseni	"Inoceramus" oblongus		
					73.41 ± 0.47	*Baculites reesidei*			
						Baculites cuneatus			
			upper		74.05 ± 0.39	*Baculites compressus*	"Inoceramus" altus		
				C32r		*Didymoceras cheyennense*			
75					74.85 ± 0.43	*Exiteloceras jenneyi*	*Sphaeroceramus pertenuiformis*		
						Didymoceras stevensoni			
						Didymoceras nebrascense			*Aquilapollenites quadrilobus* Interval Biozone
					76.62 ± 0.51	*Baculites scotti*	"Inoceramus" tenuilineatus		

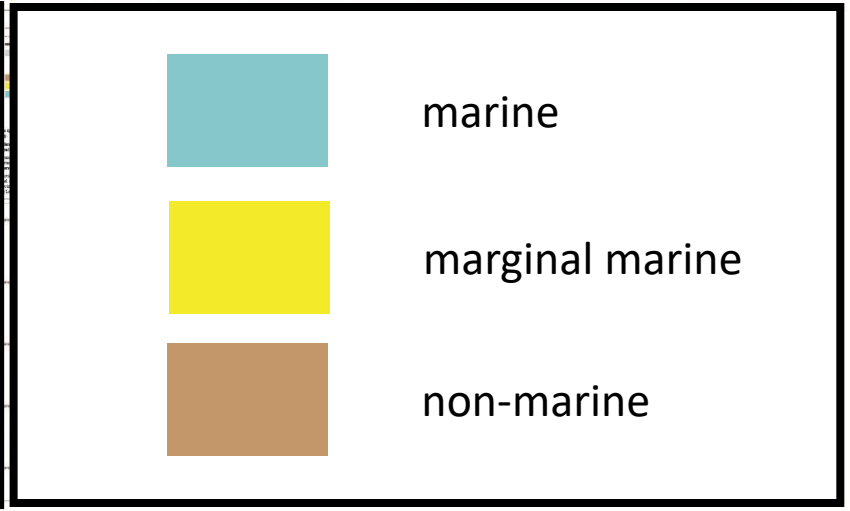


Cenomanian, Turonian, and Coniacian Stages: Detailed

Age (Ma)	Period	Epoch	Stages and Stage Boundary (Ma) (7, 58, 74)	Polarity Chron (7, 58, 74)	U.S. Western Interior Radiometric Age (Ma) (8, 49, 54, 55, 58, 69, 72)	U.S. Western Interior Ammonite Biozone (7, 23, 25, 58, 74)	U.S. Western Interior Inoceramid Biozone (7, 58, 74)	North American Land Vertebrate Age (2, 33, 35, 77)	U.S. Western Interior Palynostratigraphic Biozone (50)
86	Cretaceous (part)	Upper (part)	Coniacian: 86.3 ± 0.5 – upper	C34n (part)	86.52 ± 0.33	*Clioscaphites saxitonianus* (part)	*Cladoceramus undulatoplicatus* (part)	Fencelakian (part)	*Proteacidites refusus* Interval Biozone (part)
					87.13 ± 0.19	*Scaphites depressus*	*Magadiceramus crenelatus*		
							Magadiceramus subquadratus		
			Coniacian: middle			*Scaphites ventricosus*	*Volviceramus koeneni*		
							Volviceramus involutus		
							Cremnoceramus crassus inconstans		
			Coniacian: lower		89.32 ± 0.34	*Scaphites preventricosus*	*Cremnoceramus crassus crassus*		
							Cremnoceramus deformis erectus		
							Cremno. deformis dobrogensis		
			89.8 ± 0.4		89.87 ± 0.18	*Scaphites mariasensis*	*Cremno. walterdorfensis*		
90						*Prionocyclus germari*	*Mytiloides scupini*		
			Turonian: upper			*Scaphites nigricollensis*	*Mytiloides incertus*		
						Scaphites whitfieldi	*Inoceramus dakotensis*		
							Inoceramus perplexus		
						Scaphites ferronensis	*Inoceramus dimidius*		
						Scaphites warreni			
					91.24 ± 0.23	*Prionocyclus macombi*	*Inoceramus aff. dimidius*		
						Prionocyclus hyatti	*Inoceramus howelli*		
			Turonian: middle			*Collignoniceras praecox*	*Inoceramus n. sp.*		
						Collignoniceras woolgari	*Mytiloides hercynius*		*Nyssapolenites abertensis* Interval Biozone
							Mytiloides subhercynius		
			Turonian: lower			*Mammites nodosoides*	*Mytiloides mytiloides*		
						Vascoceras birchbyi	*Mytiloides kossmati*		
					93.67 ± 0.31	*Pseudaspidoceras flexuosum*			
					93.79 ± 0.26	*Watinoceras devonense*	*Mytiloides puebloensis*		
			93.9 ± 0.2		94.10 ± 0.27	*Nigericeras scotti*	*Mytiloides hattini*		
					94.20 ± 0.28	*Neocardioceras juddii*			
					94.43 ± 0.29	*Burroceras clydense*	*Inoceramus pictus*		
			Turonian: upper			*Euomph. septemseriatum*			
						Vascoceras diartianum	*Inoceramus ginterensis*		
						Dunveganoceras conditum			
						Dunveganoceras albertense			
95					95.32 ± 0.61	*Dunveg. problematicum*	*Inoceramus prefragilis*		
					95.53 ± 0.25	*Dunveganoceras pondi*			
						Plesiacanth. wyomingense			
			Cenomanian: middle			*Acanthoceras amphibolum*	*Inoceramus rutherfordi*		
						Acanthoceras bellense	*Inoceramus anyanus*		
						Acanthoceras muldoonense	*Inoceramus eulessanus*		
					96.12 ± 0.31	*Acanthoceras granerosense*			
						Conlinoceras tarrantense	Unzoned		
					96.56 ± 0.45	Unzoned			
			Cenomanian: lower			*Beattonoceras beattonense*	*Posidonioceramus dunveganensis*	Mussentuchian	*Plicatella unica* Interval Biozone (part)
						Ireniceras bahani			
						Neogastroplites septimus			
						Neogastroplites maclearni	*Gnesioceramus mowriensis*		
						Neogastroplites americanus			
						Neogastroplites muelleri			
						Neogastroplites cornutus			
					99.26 ± 0.70	*Neogastroplites haasi*	*Posidonioceramus nahwisi*		
					99.46 ± 0.59				
100			100.5 ± 0.4						

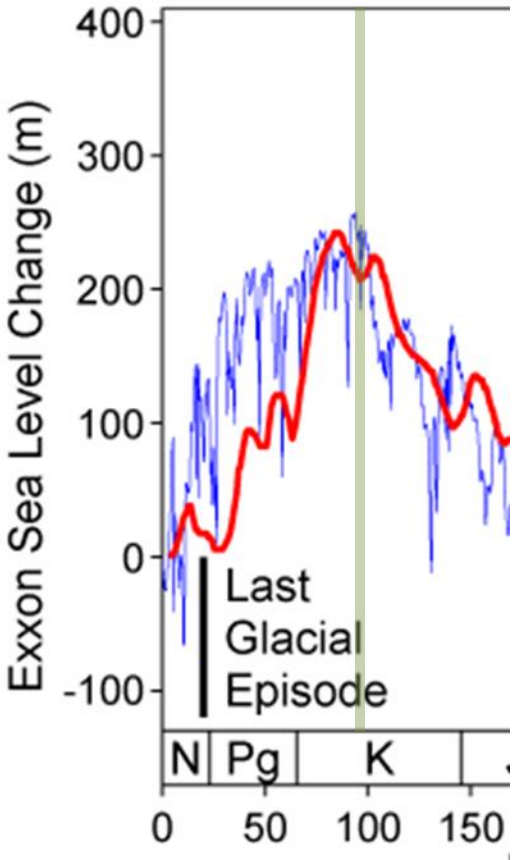






Early Cenomanian

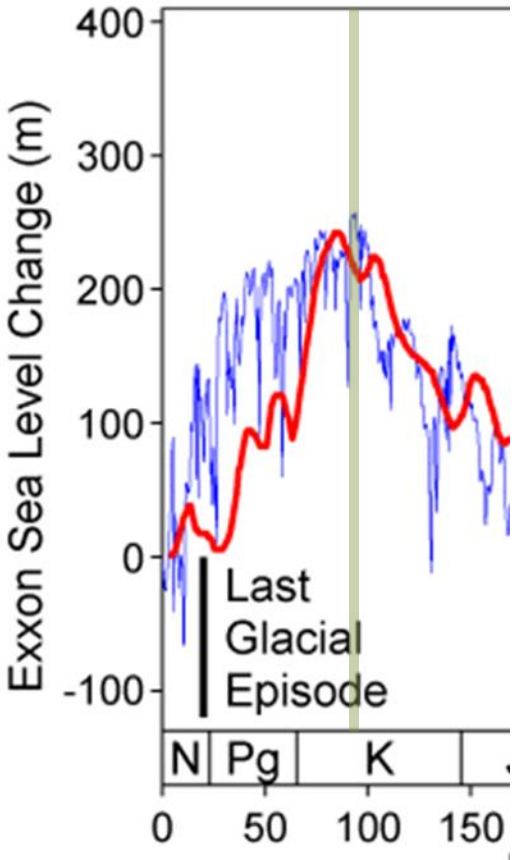
- Loss of connection between Gulf of Mexico and Arctic ocean
- Mowry Seaway



Slattery and others, 2015

Late Cenomanian

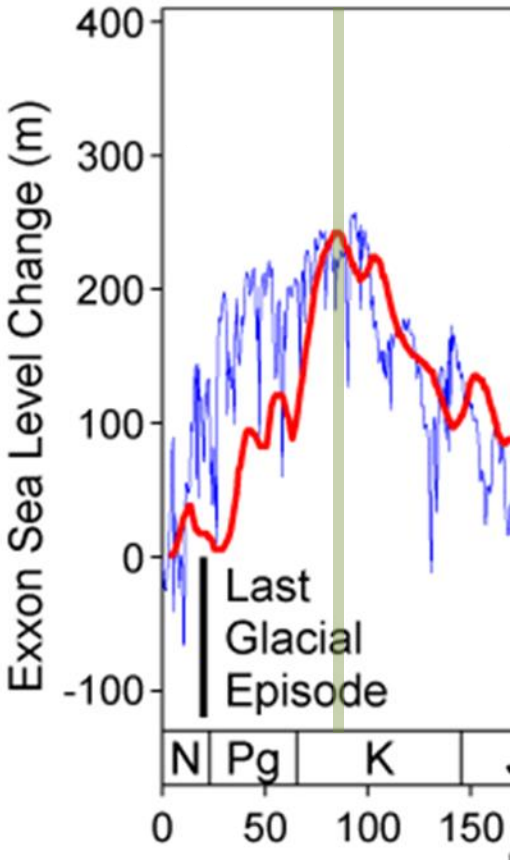
- Full connection between Gulf of Mexico and Arctic Ocean
- Greenhorn Seaway



Slattery and others, 2015

Middle Coniacian

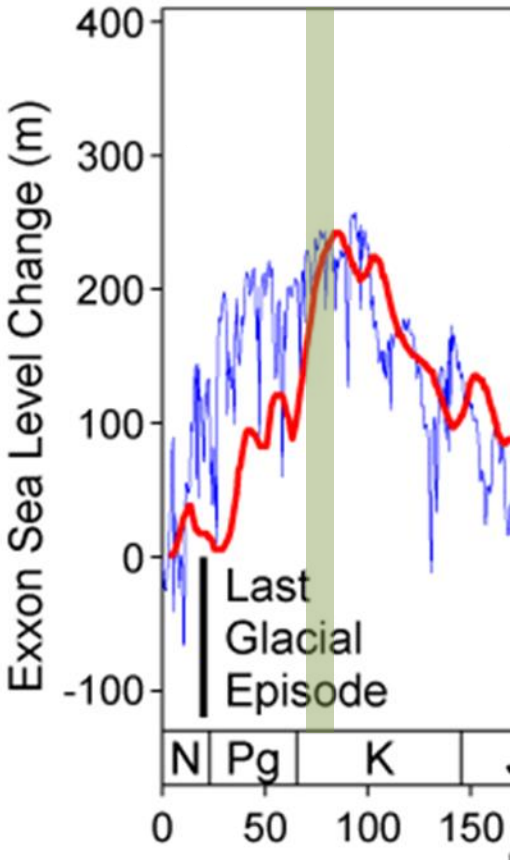
- Continued connection between Gulf of Mexico and Arctic Ocean
- Niobrara high stand



Slattery and others, 2015

Middle Campanian

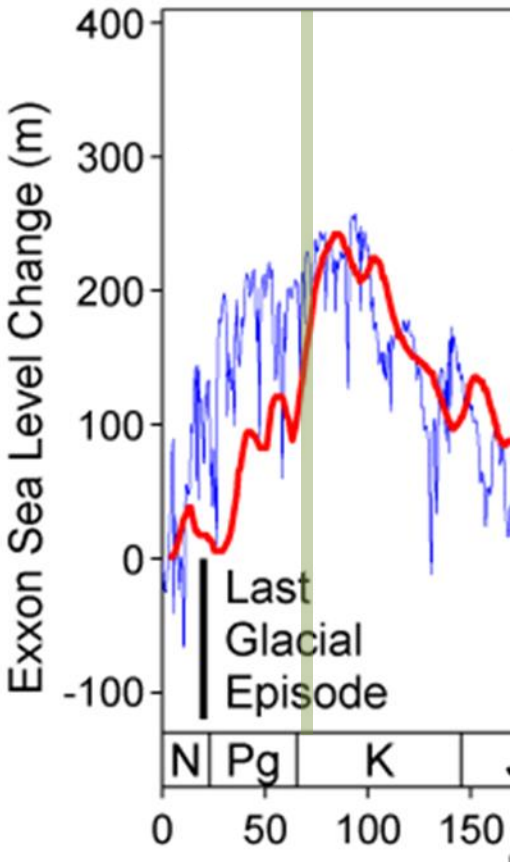
- Narrowing of WIS
- Mesaverde progradational regression



Slattery and others, 2015

Early Maastrichtian

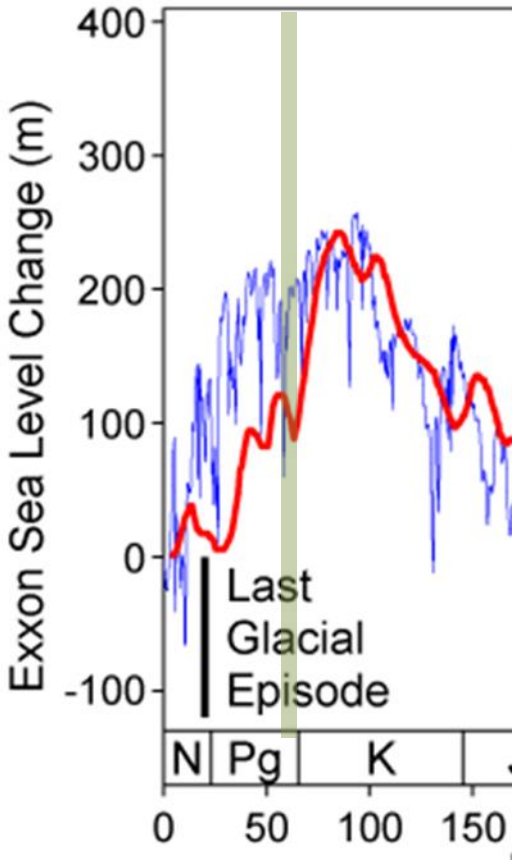
- Major eastward shift of shoreline
- Drop in eustatic sea level and onset of Laramide Orogeny
- Late Pierre (Lewis) Seaway



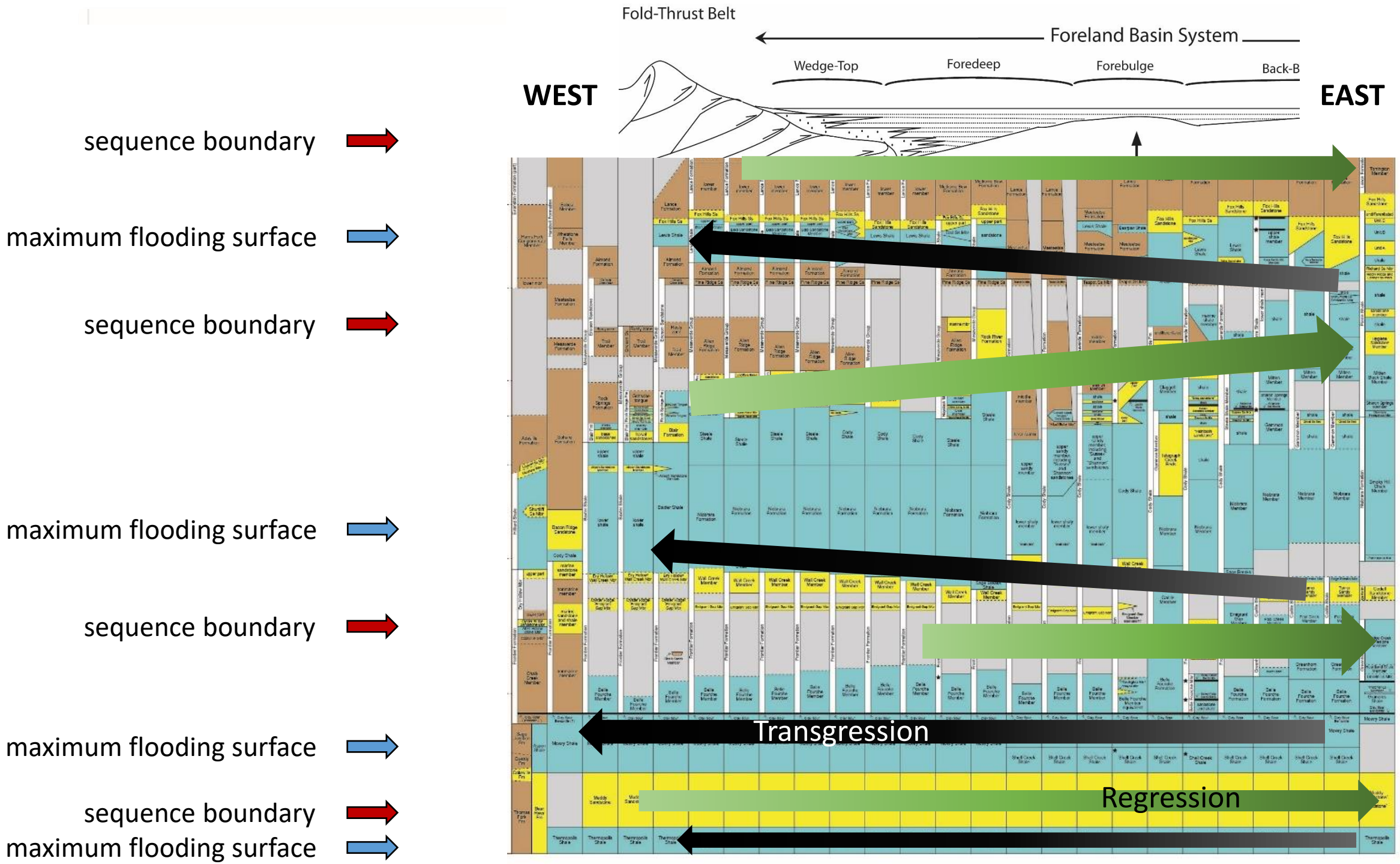
Slattery and others, 2015

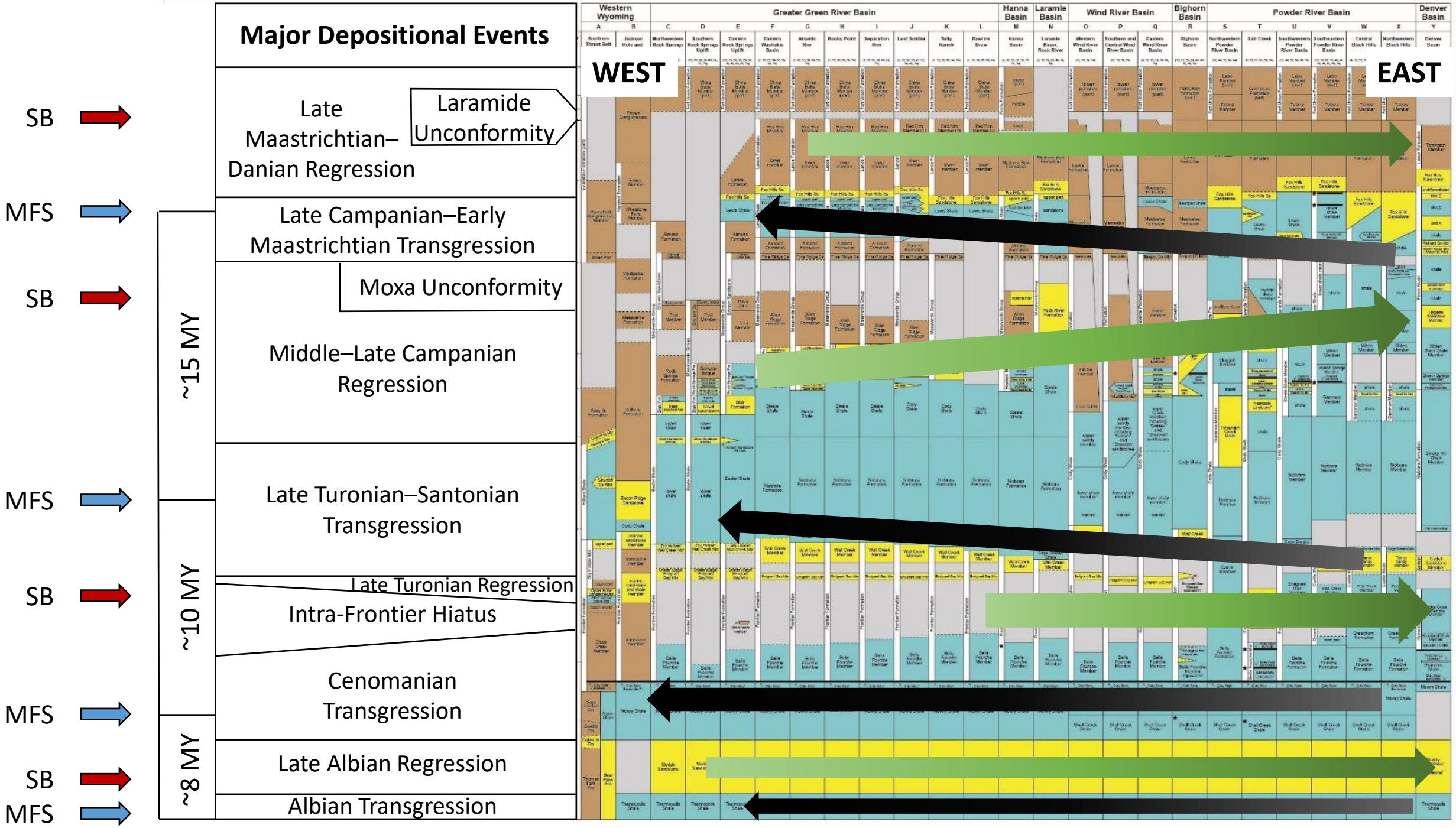
Paleocene

- Retreat of the WIS
- Cannonball Formation in Dakotas
- Ferris and Fort Union formations in Wyoming
- Peace Garden Member in Alberta

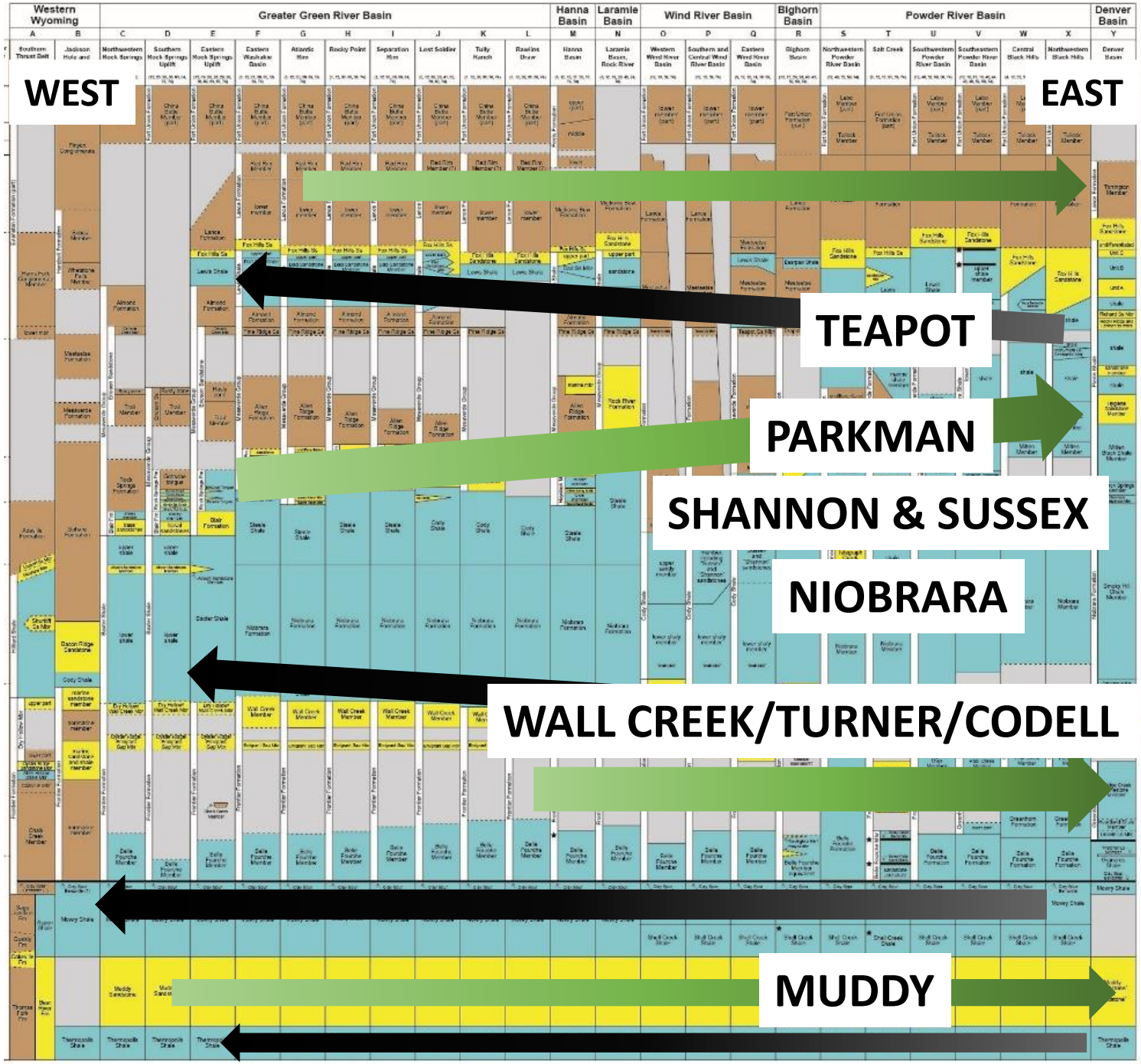


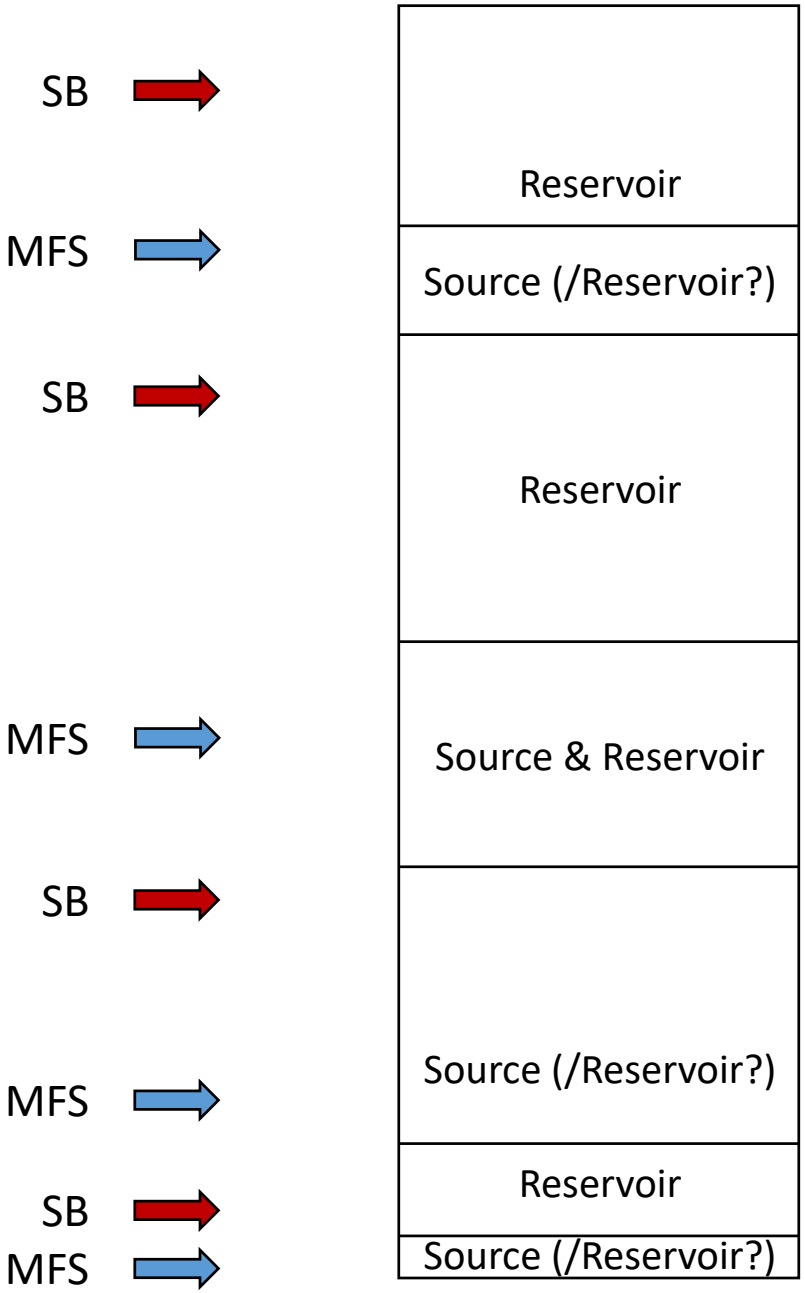
Slattery and others, 2015

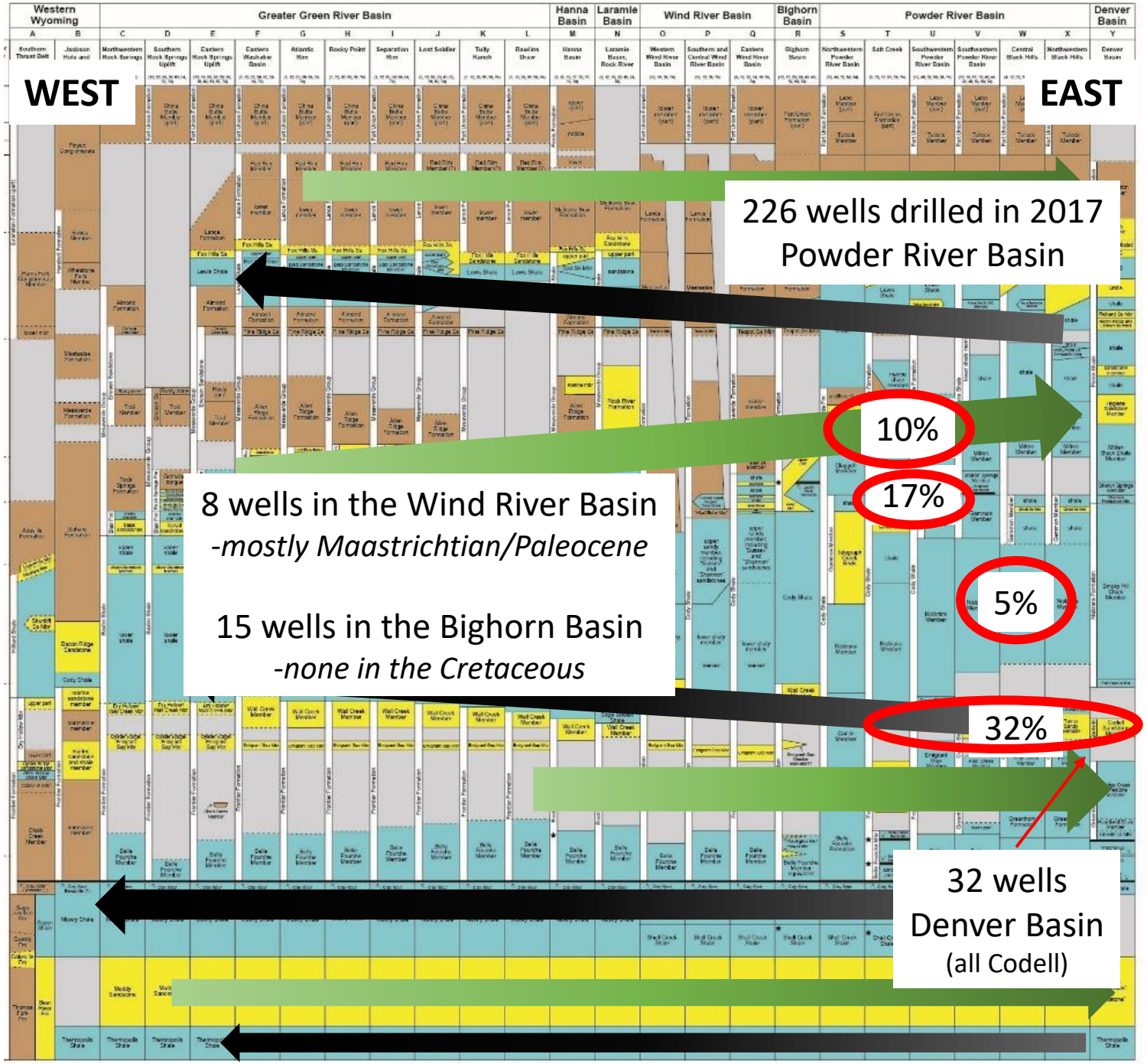

Fold-Thrust Belt
Foreland Basin System
Wedge-Top
Foredeep
Forebulge
Back-B
WEST
EAST
sequence boundary
maximum flooding surface
sequence boundary
maximum flooding surface
sequence boundary
maximum flooding surface
sequence boundary
maximum flooding surface
Transgression
Regression

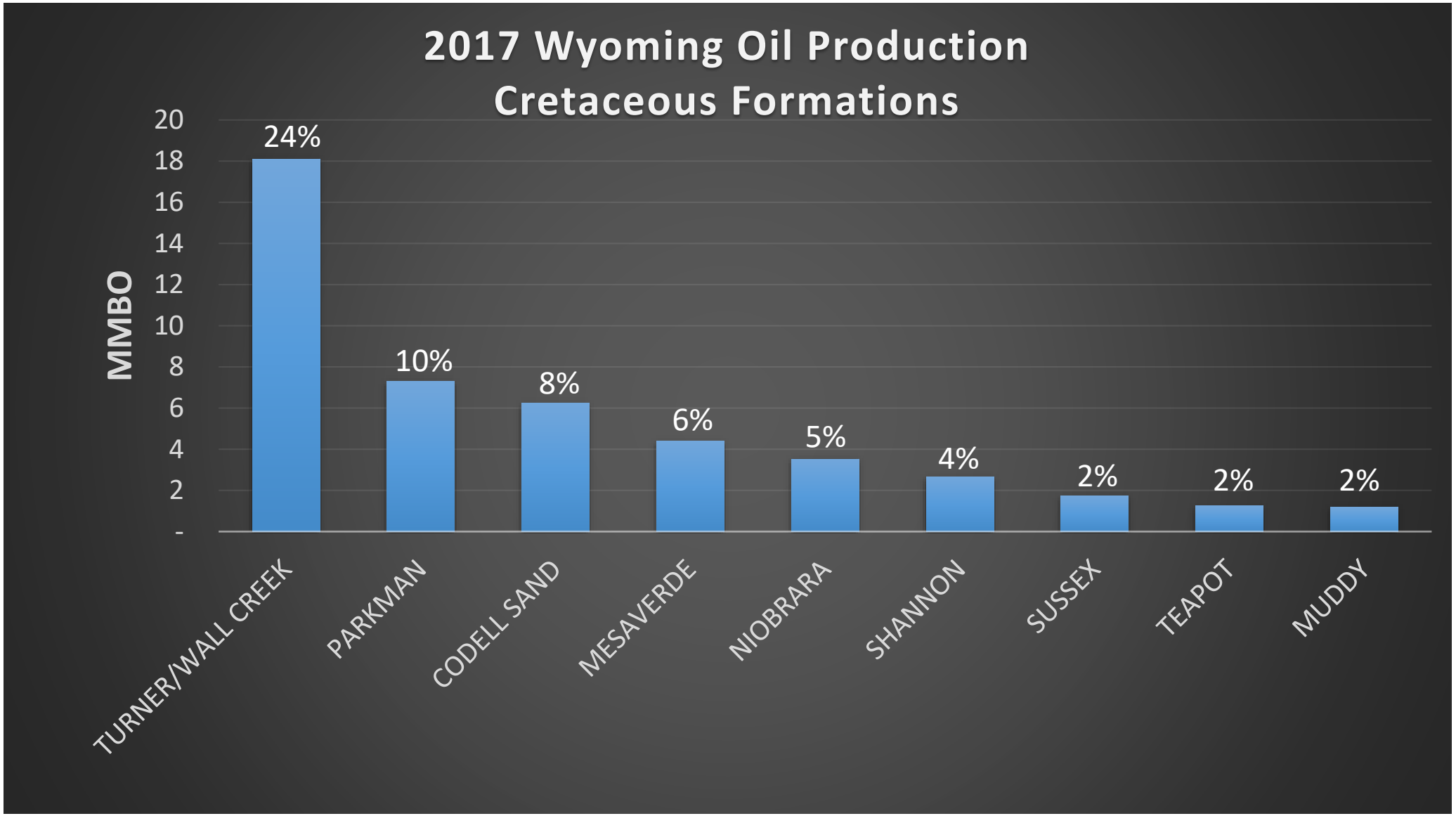

Major Depositional Events
SB
MFS
SB
MFS
SB
MFS
SB
MFS
Late Maastrichtian–Danian Regression
Laramide Unconformity
Late Campanian–Early Maastrichtian Transgression
Moxa Unconformity
Middle–Late Campanian Regression
Late Turonian–Santonian Transgression
Late Turonian Regression
Intra-Frontier Hiatus
Cenomanian Transgression
Late Albian Regression
Albian Transgression
~15 MY
~10 MY
~8 MY
WEST
EAST
Western Wyoming
Greater Green River Basin
Hanna Basin
Laramie Basin
Wind River Basin
Bighorn Basin
Powder River Basin
Denver Basin

SB	Reservoir
MFS	Source (/Reservoir?)
SB	Reservoir
MFS	Source & Reservoir
SB	Source (/Reservoir?)
MFS	Reservoir
SB	Source (/Reservoir?)
MFS	




SB
MFS
SB
MFS
SB
MFS
SB
MFS
Reservoir
Source (/Reservoir?)
Reservoir
Source & Reservoir
Source (/Reservoir?)
Reservoir
Source (/Reservoir?)


Western Wyoming
Greater Green River Basin
Hanna Basin
Laramie Basin
Wind River Basin
Bighorn Basin
Powder River Basin
Denver Basin
WEST
EAST
226 wells drilled in 2017
Powder River Basin
10%
17%
5%
32%
8 wells in the Wind River Basin
-mostly Maastrichtian/Paleocene
15 wells in the Bighorn Basin
-none in the Cretaceous
32 wells
Denver Basin
(all Codell)

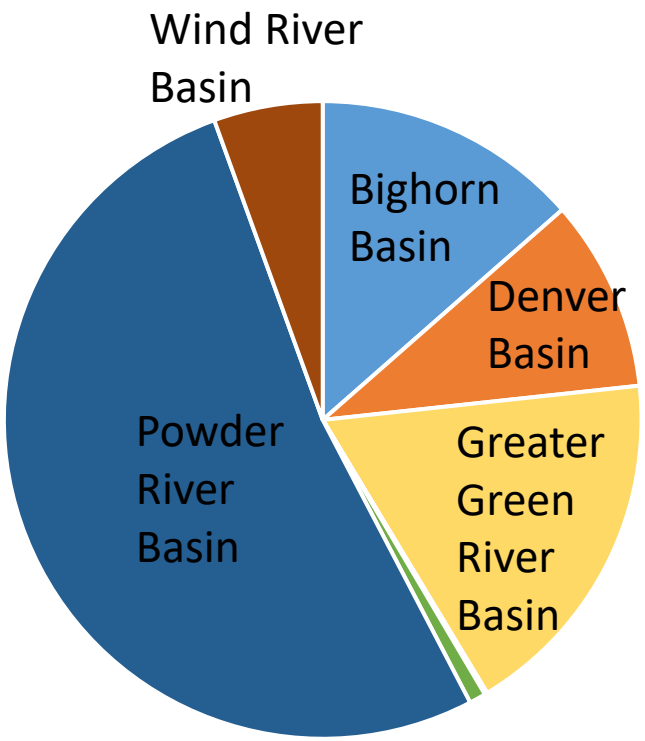

2017 Wyoming Oil Production
Cretaceous Formations
MMBO
20
18
16
14
12
10
8
6
4
2
-
24%
10%
8%
6%
5%
4%
2%
2%
2%
TURNER/WALL CREEK
PARKMAN
CODELL SAND
MESAVERDE
NIOBRARA
SHANNON
SUSSEX
TEAPOT
MUDDY

Conclusions

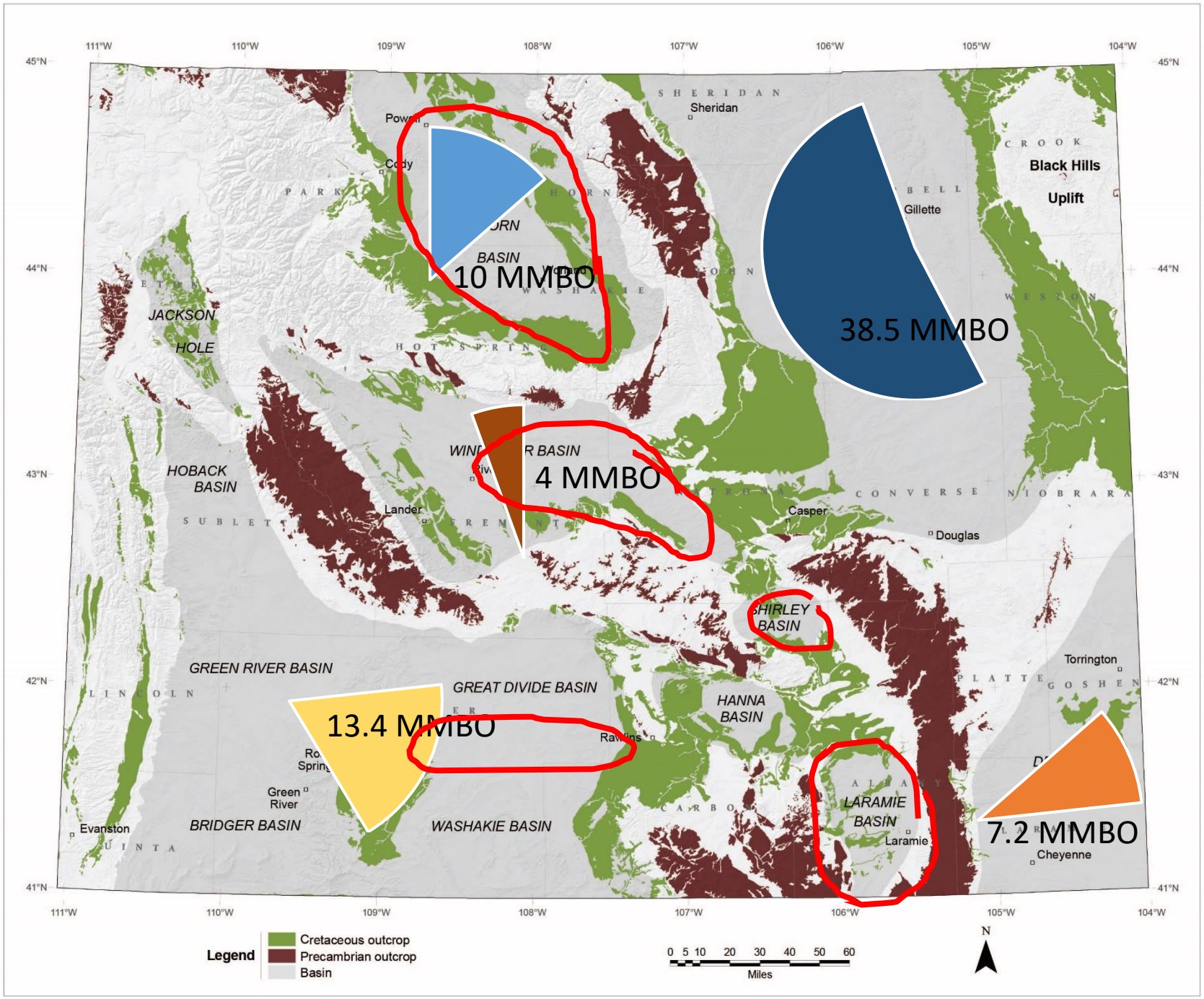
- During the Late Cretaceous in Wyoming, 2nd-order sea level fluctuations occurred on 8 to 15 MY intervals.
- Organic-rich source rocks were deposited during all high stands of the WIS.
  - The Niobrara Formation is part of the Coniacian–Santonian high stand and is both a source and reservoir, with 5% of Wyoming's 2017 oil production.
- Transgression during the late Turonian resulted in a retrogradational reservoir package of the Wall Creek/Turner/Codell, with 32% of Wyoming oil production in 2017.
- The middle Campanian narrowing of the WIS left the progradational/ aggradational Mesaverde (Parkman) reservoir, with 10% of Wyoming's 2017 oil production.

Conclusions, cont.

- The eight Upper Cretaceous formations with the most production were responsible for approximately 60% of oil recovered in Wyoming in 2017, or 45 MMBO.
- Exploration of unconventional plays in other basins may benefit from consideration of the regional chrono-stratigraphic setting.



2017 WY Oil Production
73.9 MMBO



Many Thanks

- Biostratigraphy: W. Cobban, J. Gill, and E. Merewether
- Lithostratigraphy: W. Cobban, J. Gill, E. Merewether, M. Kirschbaum, H. Roehler
- Radiometric Ages: J. Ogg, L. Hinnov, M. Schmitz, and B. Sageman et al.
- USGS Mesozoic Invertebrate Database
- Chart reviews by M. Kirschbaum, R. Raynolds, R. Scott, D. Sawyer, J. Fox, A. Wroblewski, and D. Boyd
- And many, many others…

Download chart at:
http://www.wsgs.wyo.gov/products/wsgs-2017-ofr-03.pdf