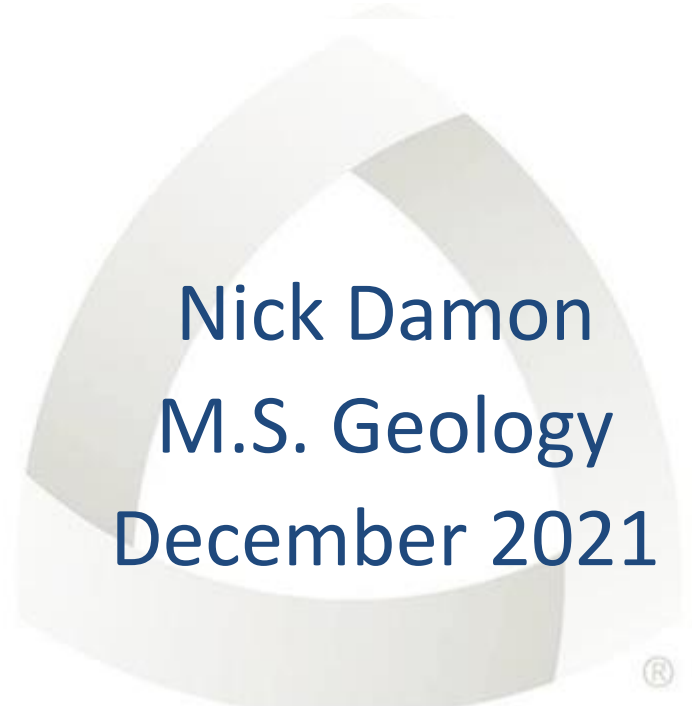


Reservoir Characterization of the Codell Sandstone at Redtail Field, Weld County, Colorado



Nick Damon
M.S. Geology
December 2021

ndamon@mymail.mines.edu



- Project Overview
- Geologic History
- Codell Sandstone - Redtail Field
- Razor 25-2514H Core
- Conclusions

Project Overview



MUDTOC Research 2010 - 2020



Codell SS

- Adam Anderson
- John Stamer
- Tofer Lewis
- Steve Crouch
- ❖ Nick Damon

Niobrara Regional Studies

- Phylcia Saner
- David Thul
- Lauren Stout
- David Underwood
- Evan Allred
- Julia Wood
- John Stamer
- Michael Harty (Juana Lopez)
- ❖ Cankut Kondacki (PhD)

NW Colorado

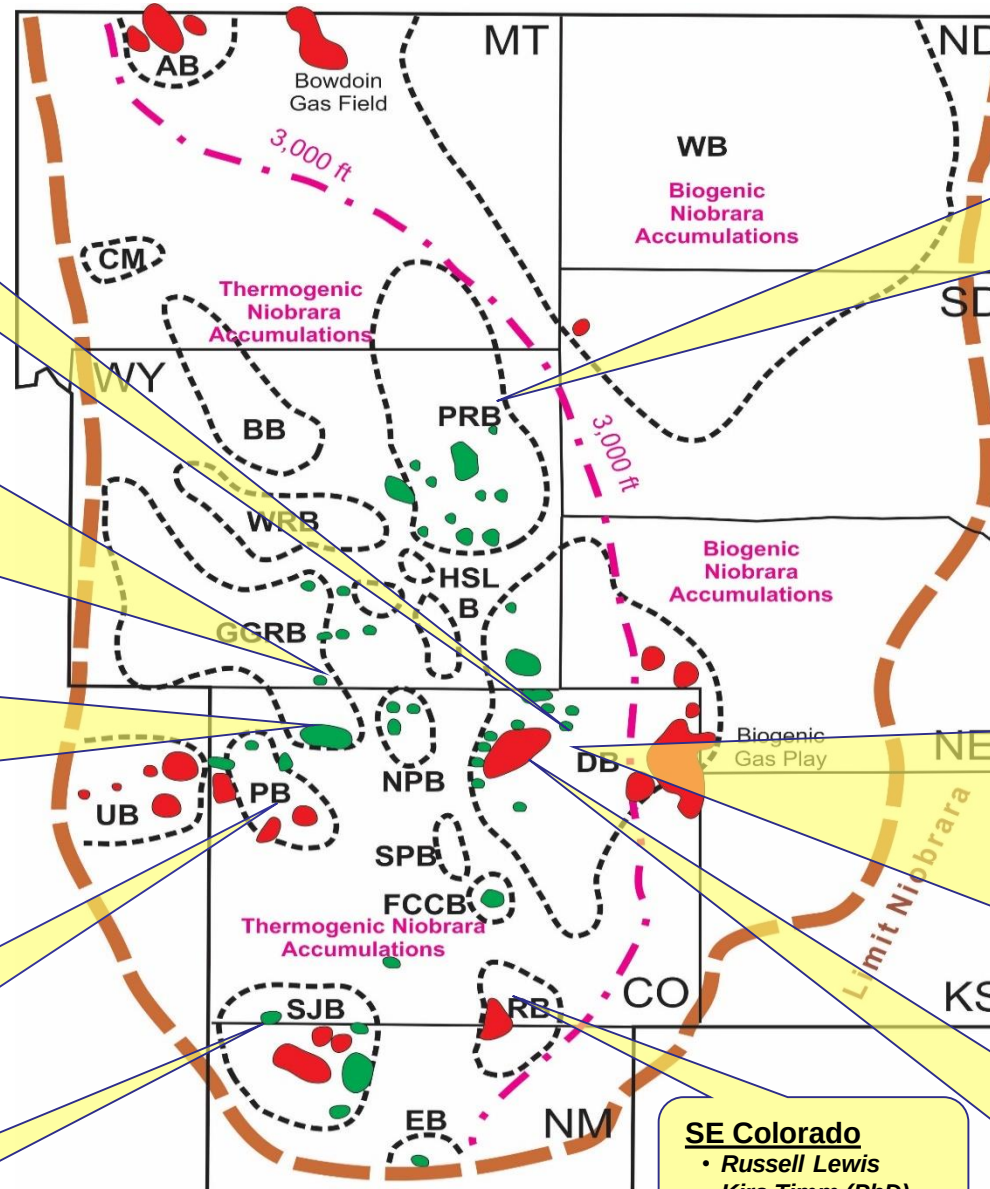
- Jon Charzynski
- Katarzyna Kuzniak
- Vivian Lin
- Kelly Bruchez
- Ben Dellenbach
- Michael Harty III
- Shawn Lopez

Piceance Basin

- Kasia Kuzniak
- Martin Krueger
- John Harper
- Marcus Hinricher

San Juan Basin

- Tom Arthur
- Walter Nelson
- Scott Kennedy



Research 2010 – 2020

• Completed Theses

❖ In Progress

Powder River Basin

- James Taylor
- Armagan Kaykun
- Andrew Heger
- Cankut Kondacki
- Courtney Bone
- ❖ Brain Hankins
- ❖ Corey Milar
- ❖ Rebekah Parks
- ❖ Lisa Reeves

Denver Basin

- Mike Collins
- Melanie Peterson
- Teresa Malesardi (Silo)
- Alejandra Maldonado
- Elena Finley (Silo)
- Denton O'Neal
- Nico Kernan (Wyo)
- Kazumi Nakamura (PhD)
- Devin Murray
- Lindsay Hefton
- Hannah Durkee (Greenhorn)
- Isabel Gary
- David Thul
- Lauren Stout
- David Underwood
- Caleb Garbus
- Lauren Bane
- ❖ Scott Manwaring
- ❖ Adam Simonsen
- ❖ Chris Beliveau
- ❖ Chris Matson
- ❖ Adrienne Bryant

Denver Basin: Wattenberg

- Craig Kaiser
- Nick Matthies
- Rana ElGhonimy
- Jennie Rietman
- Elvan Aydin
- Daniel Brugioni
- ❖ Patrick Sullivan

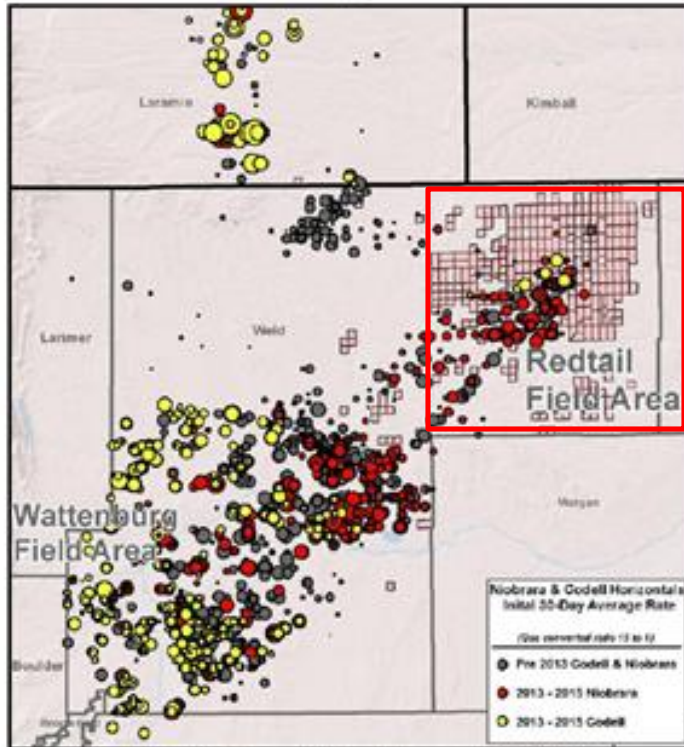
SE Colorado

- Russell Lewis
- Kira Timm (PhD)
- Nick Matthies

Redtail Field – By the Numbers



Economic Sweet Spot in Oil Window (Weld County, Colorado)



OBJECTIVE

Niobrara "A" Shale
Niobrara "B" Shale
Niobrara "C" Shale
Codell/Fort Hays

DEVELOPMENT PLAN

- Mix of 1,280, 960 and 640-acre spacing units
- 6,318 potential gross drilling locations as of December 31, 2015.
- Targeting 465 MBOE EUR for 960-acre spaced wells in 2016.
- Plan to defer completions for balance of 2016 and project inventory of 95 drilled uncompleted wells by 12/31/2016.

ACREAGE

Whiting has assembled 154,256 gross (126,363 net) acres in our Redtail prospect in the northeastern portion of the DJ Basin.
100% held by production, expires beyond 2018, or can be extended for under \$4 million.

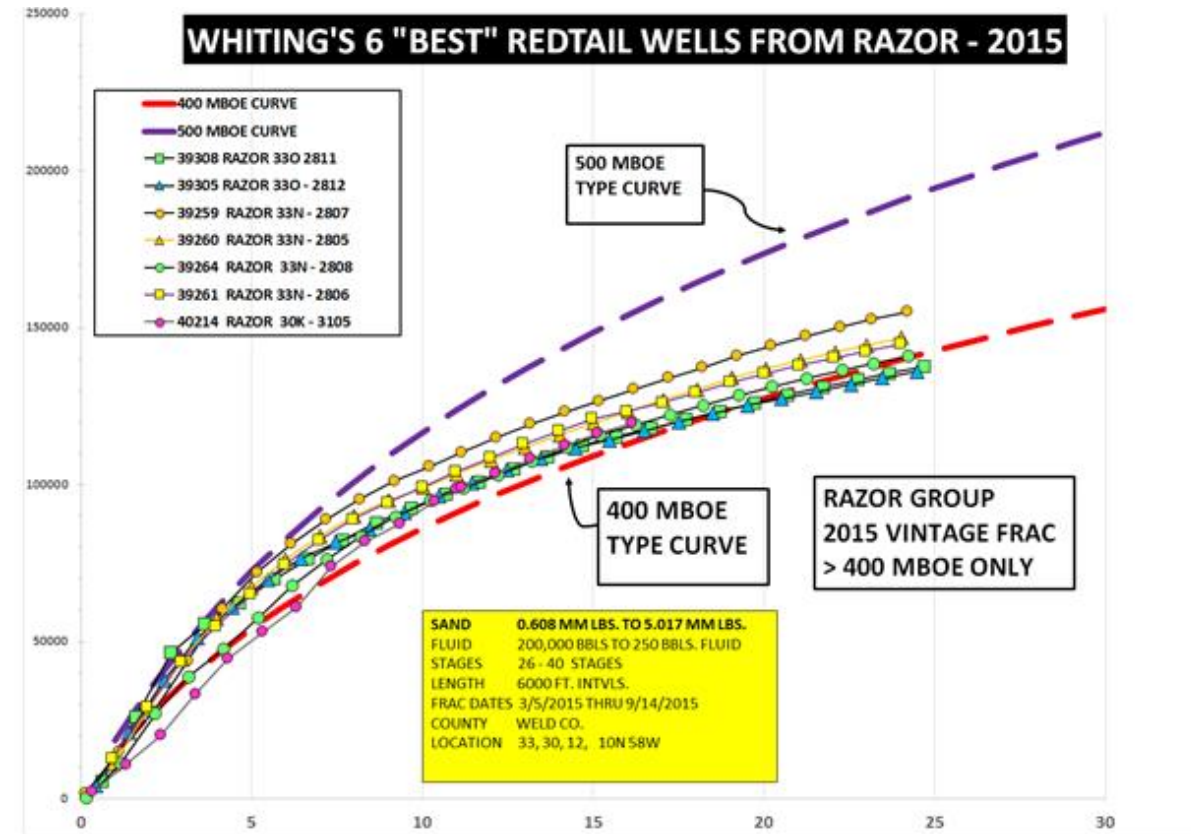
- Average WI of 82%
- Average Royalty of 66%

COMPLETED WELL COST

Horizontal: \$4.0 MM

OPERATIONAL HIGHLIGHTS

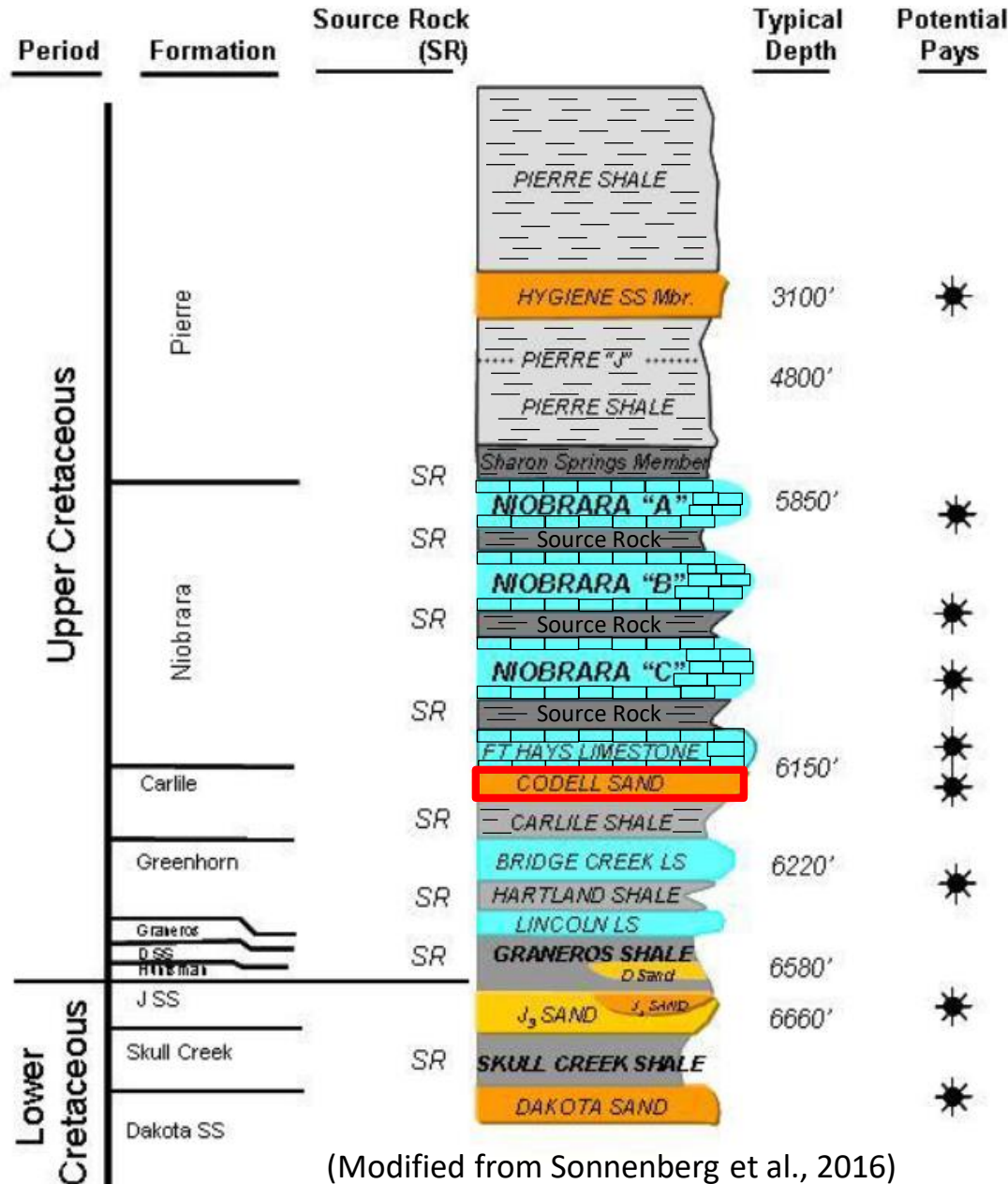
Redtail production averaged 14,345 BOE/d in Q4 2015.



(Modified from Whiting Petroleum, 2015)

(Whiting Petroleum, 2015)

Denver Basin Stratigraphic Column



Redtail/East Pony Data

Depth: 5300-6200 ft (vertical)

Thickness:

- Niobrara A chalk – 20-40 ft
- Niobrara A marl – 20-70 ft
- Niobrara B chalk – 60-80 ft
- Niobrara B marl – 30-70 ft
- Niobrara C chalk – 40-70 ft
- Niobrara C marl – 20-55 ft
- D chalk – 15-35 ft
- Niobrara Fort Hays – 20-25 ft
- Codell – 5-20 ft

Porosity: Niobrara 10-13%; Codell 14-18%

Permeability: < 0.1 md

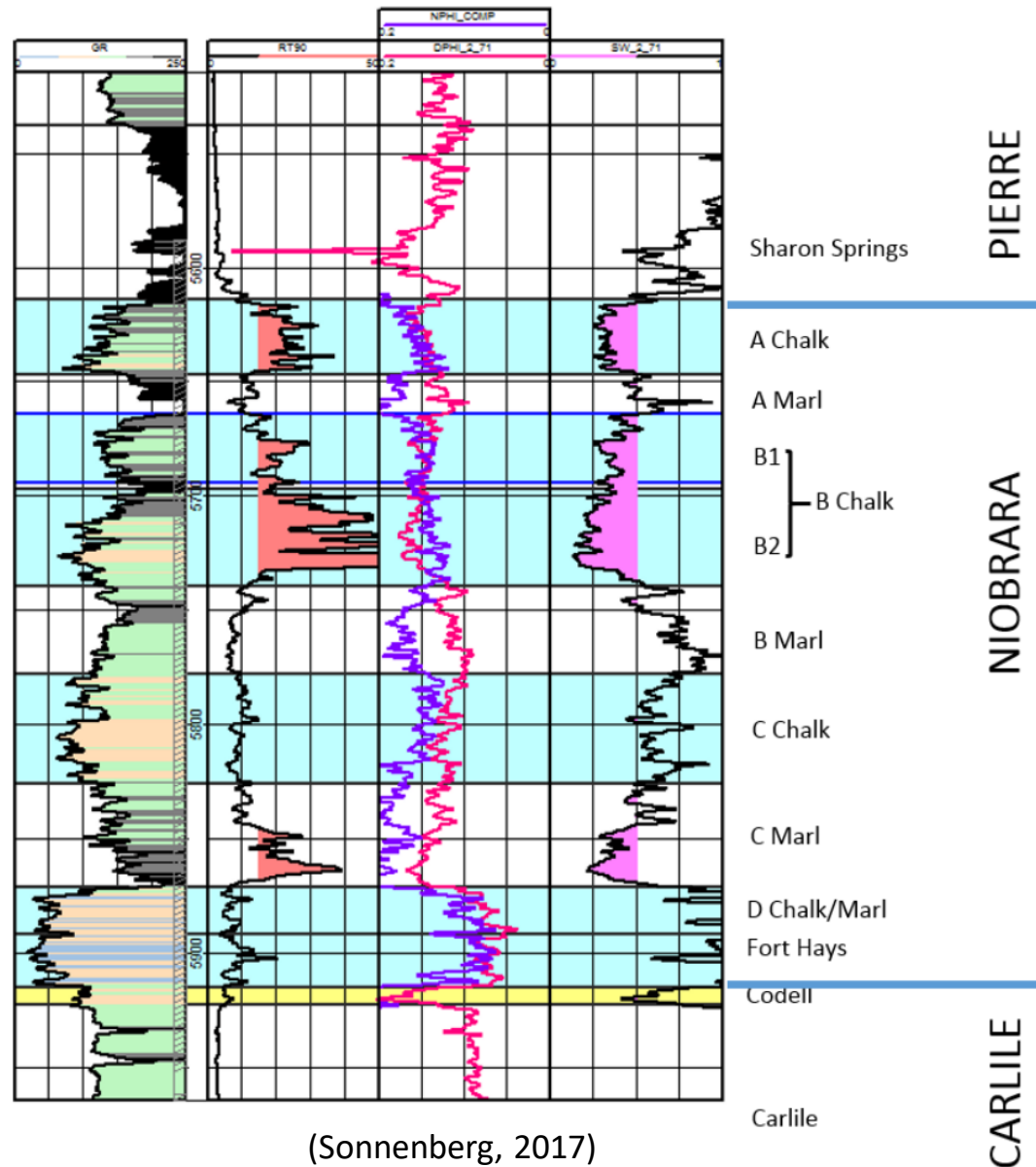
(Modified from Sonnenberg, 2017)

(Modified from Sonnenberg et al., 2016)

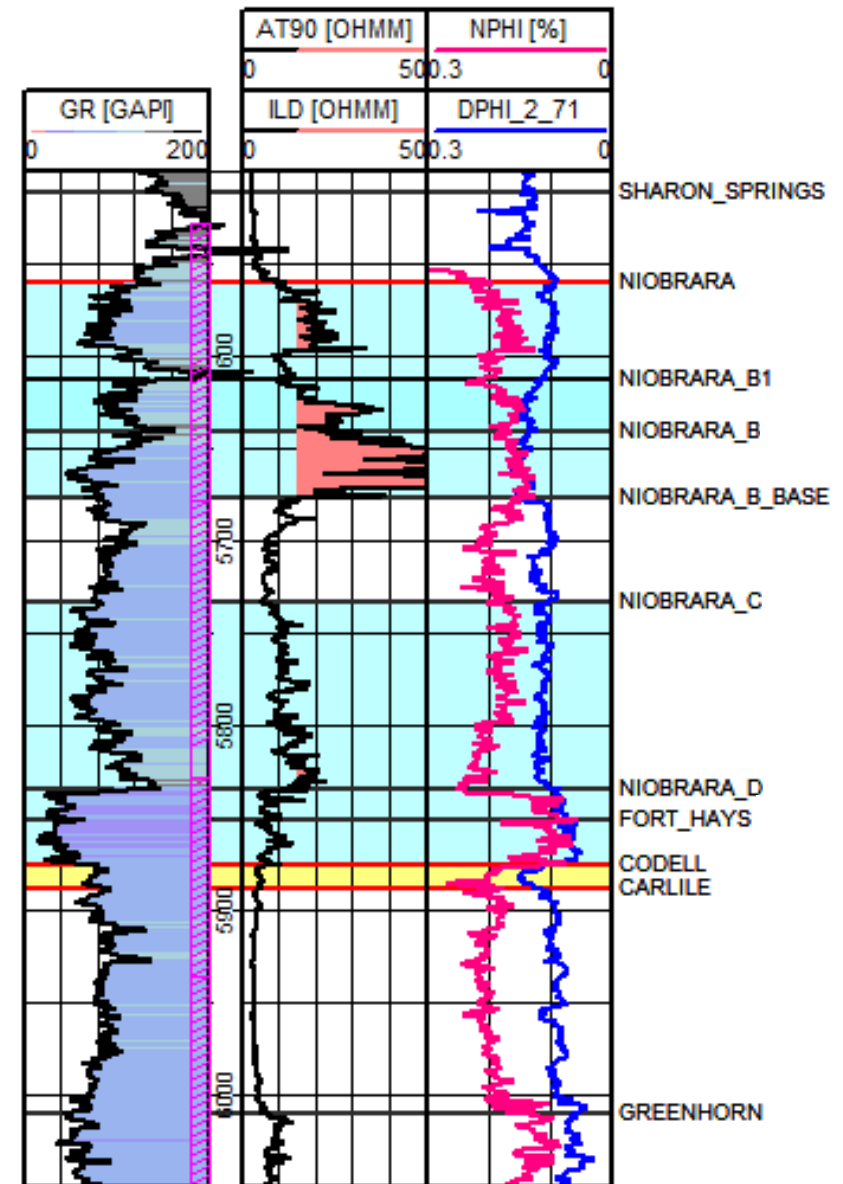
Type Wells – DJ and Redtail



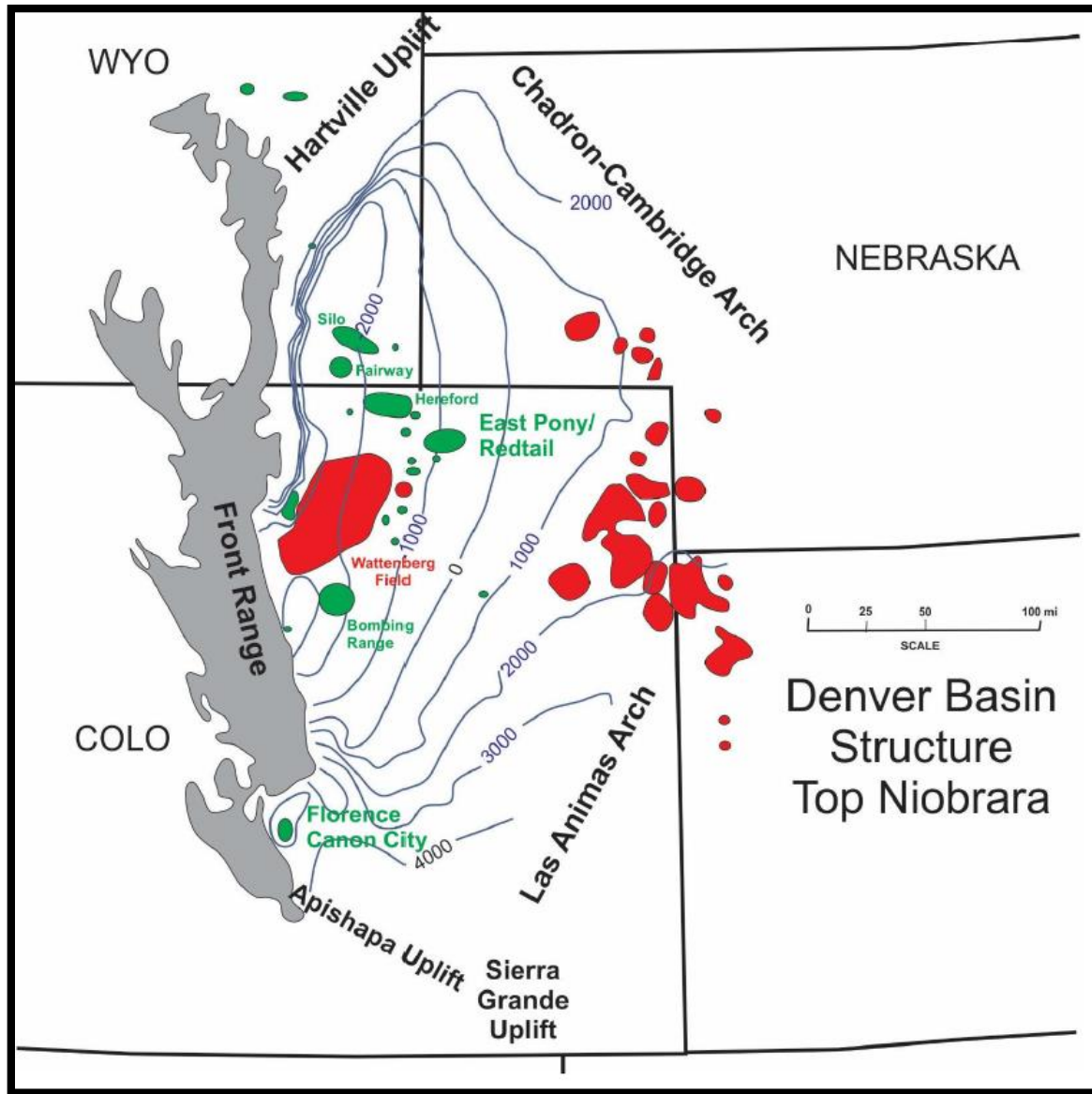
DJ Type Well: Timbro PC LD16-17



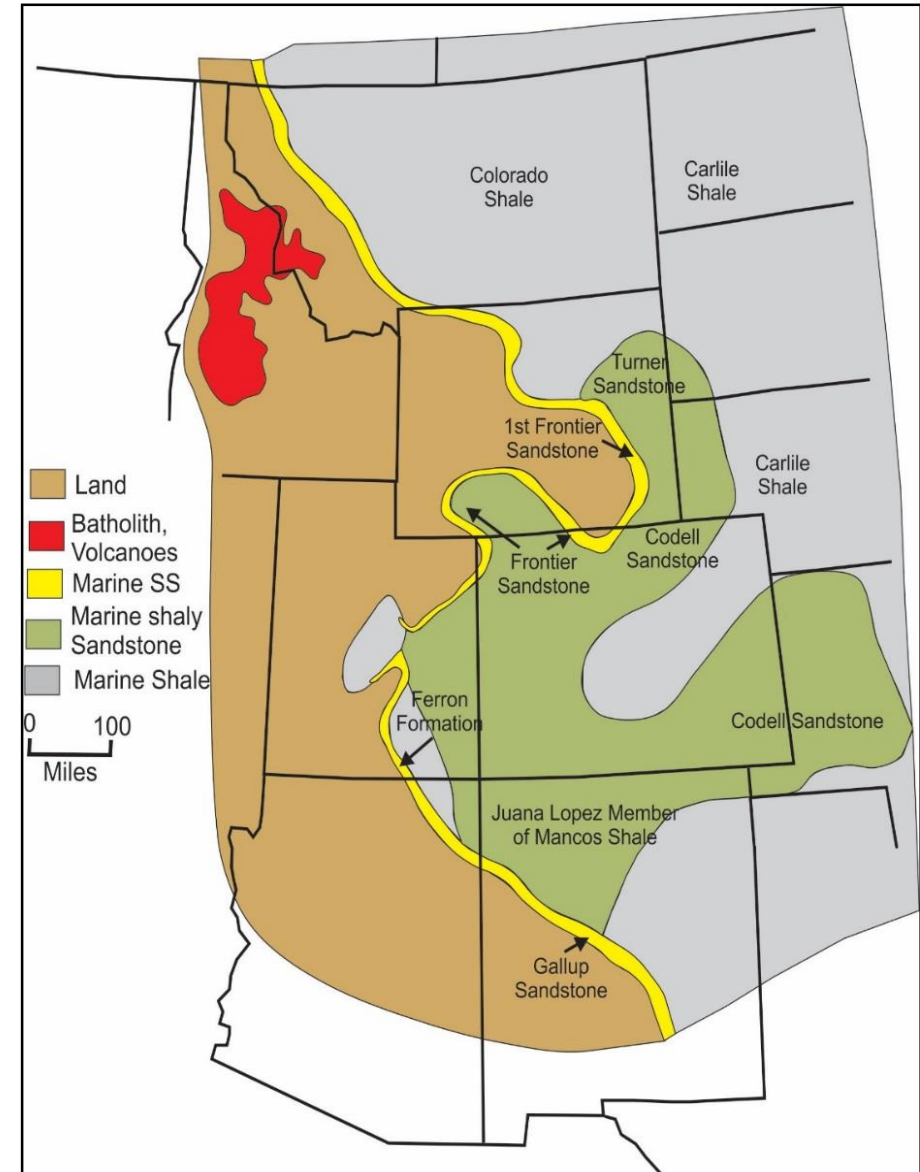
Redtail Type Well: Razor 25-2514H



East Pony/Redtail Field Locality



(Sonnenberg, 2017)



(Modified from Mallory, 1972)

Codell Extent and Environment

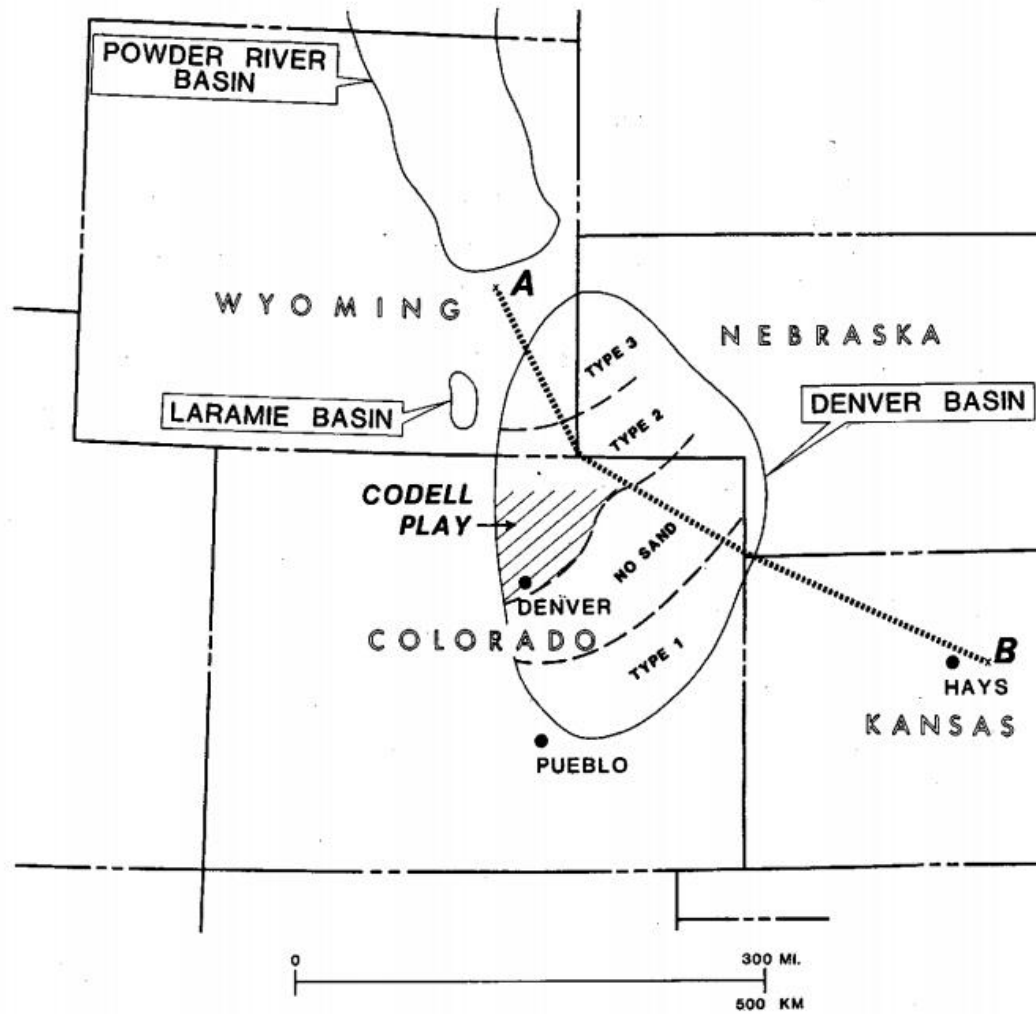
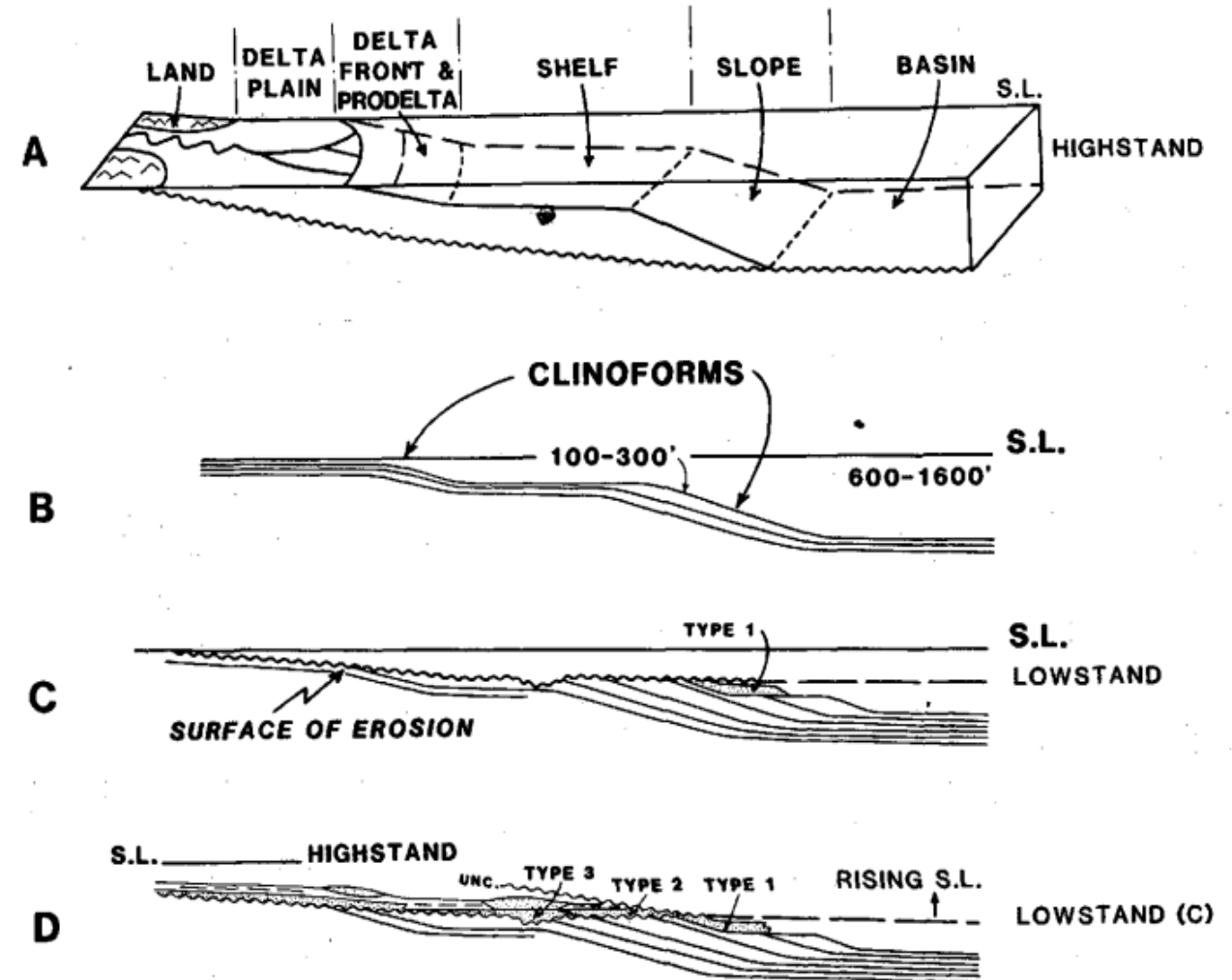


Figure 1 Distribution of Codell Sandstone

(Modified from Weimer and Sonnenberg, 1983)



(Modified from Weimer and Sonnenberg, 1983)

Geologic History

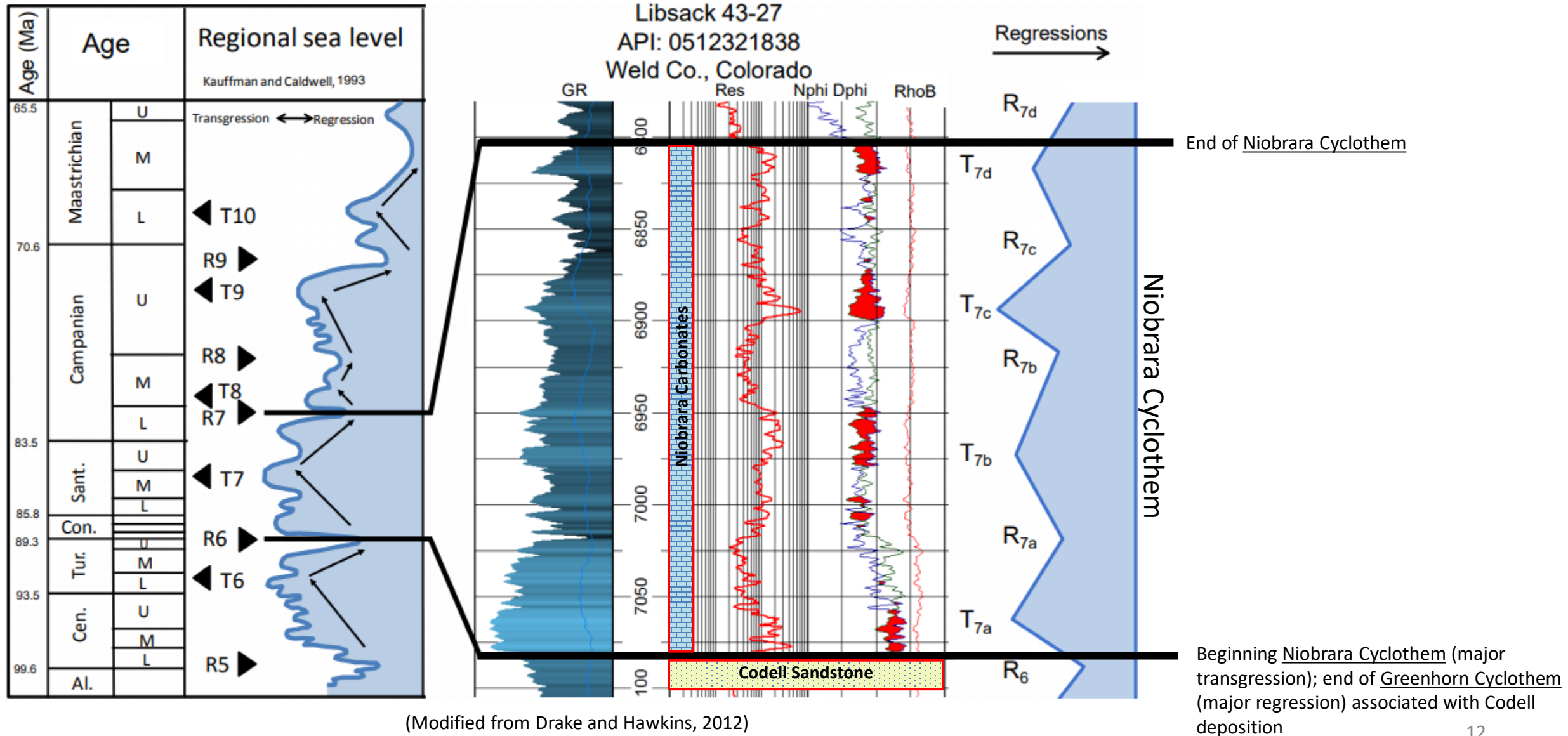


Geologic History – Greenhorn Cyclothem

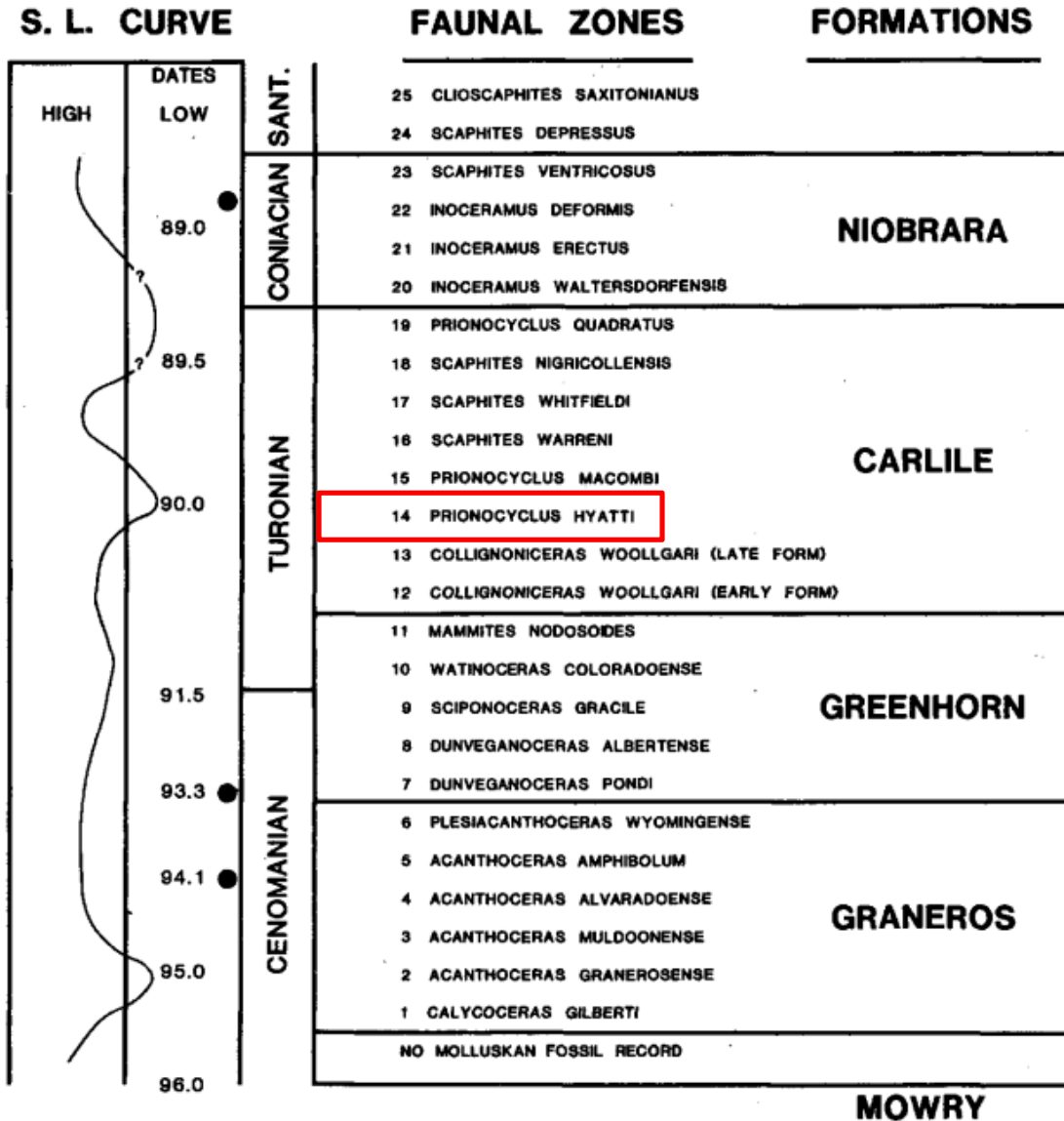


(Modified from Blakey, 2016)

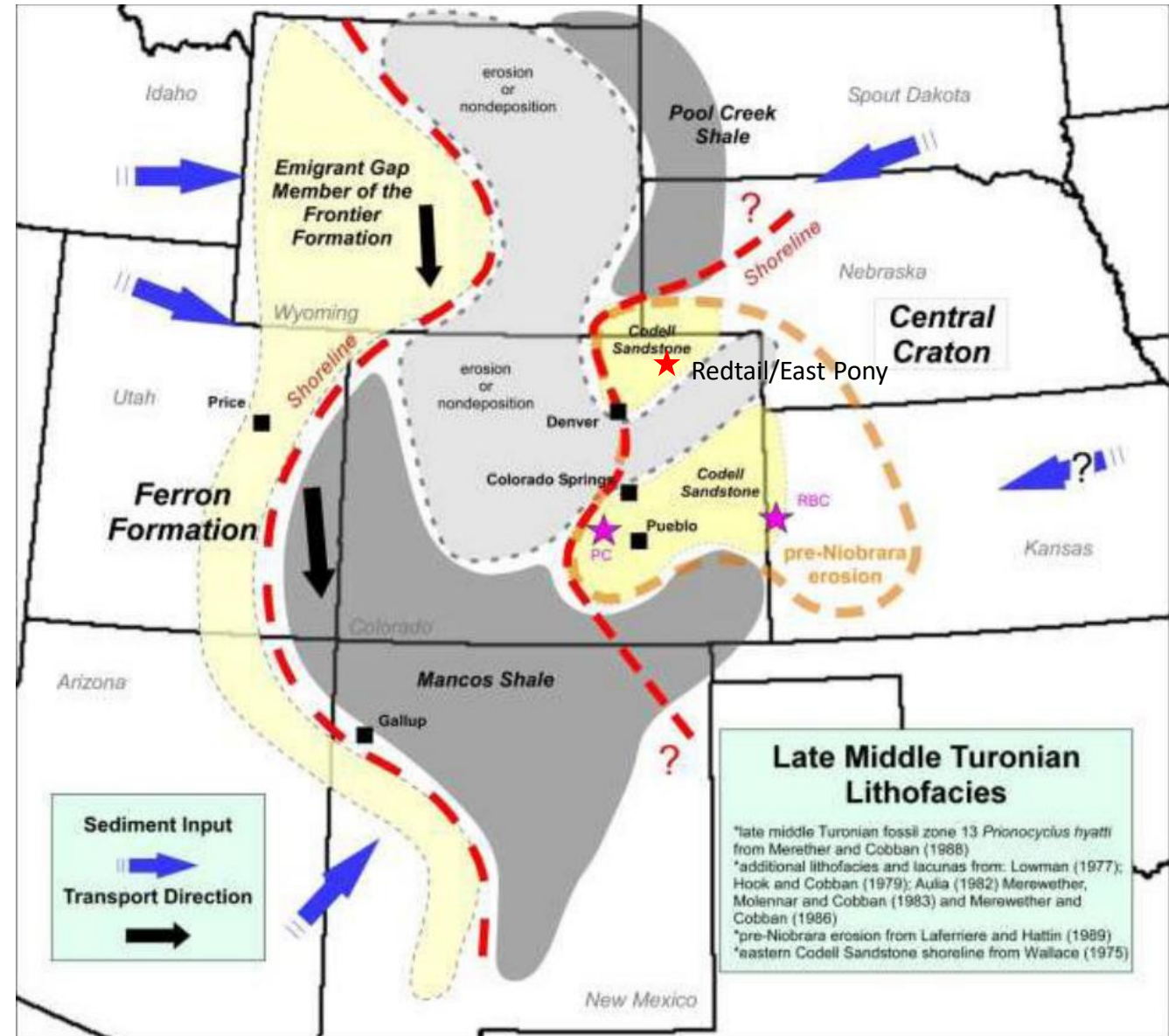
Geologic History – Sea Level Fluctuation



Geologic History – Lithofacies and Faunal Zones

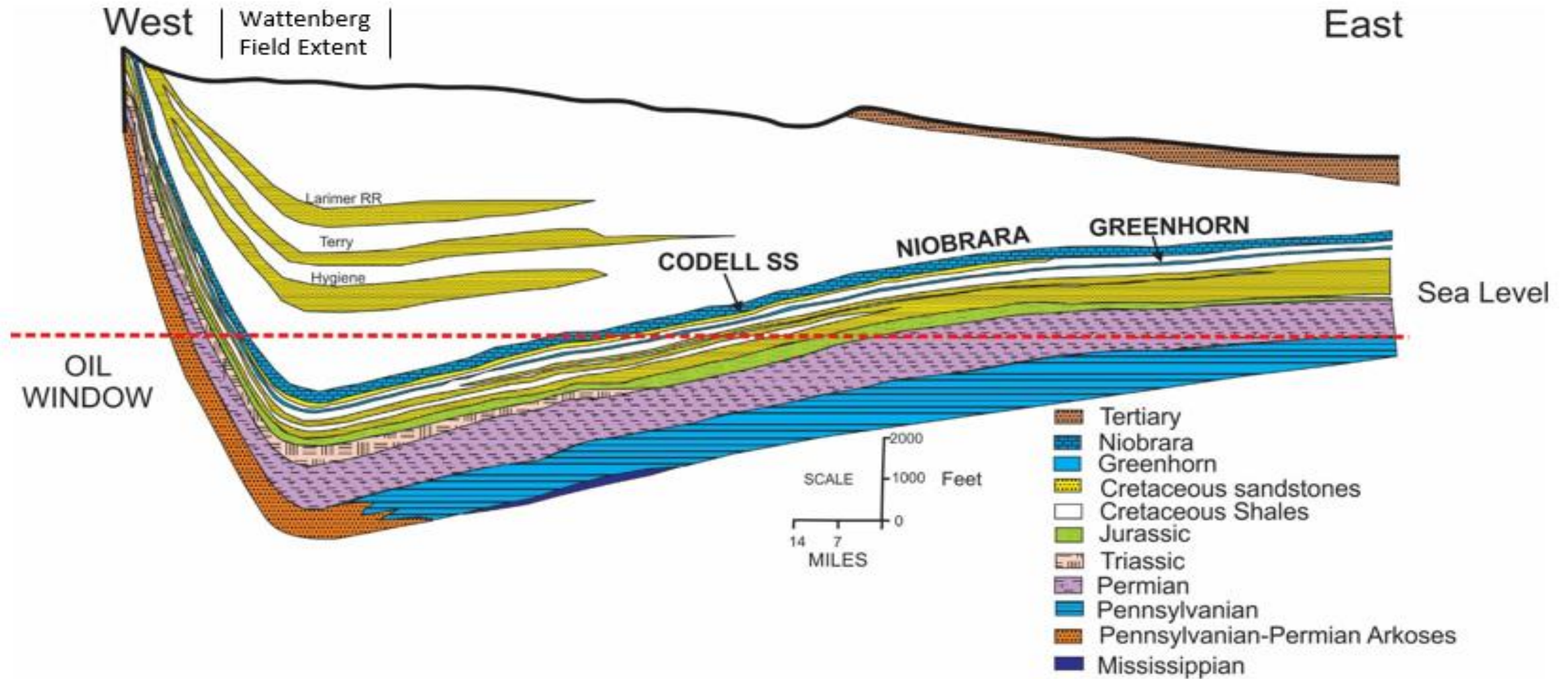


(Modified from Weimer and Sonnenberg, 1983)



(Modified from Lewis, 2013)

Petroleum System Cross Section



(Modified from Sonnenberg, 2015)

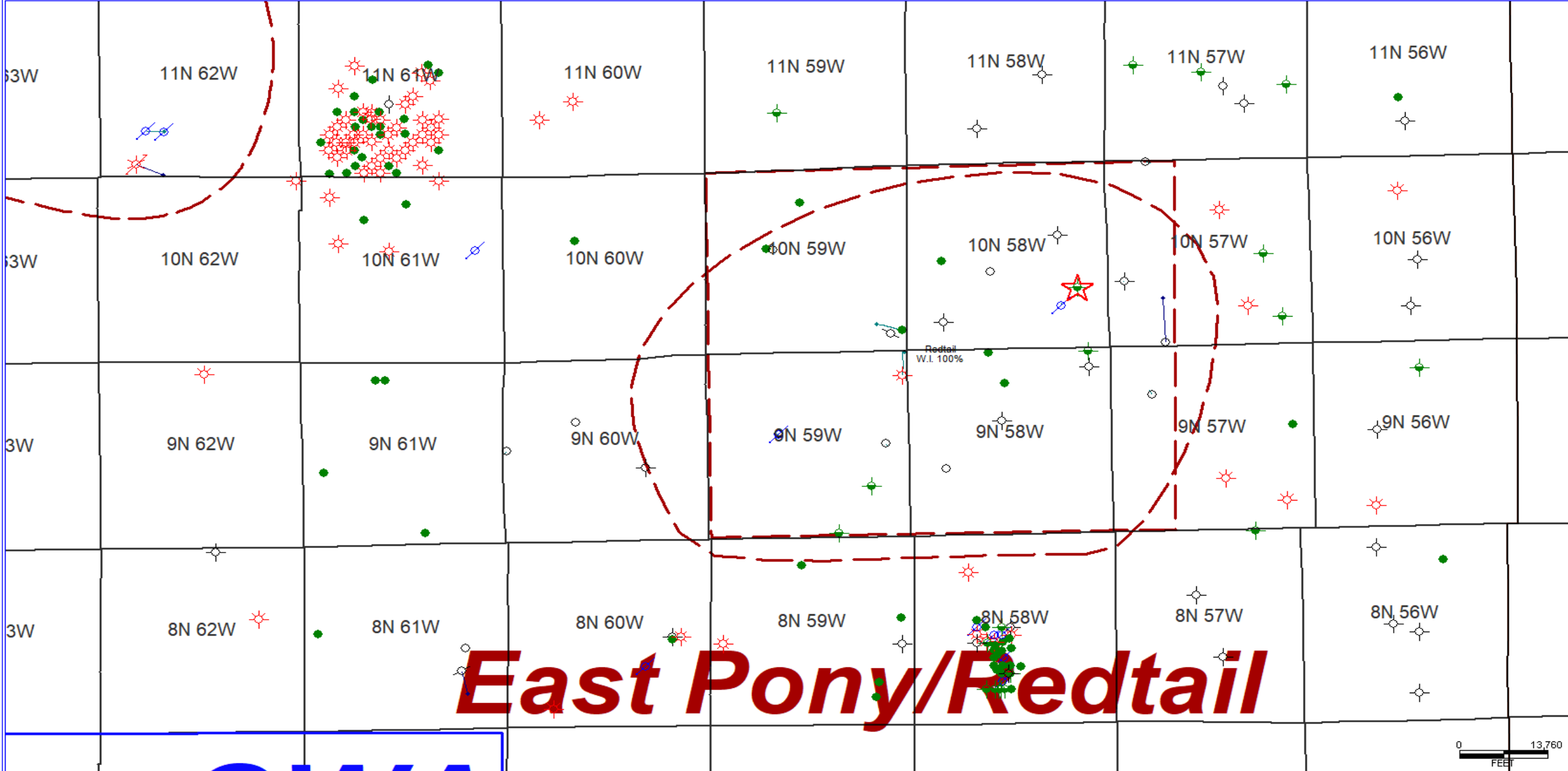
Codell Sandstone – Redtail Field



Mapping Area – Redtail Field Area

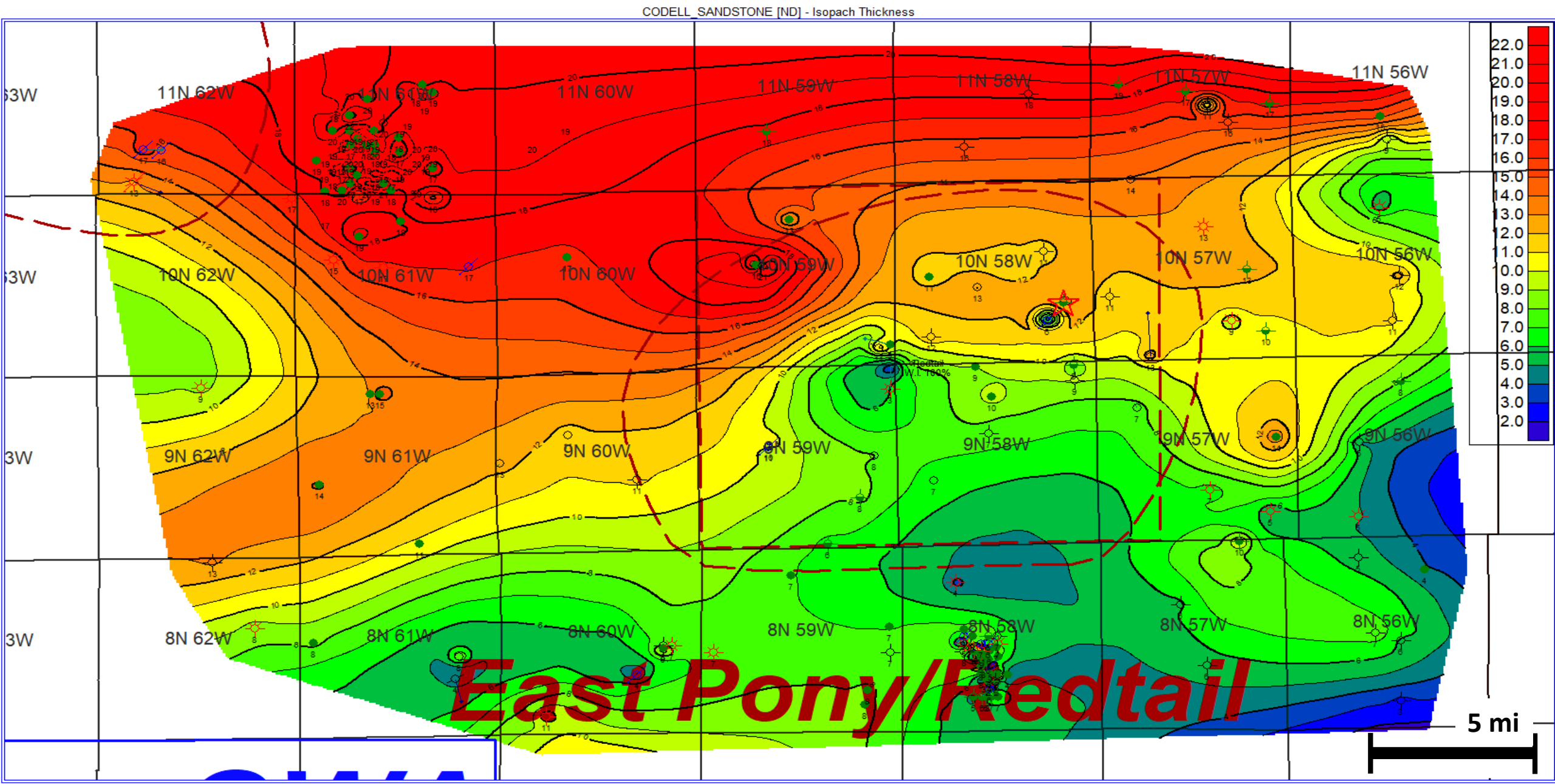


REDTAIL_NICK DAMON - REDTAIL_NICK DAMON

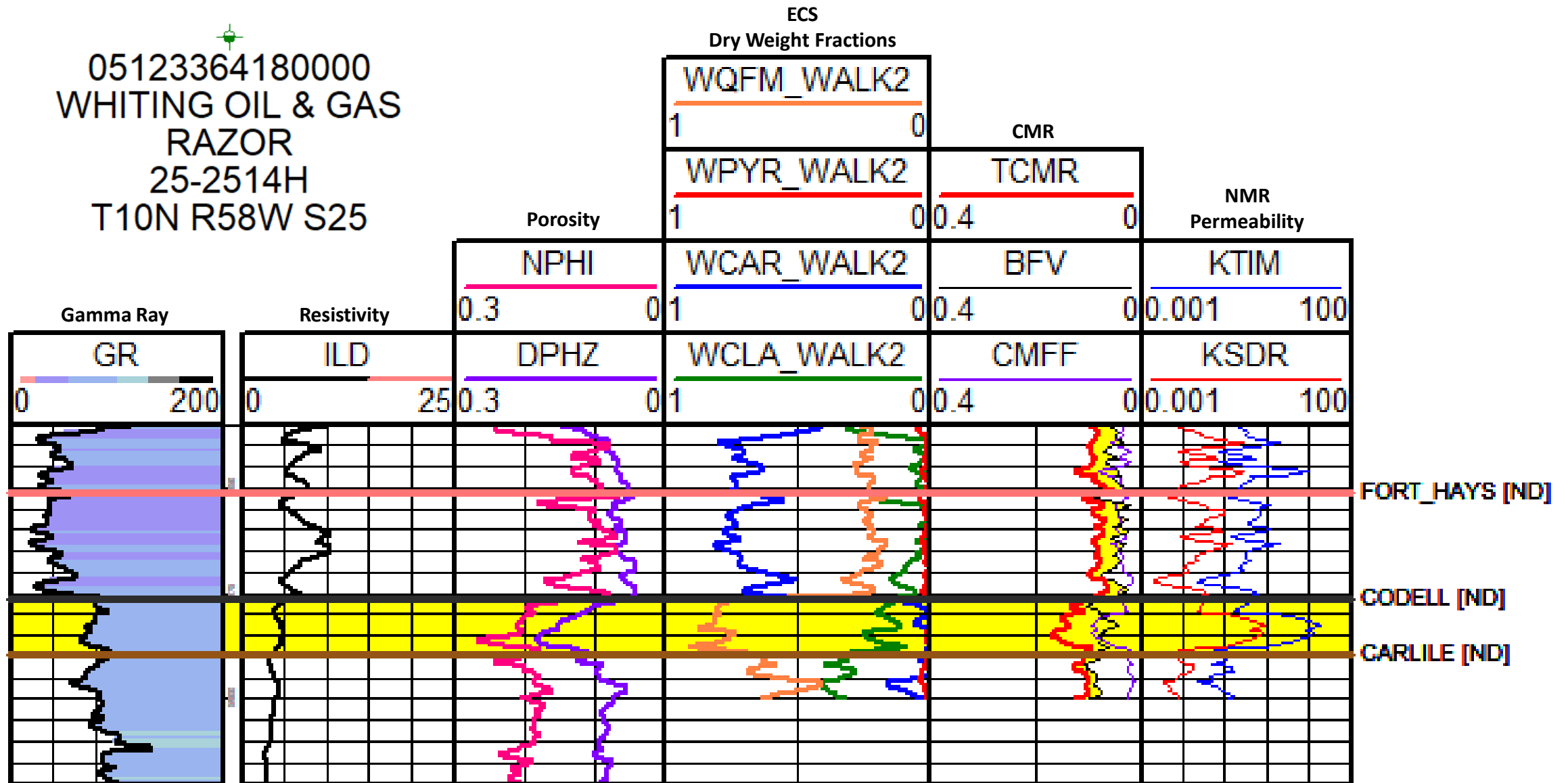


This map displays the East Pony/Redtail area, characterized by depth contours and station data. The map is divided into a grid of latitude and longitude cells, ranging from 11N 62W to 8N 56W. Depth contours are shown in various colors, with a legend on the right indicating depths from -700 to -2100. Station data points are plotted across the map, with some points labeled with values such as 7.233, 7.224, 7.143, 7.127, 7.115, 7.092, 7.081, 7.071, 7.061, 7.051, 7.041, 7.031, 7.021, 7.011, 7.001, 6.991, 6.981, 6.971, 6.961, 6.951, 6.941, 6.931, 6.921, 6.911, 6.901, 6.891, 6.881, 6.871, 6.861, 6.851, 6.841, 6.831, 6.821, 6.811, 6.801, 6.791, 6.781, 6.771, 6.761, 6.751, 6.741, 6.731, 6.721, 6.711, 6.701, 6.691, 6.681, 6.671, 6.661, 6.651, 6.641, 6.631, 6.621, 6.611, 6.601, 6.591, 6.581, 6.571, 6.561, 6.551, 6.541, 6.531, 6.521, 6.511, 6.501, 6.491, 6.481, 6.471, 6.461, 6.451, 6.441, 6.431, 6.421, 6.411, 6.401, 6.391, 6.381, 6.371, 6.361, 6.351, 6.341, 6.331, 6.321, 6.311, 6.301, 6.291, 6.281, 6.271, 6.261, 6.251, 6.241, 6.231, 6.221, 6.211, 6.201, 6.191, 6.181, 6.171, 6.161, 6.151, 6.141, 6.131, 6.121, 6.111, 6.101, 6.091, 6.081, 6.071, 6.061, 6.051, 6.041, 6.031, 6.021, 6.011, 6.001, 5.991, 5.981, 5.971, 5.961, 5.951, 5.941, 5.931, 5.921, 5.911, 5.901, 5.891, 5.881, 5.871, 5.861, 5.851, 5.841, 5.831, 5.821, 5.811, 5.801, 5.791, 5.781, 5.771, 5.761, 5.751, 5.741, 5.731, 5.721, 5.711, 5.701, 5.691, 5.681, 5.671, 5.661, 5.651, 5.641, 5.631, 5.621, 5.611, 5.601, 5.591, 5.581, 5.571, 5.561, 5.551, 5.541, 5.531, 5.521, 5.511, 5.501, 5.491, 5.481, 5.471, 5.461, 5.451, 5.441, 5.431, 5.421, 5.411, 5.401, 5.391, 5.381, 5.371, 5.361, 5.351, 5.341, 5.331, 5.321, 5.311, 5.301, 5.291, 5.281, 5.271, 5.261, 5.251, 5.241, 5.231, 5.221, 5.211, 5.201, 5.191, 5.181, 5.171, 5.161, 5.151, 5.141, 5.131, 5.121, 5.111, 5.101, 5.091, 5.081, 5.071, 5.061, 5.051, 5.041, 5.031, 5.021, 5.011, 5.001, 4.991, 4.981, 4.971, 4.961, 4.951, 4.941, 4.931, 4.921, 4.911, 4.901, 4.891, 4.881, 4.871, 4.861, 4.851, 4.841, 4.831, 4.821, 4.811, 4.801, 4.791, 4.781, 4.771, 4.761, 4.751, 4.741, 4.731, 4.721, 4.711, 4.701, 4.691, 4.681, 4.671, 4.661, 4.651, 4.641, 4.631, 4.621, 4.611, 4.601, 4.591, 4.581, 4.571, 4.561, 4.551, 4.541, 4.531, 4.521, 4.511, 4.501, 4.491, 4.481, 4.471, 4.461, 4.451, 4.441, 4.431, 4.421, 4.411, 4.401, 4.391, 4.381, 4.371, 4.361, 4.351, 4.341, 4.331, 4.321, 4.311, 4.301, 4.291, 4.281, 4.271, 4.261, 4.251, 4.241, 4.231, 4.221, 4.211, 4.201, 4.191, 4.181, 4.171, 4.161, 4.151, 4.141, 4.131, 4.121, 4.111, 4.101, 4.091, 4.081, 4.071, 4.061, 4.051, 4.041, 4.031, 4.021, 4.011, 4.001, 3.991, 3.981, 3.971, 3.961, 3.951, 3.941, 3.931, 3.921, 3.911, 3.901, 3.891, 3.881, 3.871, 3.861, 3.851, 3.841, 3.831, 3.821, 3.811, 3.801, 3.791, 3.781, 3.771, 3.761, 3.751, 3.741, 3.731, 3.721, 3.711, 3.701, 3.691, 3.681, 3.671, 3.661, 3.651, 3.641, 3.631, 3.621, 3.611, 3.601, 3.591, 3.581, 3.571, 3.561, 3.551, 3.541, 3.531, 3.521, 3.511, 3.501, 3.491, 3.481, 3.471, 3.461, 3.451, 3.441, 3.431, 3.421, 3.411, 3.401, 3.391, 3.381, 3.371, 3.361, 3.351, 3.341, 3.331, 3.321, 3.311, 3.301, 3.291, 3.281, 3.271, 3.261, 3.251, 3.241, 3.231, 3.221, 3.211, 3.201, 3.191, 3.181, 3.171, 3.161, 3.151, 3.141, 3.131, 3.121, 3.111, 3.101, 3.091, 3.081, 3.071, 3.061, 3.051, 3.041, 3.031, 3.021, 3.011, 3.001, 2.991, 2.981, 2.971, 2.961, 2.951, 2.941, 2.931, 2.921, 2.911, 2.901, 2.891, 2.881, 2.871, 2.861, 2.851, 2.841, 2.831, 2.821, 2.811, 2.801, 2.791, 2.781, 2.771, 2.761, 2.751, 2.741, 2.731, 2.721, 2.711, 2.701, 2.691, 2.681, 2.671, 2.661, 2.651, 2.641, 2.631, 2.621, 2.611, 2.601, 2.591, 2.581, 2.571, 2.561, 2.551, 2.541, 2.531, 2.521, 2.511, 2.501, 2.491, 2.481, 2.471, 2.461, 2.451, 2.441, 2.431, 2.421, 2.411, 2.401, 2.391, 2.381, 2.371, 2.361, 2.351, 2.341, 2.331, 2.321, 2.311, 2.301, 2.291, 2.281, 2.271, 2.261, 2.251, 2.241, 2.231, 2.221, 2.211, 2.201, 2.191, 2.181, 2.171, 2.161, 2.151, 2.141, 2.131, 2.121, 2.111, 2.101, 2.091, 2.081, 2.071, 2.061, 2.051, 2.041, 2.031, 2.021, 2.011, 2.001, 1.991, 1.981, 1.971, 1.961, 1.951, 1.941, 1.931, 1.921, 1.911, 1.901, 1.891, 1.881, 1.871, 1.861, 1.851, 1.841, 1.831, 1.821, 1.811, 1.801, 1.791, 1.781, 1.771, 1.761, 1.751, 1.741, 1.731, 1.721, 1.711, 1.701, 1.691, 1.681, 1.671, 1.661, 1.651, 1.641, 1.631, 1.621, 1.611, 1.601, 1.591, 1.581, 1.571, 1.561, 1.551, 1.541, 1.531, 1.521, 1.511, 1.501, 1.491, 1.481, 1.471, 1

Codell Sandstone Isopach – Redtail Field Area



Reservoir Properties



Reservoir Properties - Permeability



CORE GAMMA, PERMEABILITY, AND POROSITY PROFILE PLOT

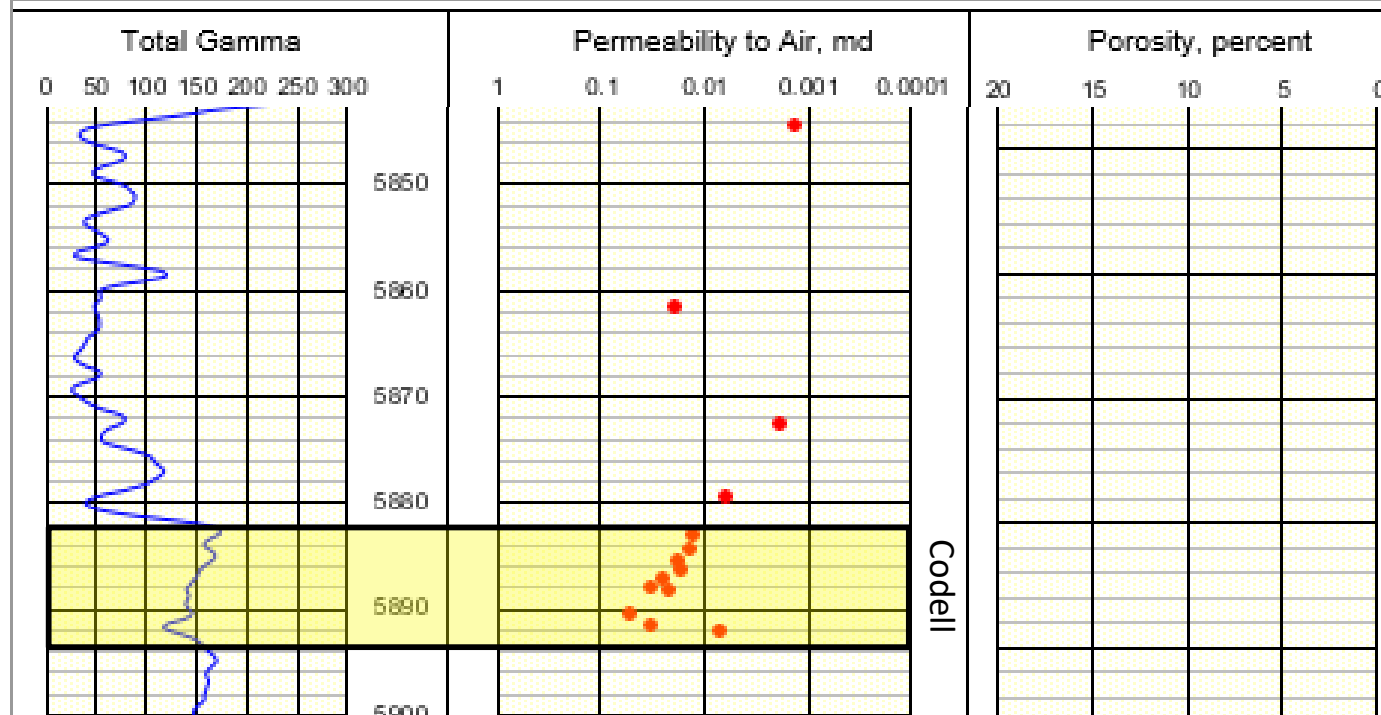
VERTICAL SCALE 5 inch:100 feet

Whiting Oil & Gas Corporation
Razor 25-2514H Well
Redtail Field

Weld County, Colorado
File No.: CO-63090
Date: 5/22/2013

Cores: 2-3 (5,679.00' - 5,829.00') & (5,829.00' - 5,935.15')

Permeability: ~.01 to .1 md



(Modified from Whiting Petroleum, 2013)

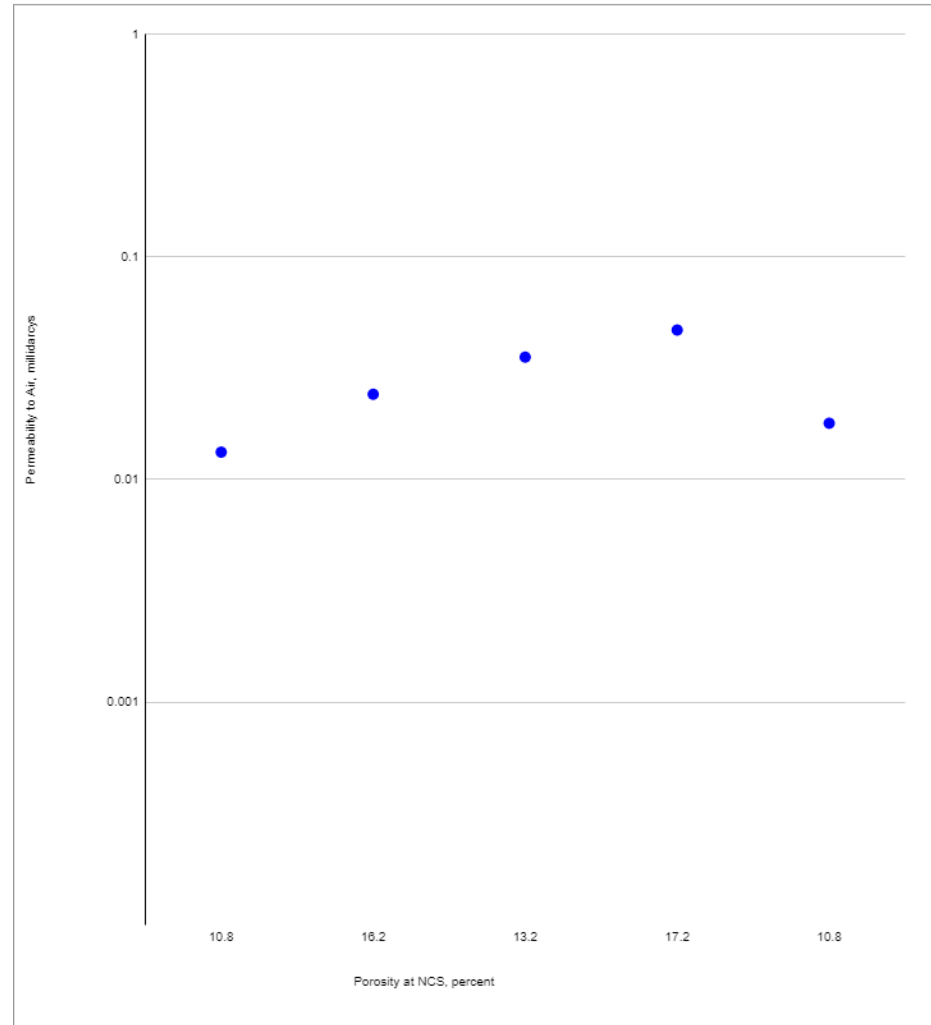


PERMEABILITY VERSUS POROSITY

Convection Oven Dried at 140° F Net Confining Stress: 2,000 psi

Whiting Oil and Gas Corporation
Razor 25-2514H Well
Redtail Field

Weld County, Colorado
File No.: CO-63090
Date: 9/23/2016



SUMMARY OF ROUTINE CORE ANALYSES RESULTS

Convection Oven Dried at 140° F Net Confining Stress: 2,000 psi

Whiting
Oil and
Gas
Corporati
on

Weld
County,
Colorado

Razor 25-
2514H
Well

File No.:
CO-
63090

Redtail
Field

Date:
9/23/2016

Core Number	Sample Number	Sample Depth, feet	Permeability, millidarcys		Porosity, percent		Grain Density, gm/cc
			to Air	Klinkenberg	Ambient	NCS	
3	3-56	5,884.80	0.013	0.0084	11.0	10.8	2.68
3	3-59	5,887.35	0.024	0.013	16.4	16.2	2.67
3	3-60	5,888.50	0.035	0.020	13.4	13.2	2.67
3	3-62	5,890.60	0.047	0.028	17.4	17.2	2.66
3	3-64	5,892.10	0.018	0.0091	11.0	10.8	2.67
Average values:			0.028	0.016	13.8	13.6	2.67

SARA & GC Data



Samp leID	15	16	17	Pr	18	Ph	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	Pr/Ph	Pr/nC1 7	Ph/nC 18	nC27/ nC17	CPI
XCLO 067	Sample was missing from the start																											
XCLO 068	6.80	7.78	8.32	4.19	7.89	2.46	7.80	7.32	7.21	6.43	5.95	5.11	4.53	3.80	3.23	2.51	2.25	1.74	1.42	1.09	0.91	0.67	0.60	1.70	0.50	0.31	0.39	1.06

(Modified from Whiting Petroleum, 2013)

- SARA:
 - Saturate, Aromatic, Resin, and Asphaltene
 - Analytical method for dividing crude oil components
- Pristane (Pr)/Phytane (Ph) Ratio:
 - Can be used to show redox conditions during diagenesis
 - Pristane – Oxidic Conditions; Phytane – Anoxic Conditions
 - **Pr/Ph ratio of 1.70** is coincident with a **marine siliciclastic environment** (range between 1-3)
 - Pr/Ph ratios of 0-1 are associated with carbonate and sulphur-rich environments
 - Pr/Ph ratios of 3-5 are associated with terrigenous and coaly environments

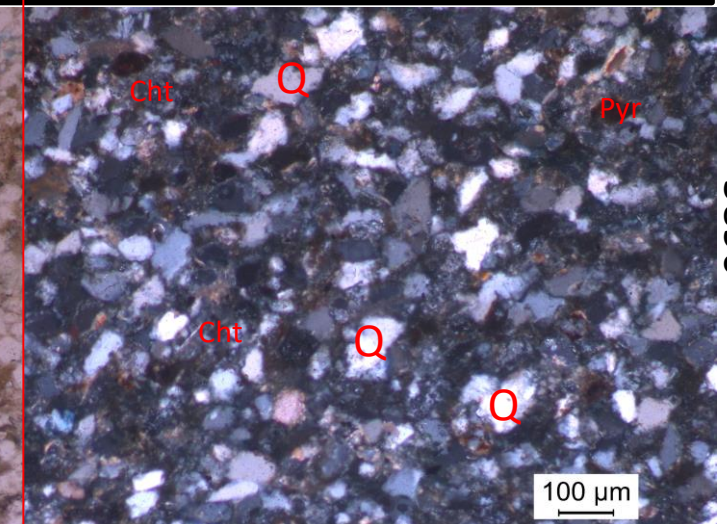
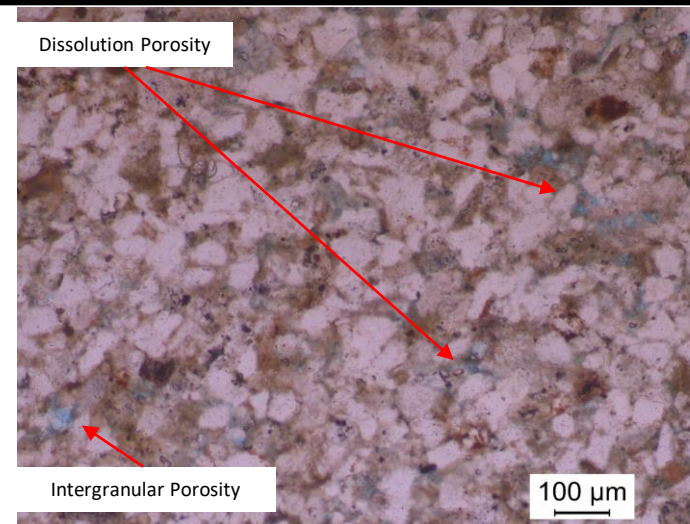
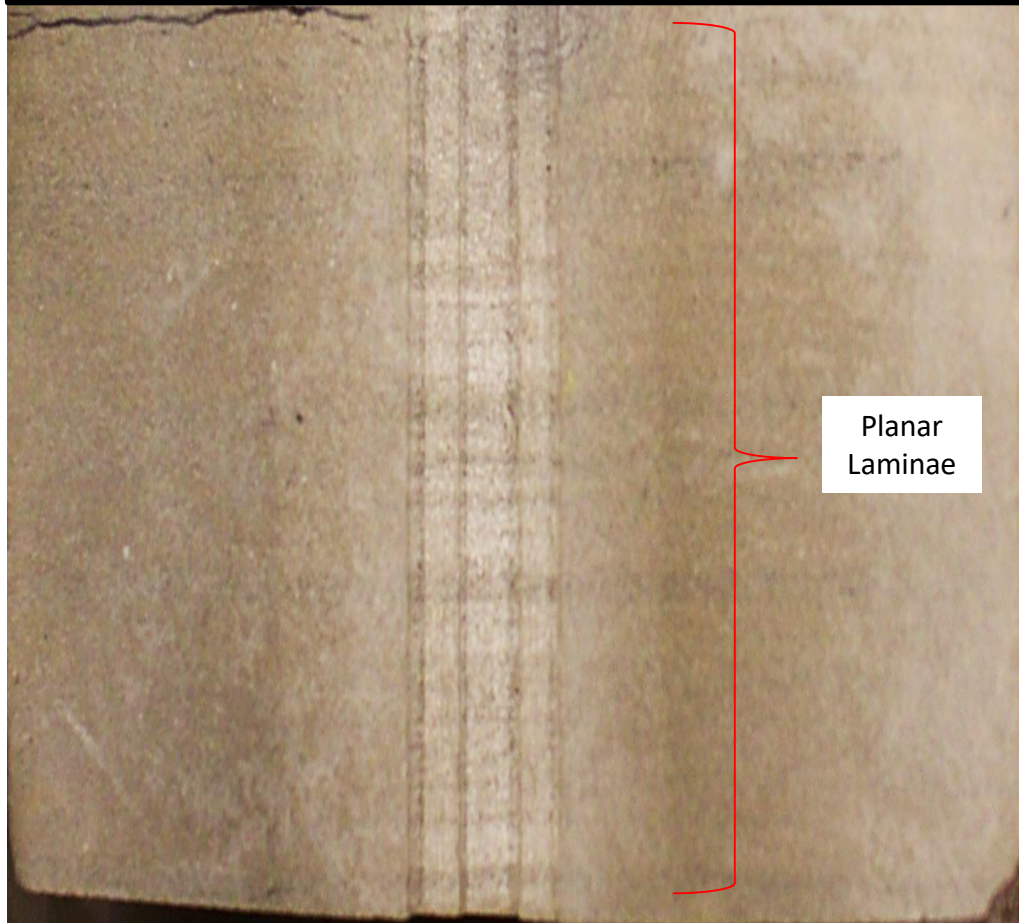
Razor 25-2514H Core



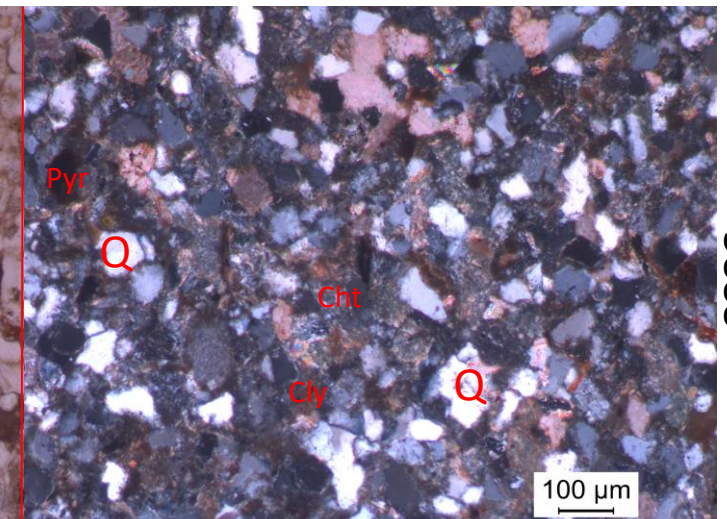
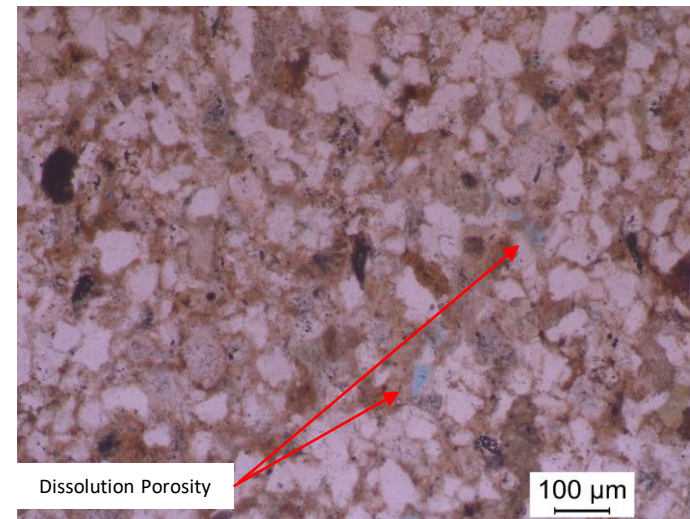
Razor 25-2514H - Facies 1: Planar Laminated Sand



Razor 25-2514H: Facies 1



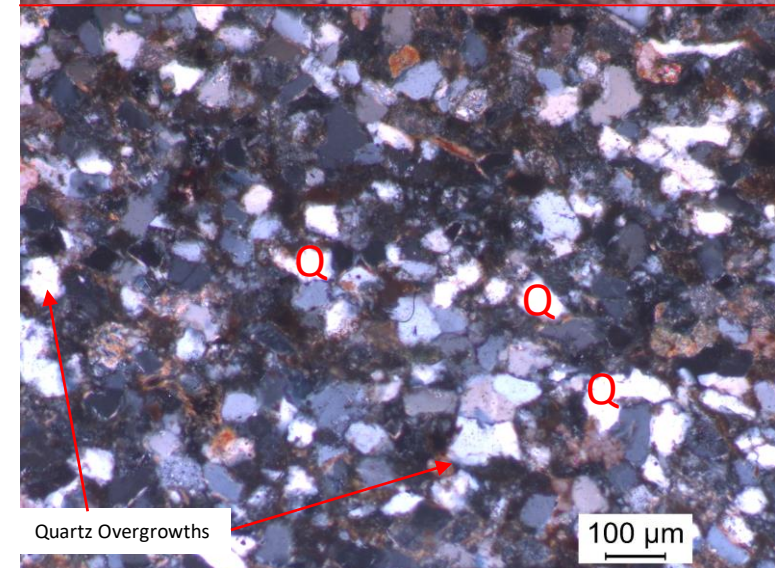
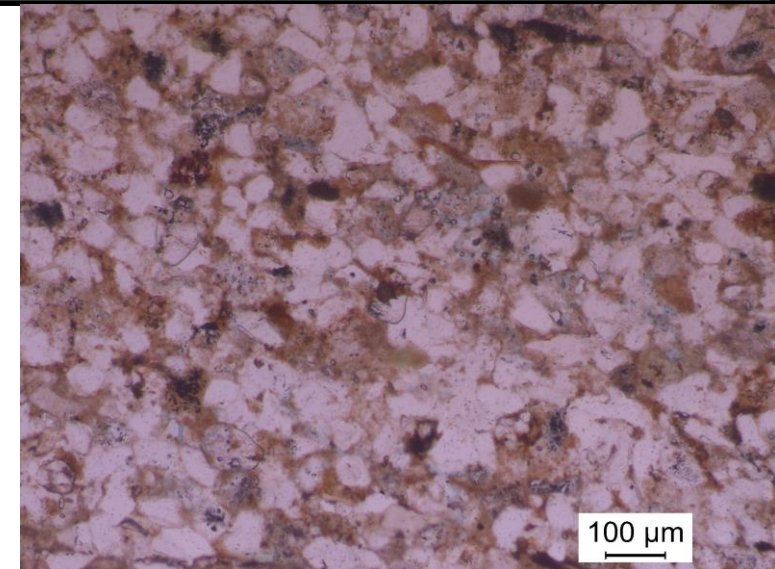
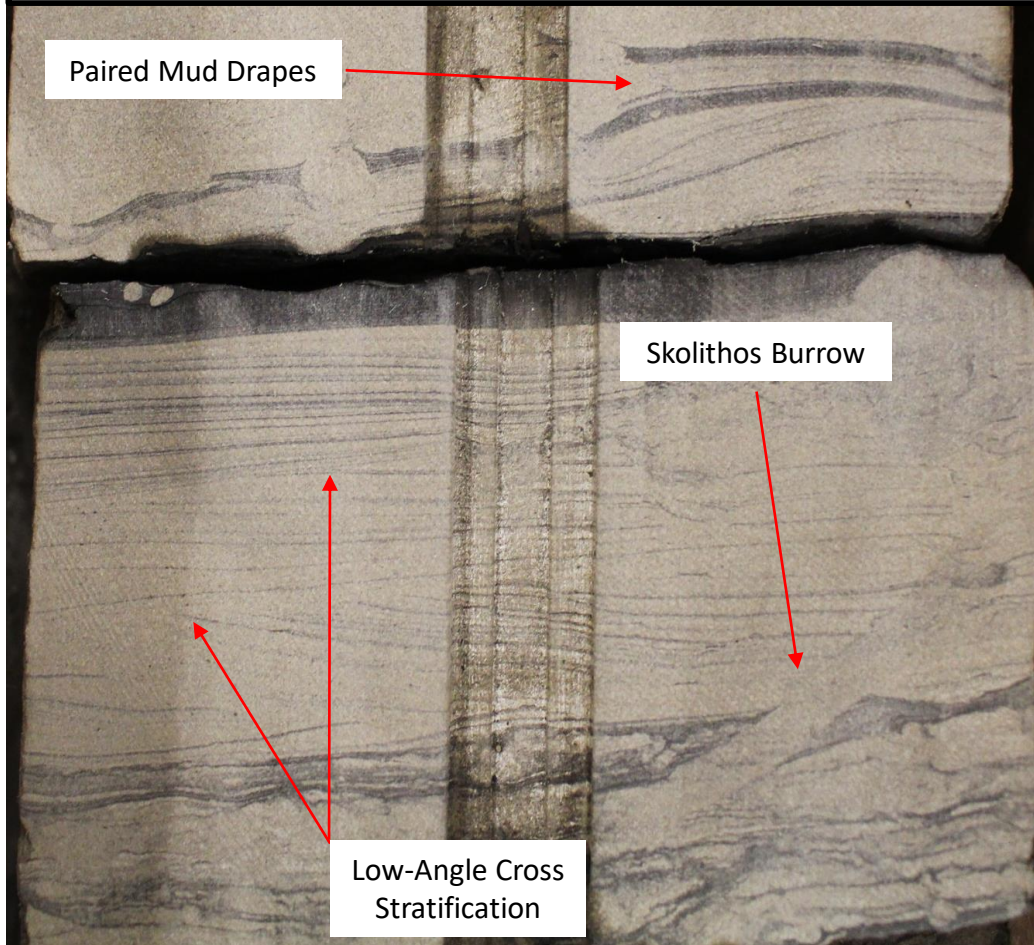
5890'



5888'



Razor 25-2514H: Facies 2

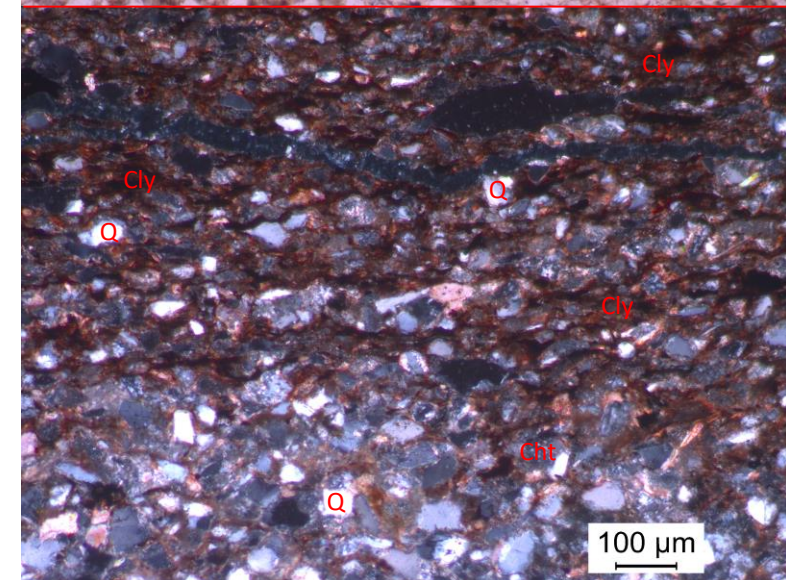
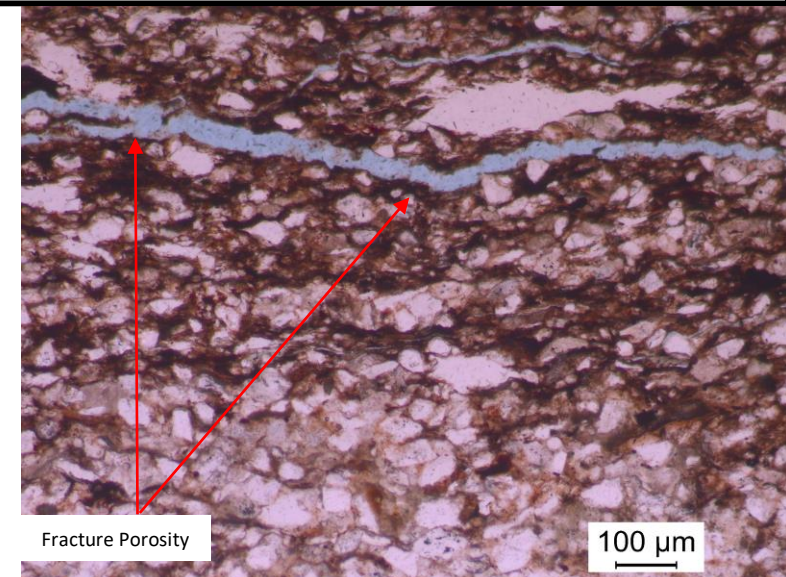
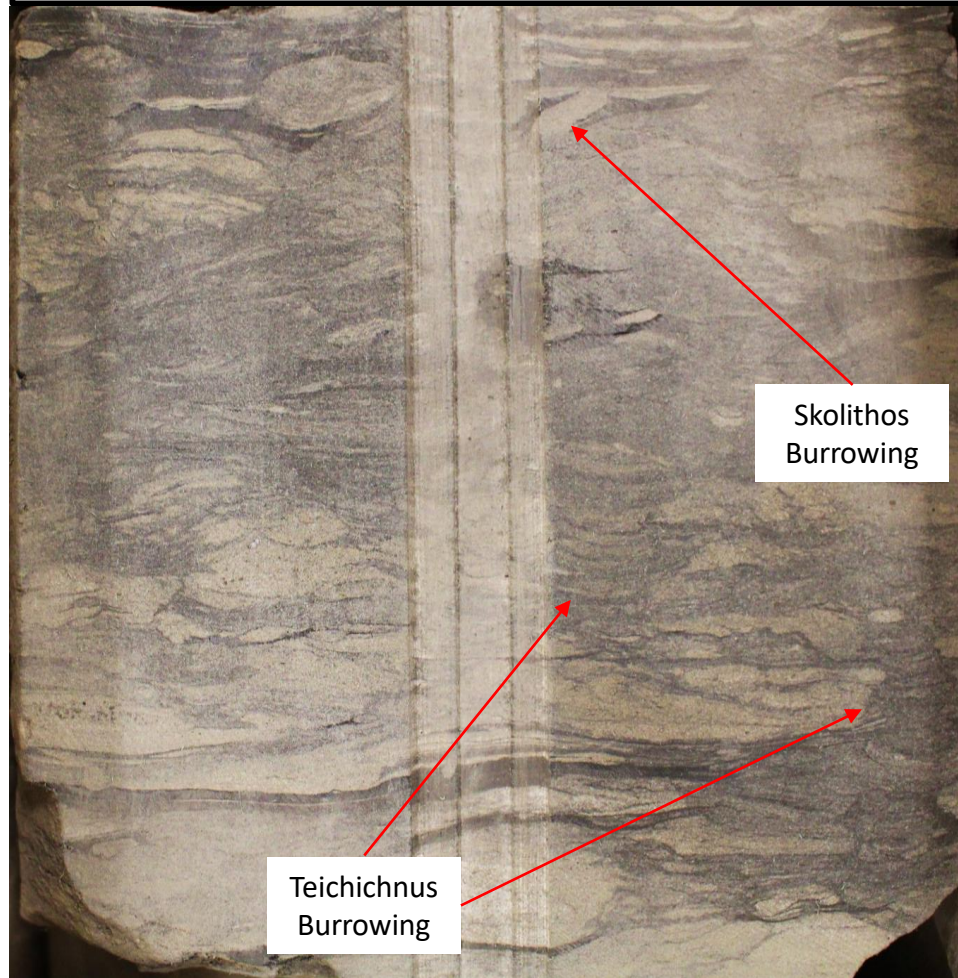


5889.5'

Razor 25-2514H - Facies 3: Lower Bioturbated Silty Sand



Razor 25-2514H: Facies 3

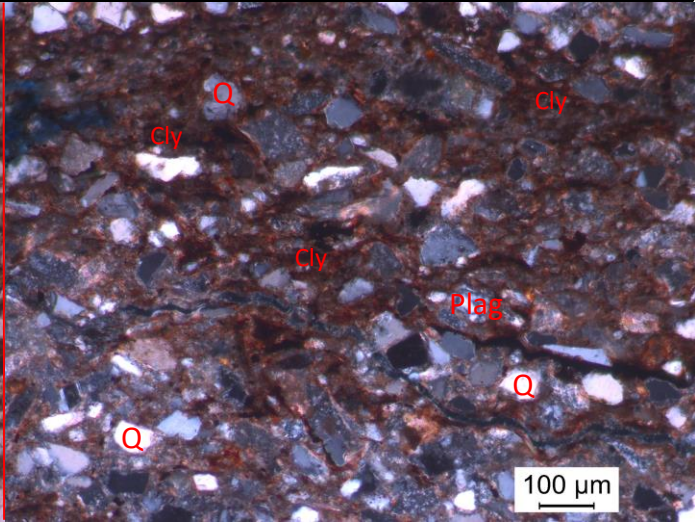
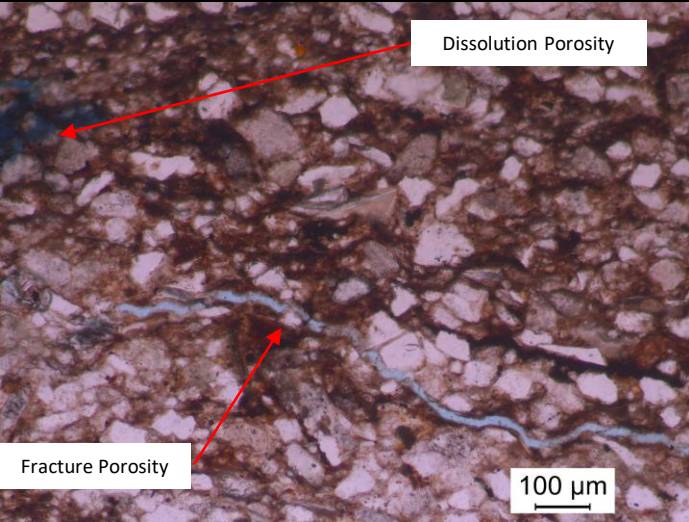
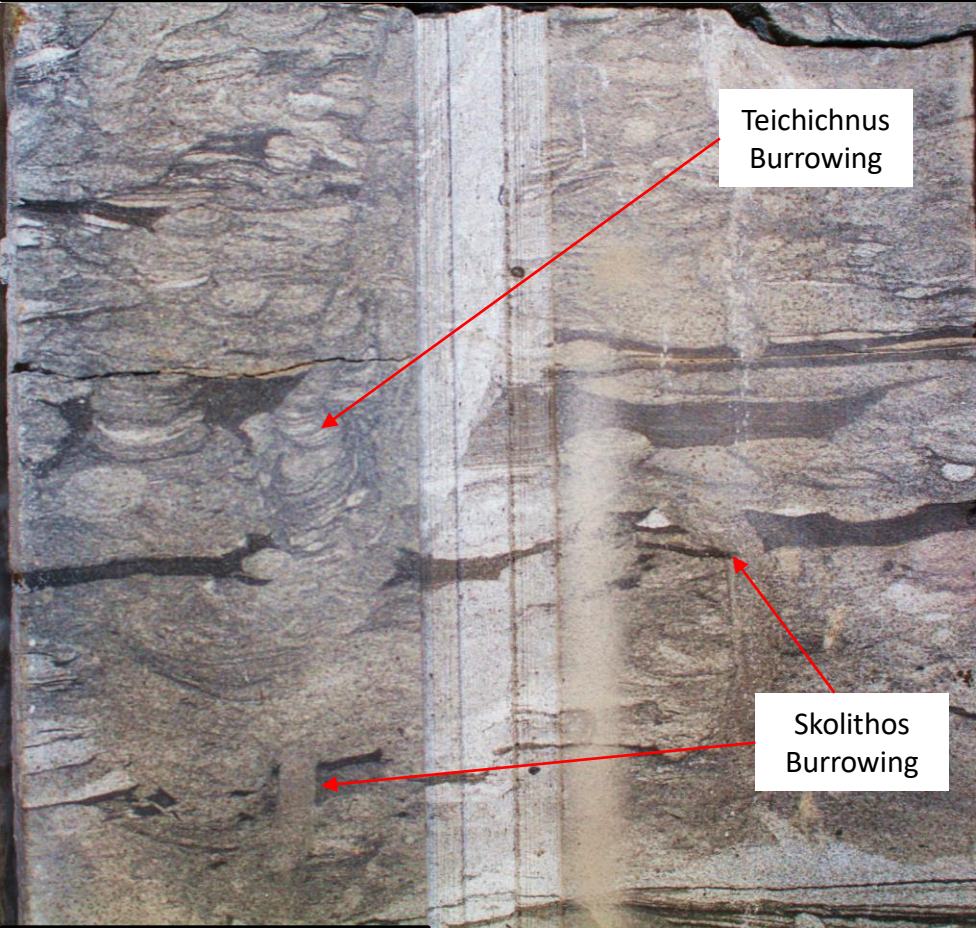


5885.5'

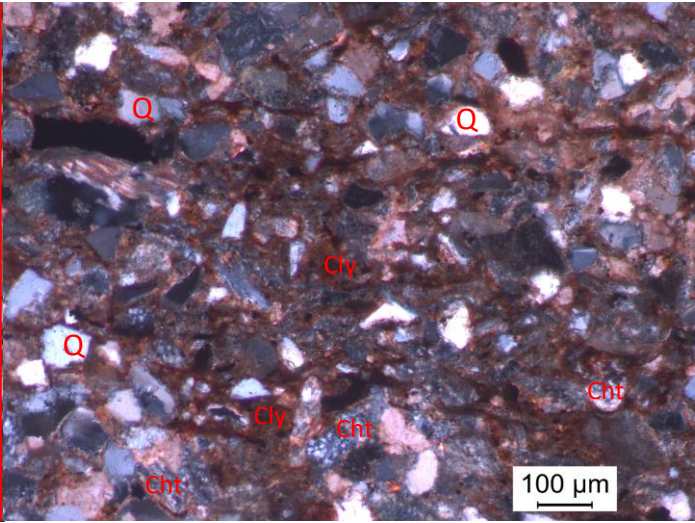
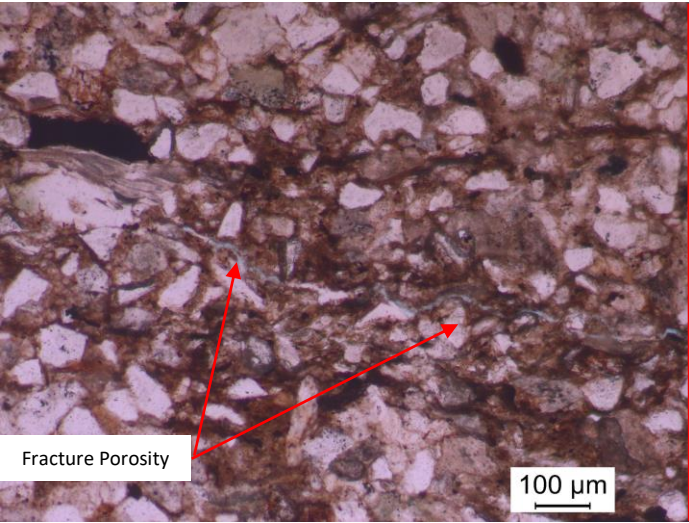
Razor 25-2514H - Facies 4: Upper Bioturbated Sandy Silt



Razor 25-2514H: Facies 4



5884'

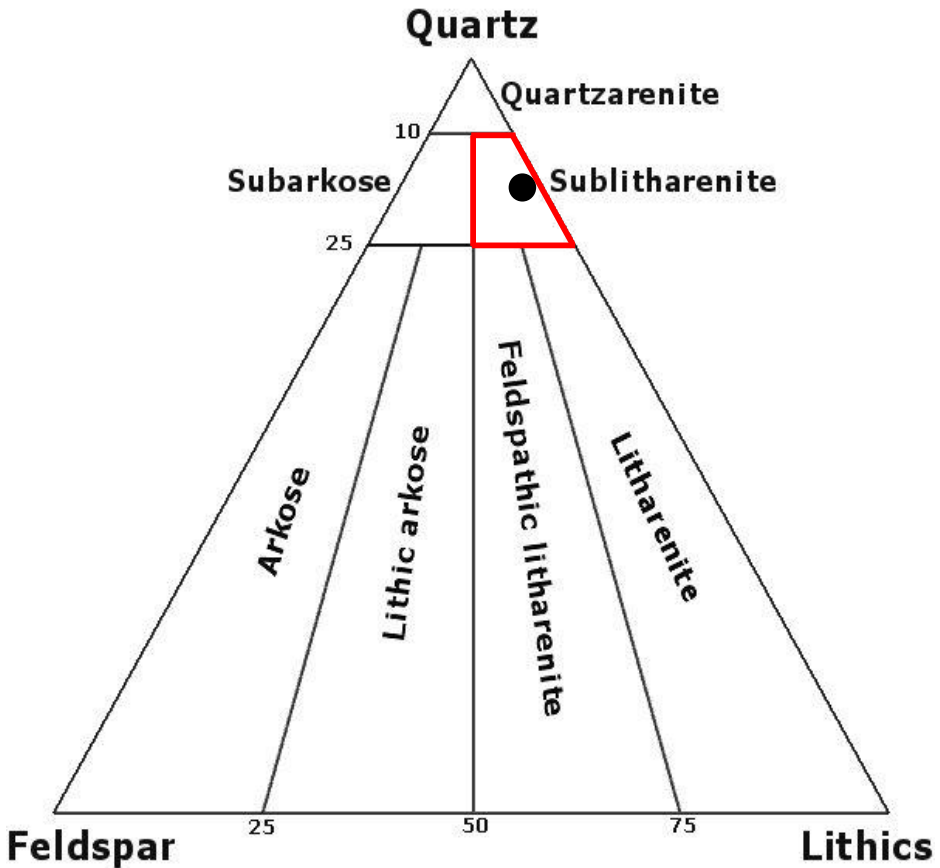


5881'

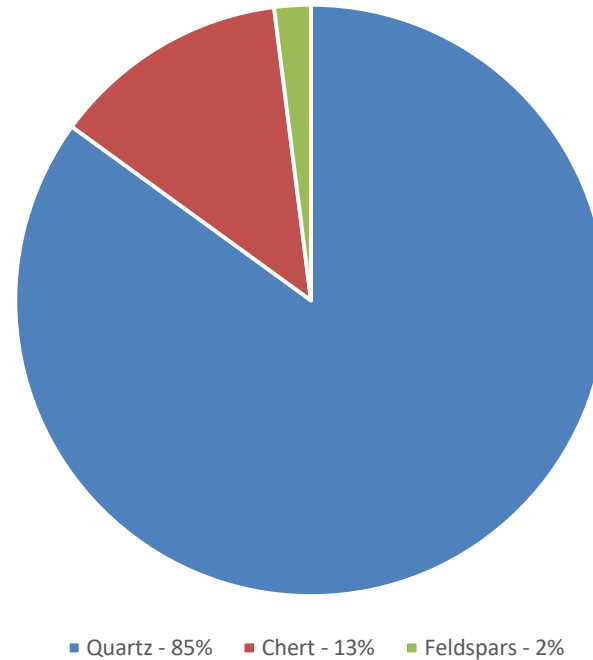
Razor 25-2514H Modal Mineralogy – Codell Sandstone



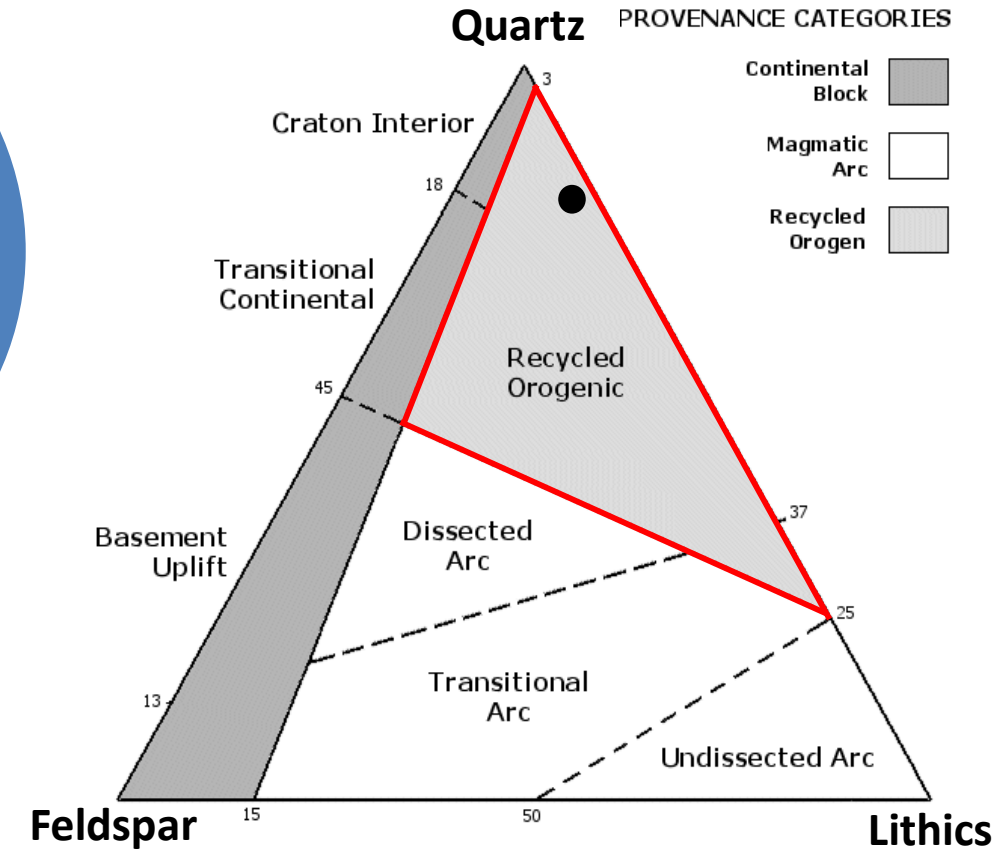
Sandstone Classification



Codell Sandstone Modal Mineralogy



Sandstone Provenance



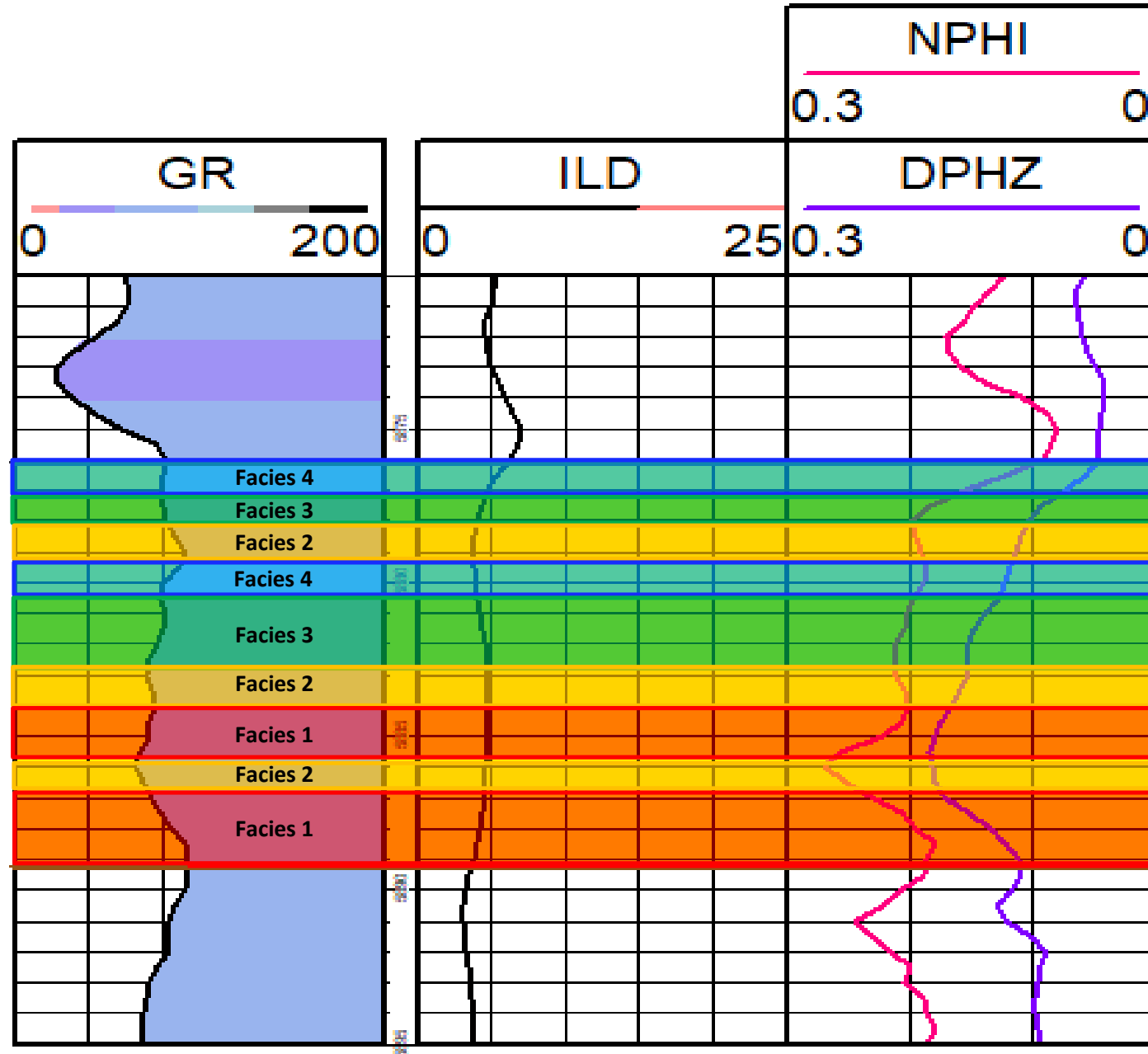
Reservoir Facies in Core



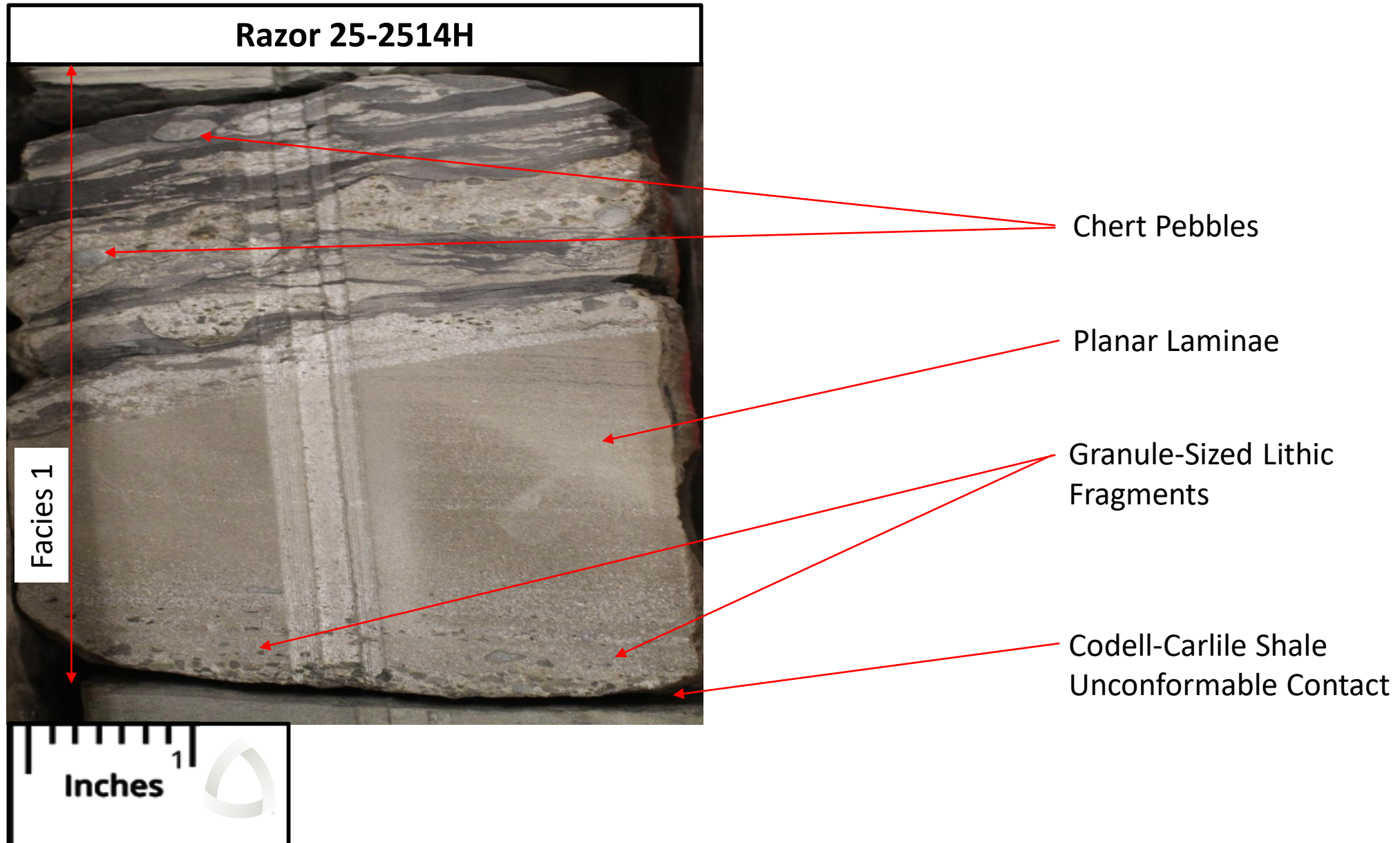
05123364180000
WHITING OIL & GAS
RAZOR
25-2514H
T10N R58W S25

Codell Top/Fort Hays Base
5876'

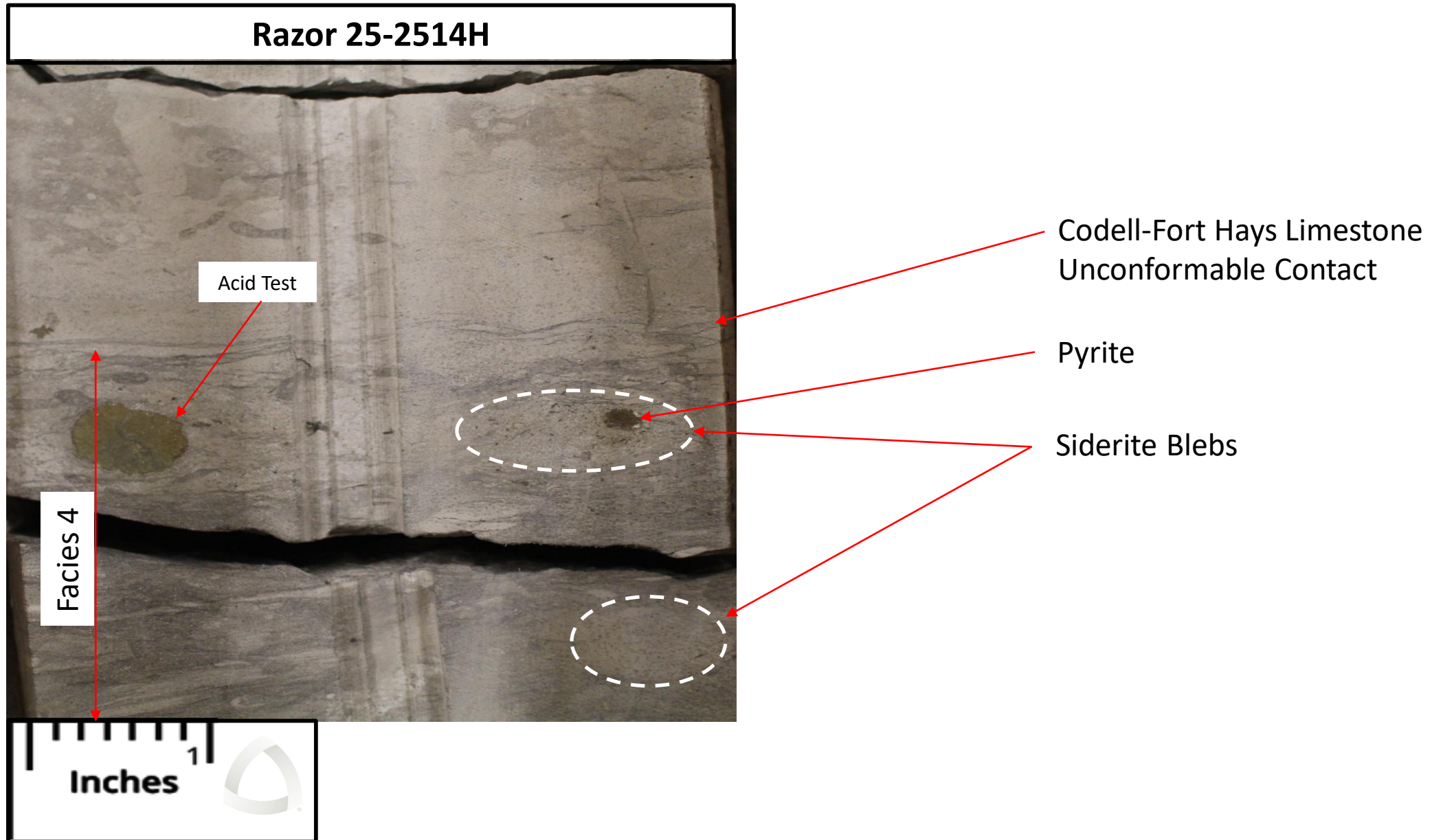
Codell Base/Carlile Top
5889'



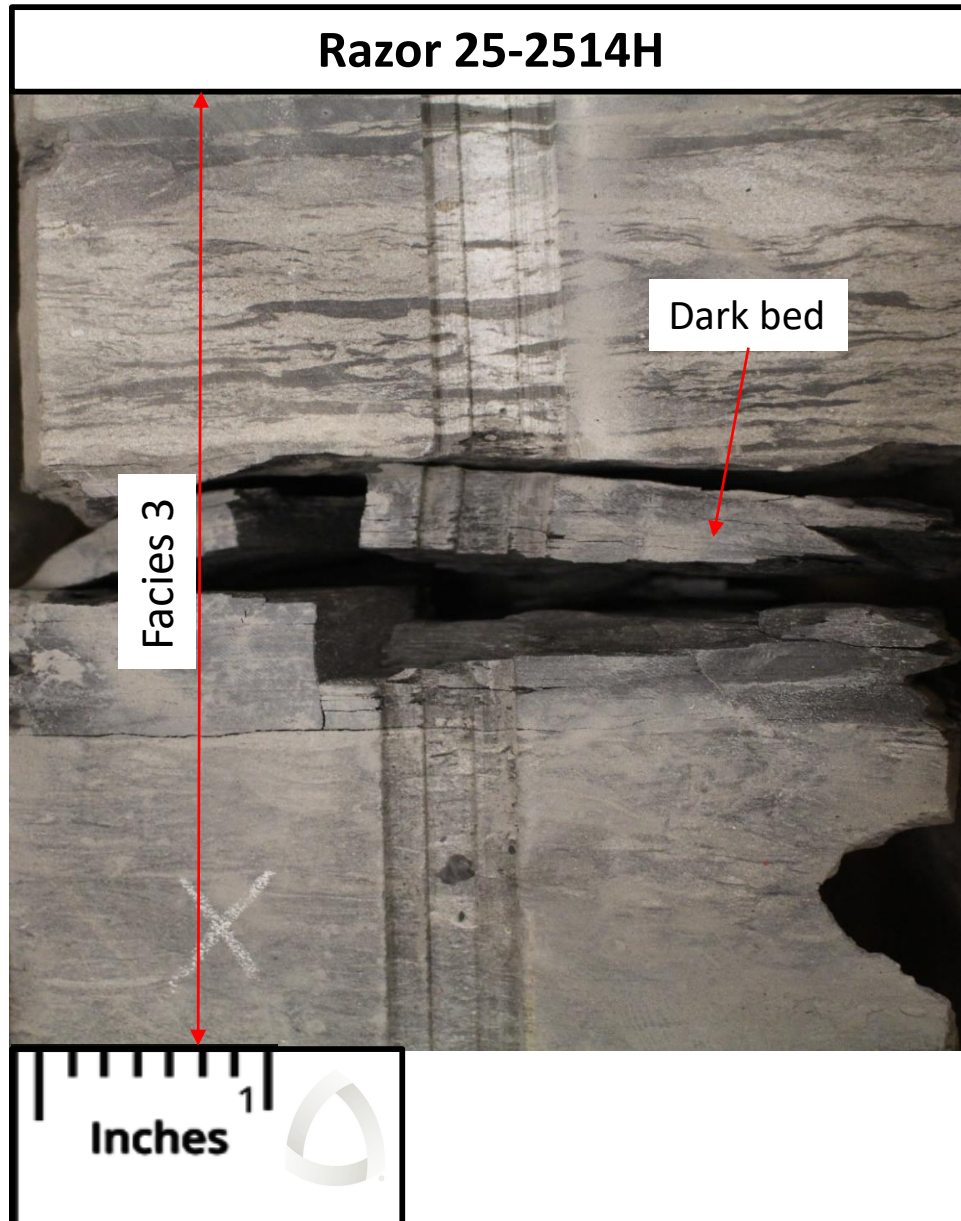
Razor 25-2514H – Lower Codell/Carlile Unconformity



Razor 25-2514H – Upper Ft. Hays LS Unconformity



Razor 25-2514H – Dark-Colored Codell Beds



- **Three** individual dark-colored beds exist within the Razor 25-2514H Codell interval
- ***Presumed*** to be organic-rich
 - *SRA testing required*

Conclusions





- The Codell Sandstone represents a prolific formation targeted in the Denver Basin
- Increased understanding of the controls on effective reservoir extent and quality will assist future drilling endeavors
 - Lower half of Codell interval appears to display favorable reservoir properties
- Initial analysis and examination has identified a potential causational relationship between facies and reservoir quality at Redtail Field
 - Additional analyses and conclusions are underway
- Analysis and Thesis completion in December 2021

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