

# **Codell Sandstone, A Review of the Northern DJ Basin Oil Resource Play, Laramie County, Wyoming, and Weld County, Colorado\*<sup>R</sup>**

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## **Abstract**

The Codell Sandstone has recently been the subject of extensive exploration and subsequent development activity in both the Colorado and Wyoming portions of northern DJ Basin. The Niobrara Formation has been the primary historical exploration target since the late 1980's due to success at the Silo Field from horizontal wells drilled in the Niobrara B Bench. In 2009, EOG Resources discovered the Hereford Field with the Jake 02-01H, producing approximately 1700 barrels of oil per day initially from the Niobrara B Bench. The next two years in the area saw much drilling focused on the Niobrara B Bench with the completion of many non-commercial wells. In 2012, SM Energy drilled a lateral focused on evaluating the Codell Sandstone. Cirque Resources, Kaiser Francis, and EOG soon followed with their own exploratory wells, establishing the play. This new play area is thermally in the oil window. Codell Sandstone oil producers have gas-oil ratios less than 2000 scf/bbl. The Codell Sandstone thins from north to south due to erosional truncation beneath an angular unconformity at the base of the Fort Hays Limestone Member of the Niobrara Formation. Gross thickness ranges from 18 to 33 feet. The Codell Sandstone is a very-fine- to fine-grained sandstone and produces oil from two main facies: bioturbated sandstone and laminated sandstone. The laminated facies is parallel to sub-horizontally bedded, has 8 to 15 percent porosity, and 0.01 to 0.10 millidarcies permeability. The bioturbated sandstone has 8 to 13 percent porosity and .008 to .05 millidarcies permeability. The Codell Sandstone is a low-resistivity pay zone that produces oil with low-water cuts from zones with less than 10 ohm-m resistivity. Clay content is 15–

25% with abundant microporosity as imaged with epifluorescent microscopy, accounting for high bound water content and explaining the low formation resistivity. Oil typing indicates the oil found in the Codell is sourced from the Niobrara and is distributed across the area through migration. Oil saturation varies across the play depending on the distance from areas of oil generation and expulsion into the Codell. Use of mercury-capillary-injection pressure analysis was essential in resolving the oil migration route throughout the play area. Drilling and completion techniques have evolved since the first wells were drilled. Best practices to date involve 1280-acre spacing units with 9300' lateral lengths, cemented liner with perf & plug completion techniques.

### **References Cited**

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- Zumberge, J.E., J.A. Russell, and S.A. Reid, 2005, Charging of Elk Hills reservoirs as determined by oil geochemistry: *AAPG Bulletin*, v. 89/10, p. 1347-1371.

**Codell SS**  
**A Review of the Northern DJ Oil Resource Play**  
**Laramie County, WY & Weld County, CO**

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AAPG ACE, Denver June 2, 2015

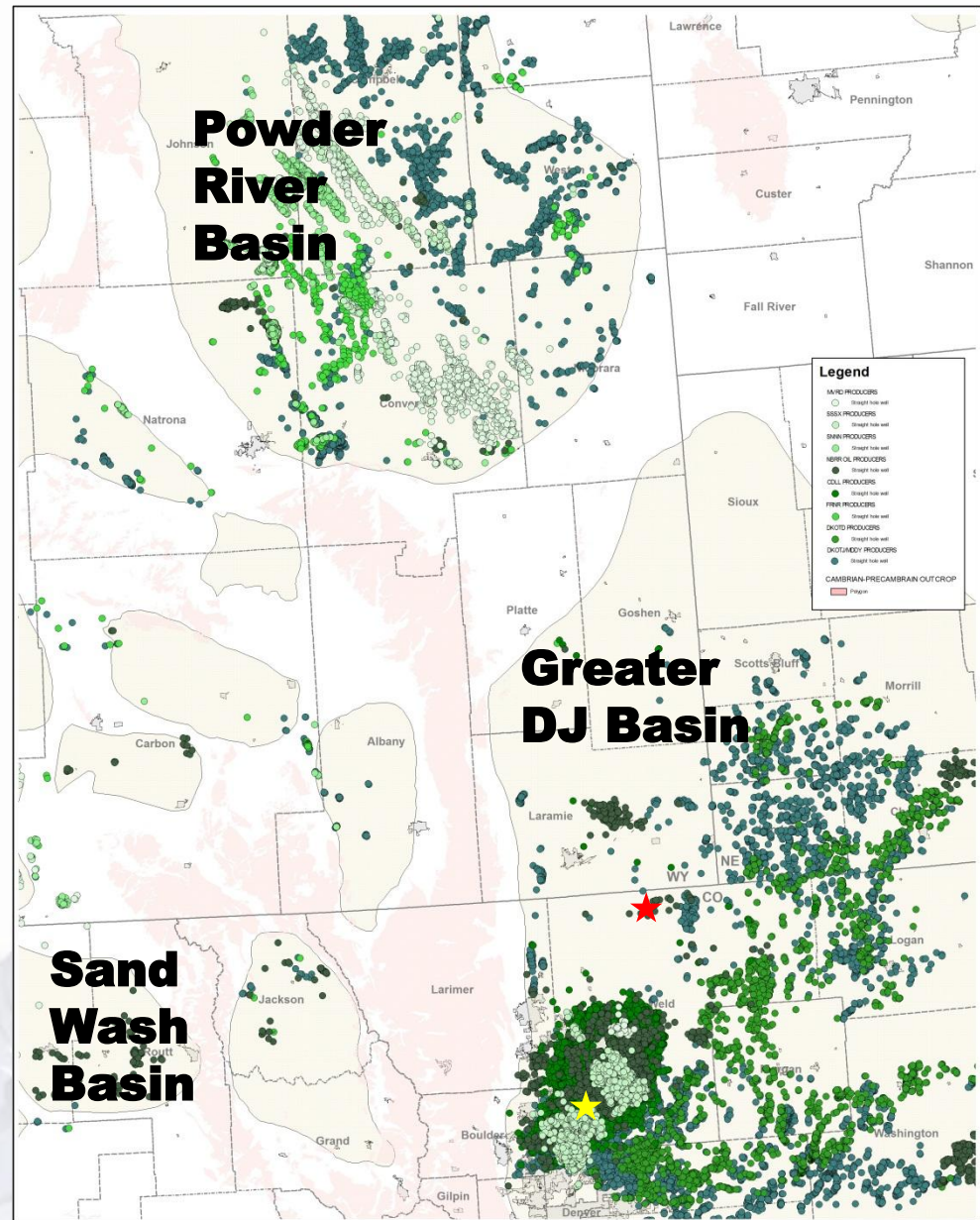
Revised for Tulsa Geologic Society February 9, 2016

## Cretaceous Petroleum System

### 3.65 Billion BO Cum to Date

## DJ Basin Activity

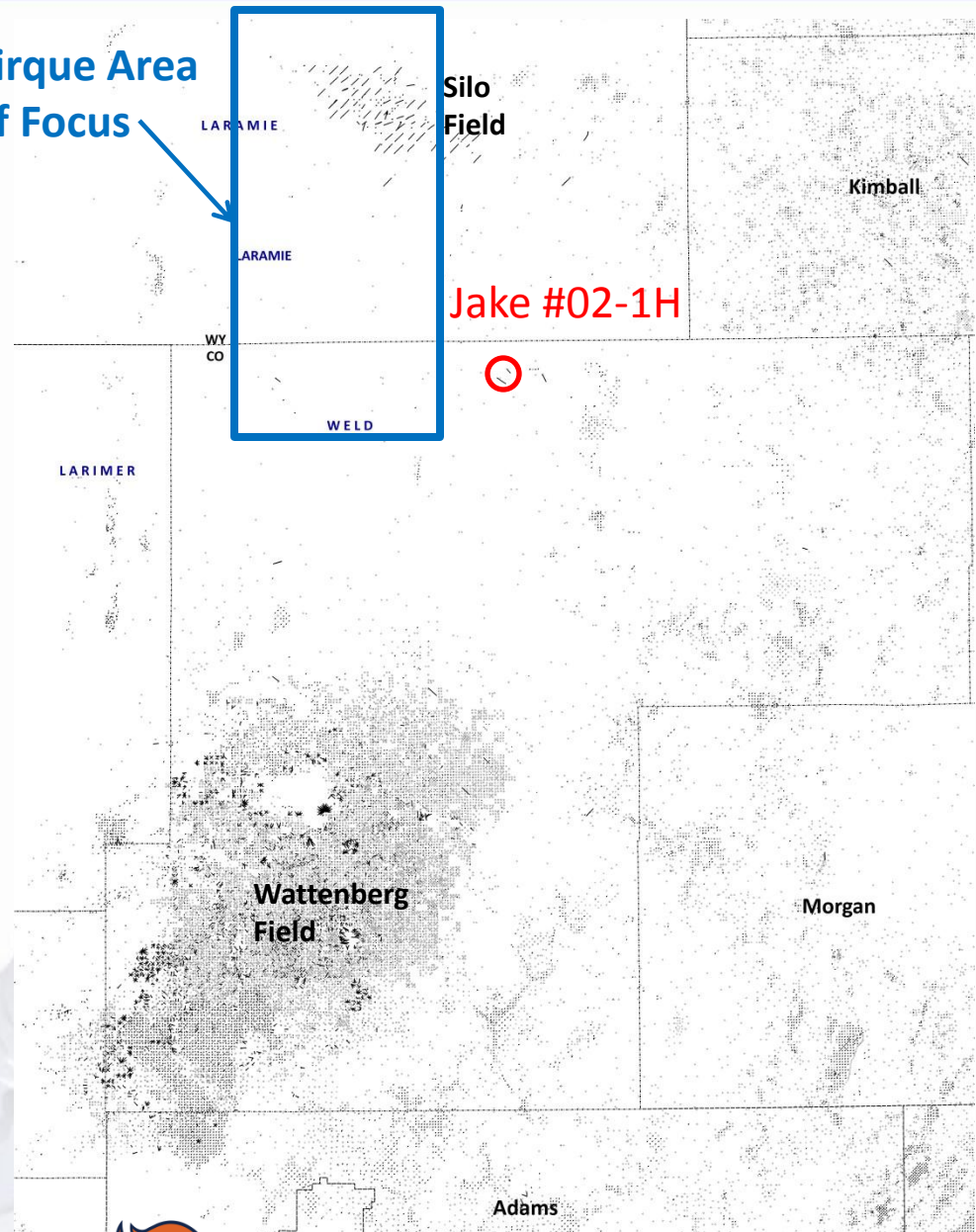
- 2010
  - Noble Gemini K01-99HZ 
    - 500 BOD first 60 days avg
    - Started horizontal program in Wattenberg
  - EOG Jake 2-01H 
    - 1500 BOD IP
    - 645 BOD first 30 day avg
    - Discovery well for Hereford Field
    - Began Niobrara “boom” outside of Wattenberg
- 2011-2012
  - Many operators leased and drilled horizontal Niobrara wells outside Wattenberg with mixed results.
  - Codell became focus of horizontal drilling both in and outside of Wattenberg



## Cirque History in DJ Basin

- EOG Jake 02-01H drilled in August 2009 started renewed interest in the Niobrara outside of core Wattenberg
- Cirque had put together a Niobrara/Codell project starting in 2008
  - Accumulated >300K acres
- Noble became partner in late 2009
  - Drilled & cored Nio/CDLL in 3 vertical wells
  - Drilled 3 Niobrara B Bench laterals
- Industry responded to the Jake success with a leasing and drilling boom focused on the Niobrara B Bench
- Results of drilling were generally poor with a few exceptions
- By 2011, industry interest in the Niobrara waned

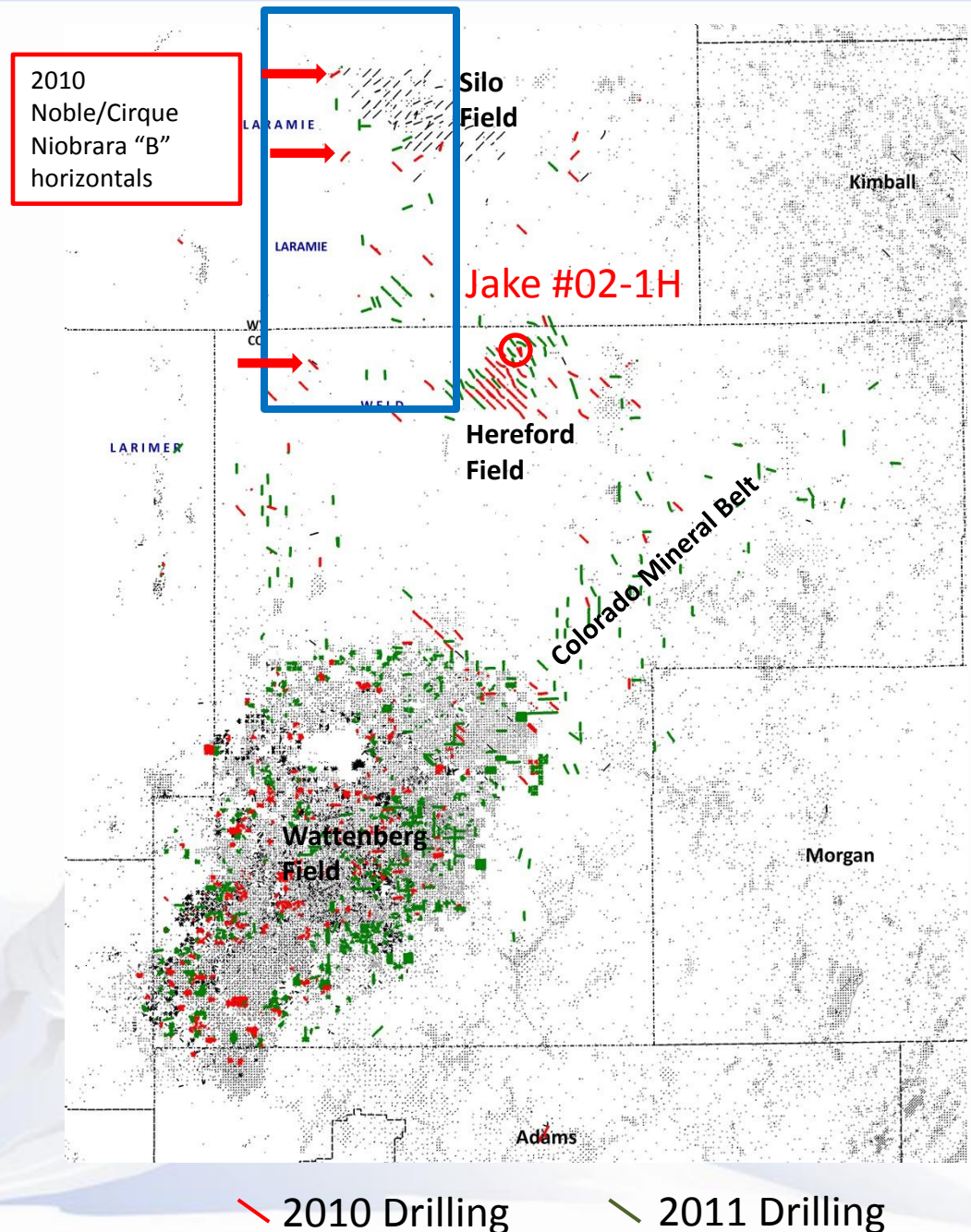
Cirque Area  
of Focus



Drilling Status as of 12/31/2009

# Drilling as of 12/31/2011

- Successful Niobrara B Bench wells limited to Hereford Field and along the Colorado Mineral Belt
- Industry lost interest in the Niobrara B Bench play across the DJ Basin
- Cirque began to look at other potential on our acreage block
  - Codell
  - Greenhorn
  - C Bench Niobrara
  - Deeper zones on structural closures
- 2012- Cirque drills a discovery well in the Codell



# Denver Julesburg Basin Horizontal Drilling Evolution and Permits 2009 – 2016 Wells Drilled

In five years, horizontal drilling reenergized the DJ Basin and led to new Codell discoveries

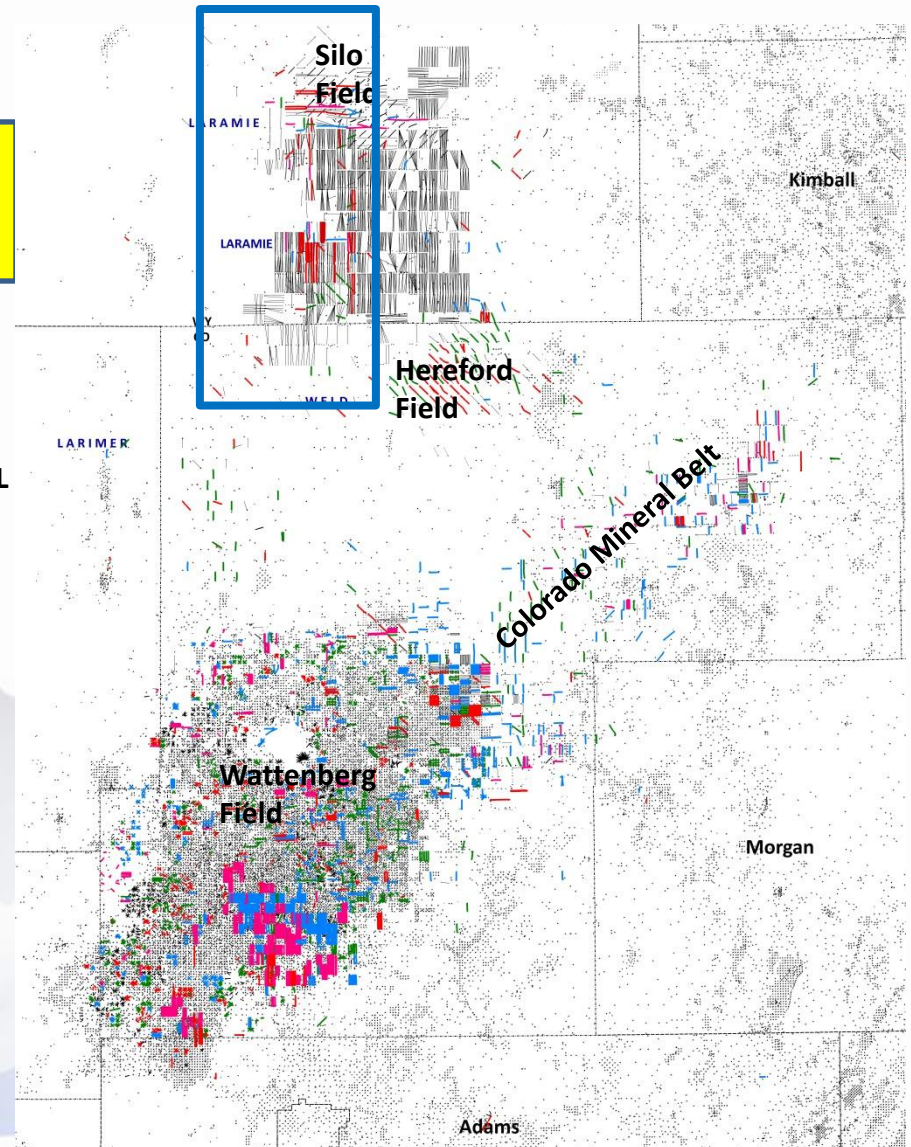
In the last 5 years DJ oil production has grown from **192,000 BOEPD** (Jan/2010) to **480,000 BOEPD** (Dec/2015) due to horizontal drilling in the Codell and Niobrara

## Codell Discoveries in Northern DJ

- Mid to late 2012
  - SM Energy drills Tomahawk 1-31H – FIRST CODELL HORZ
  - Cirque drills the Warren 17-1H Codell
- 2013
  - Cirque, Kaiser Francis & EOG begin brisk development of Codell in Laramie County WY

Niobrara C discovery by EOG in Laramie County, Wyoming

Niobrara A/B development being permitted and re-examined with the updated completion

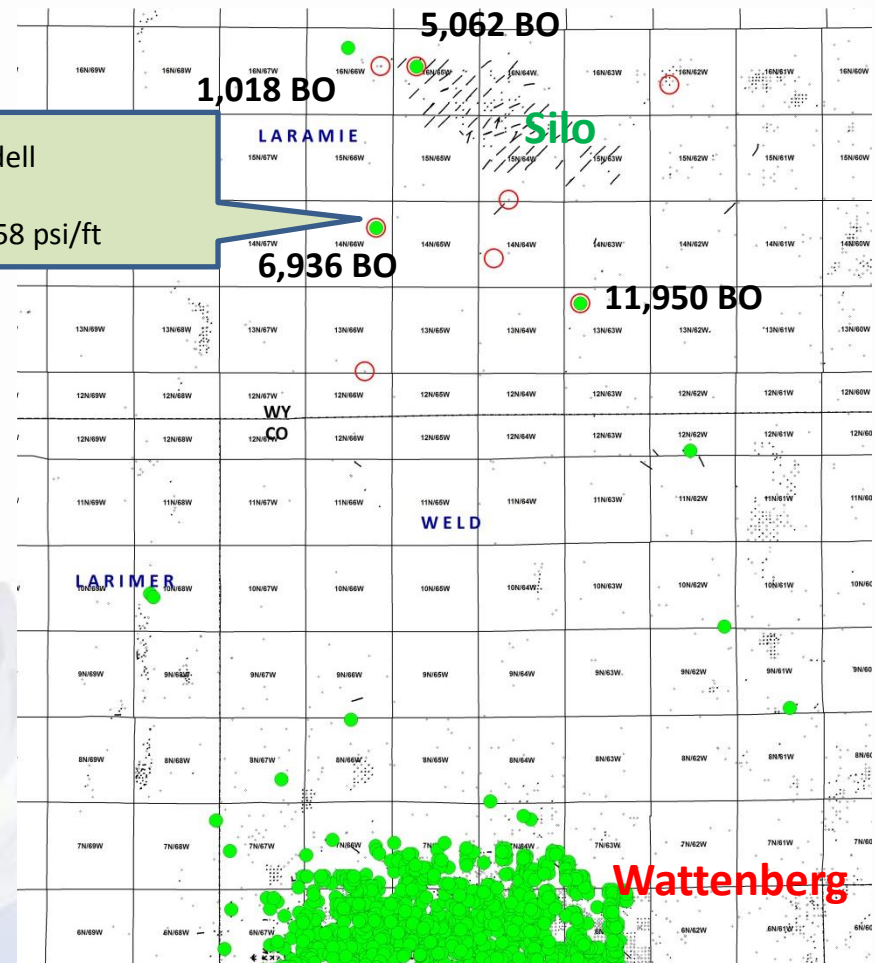


# Codell Producing Wells before 2010

- Very few vertical completion attempts north of Wattenberg Field
- Vertical Wells in oil window non-commercial
- Completions usually with small frac
- Water cut very low in all vertical wells

- Wells with shows in Codell
- Wells with Production from Codell

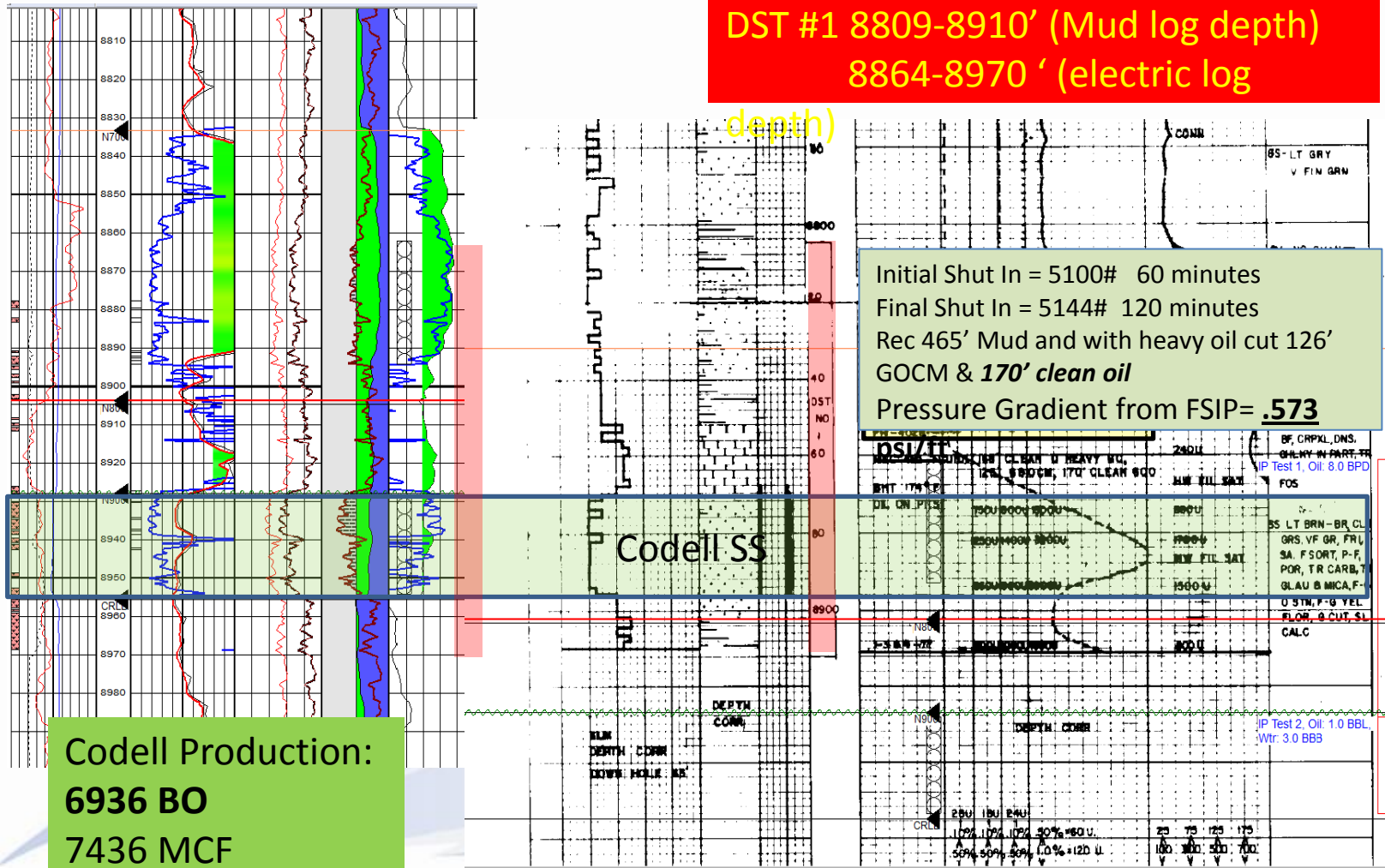
DST In Codell  
Rec oil  
Pressure .58 psi/ft



- DST Noted on mudlog critical for understanding **Basin-Centered Oil ("BCO") Potential** of area  
Slight overpressuring seen on DST suggested a BCO accumulation  
DST Data never made it into Wyoming State Database making mudlog a critical piece of data

BP Champlin 373 Amoco A 11-T14N R66W

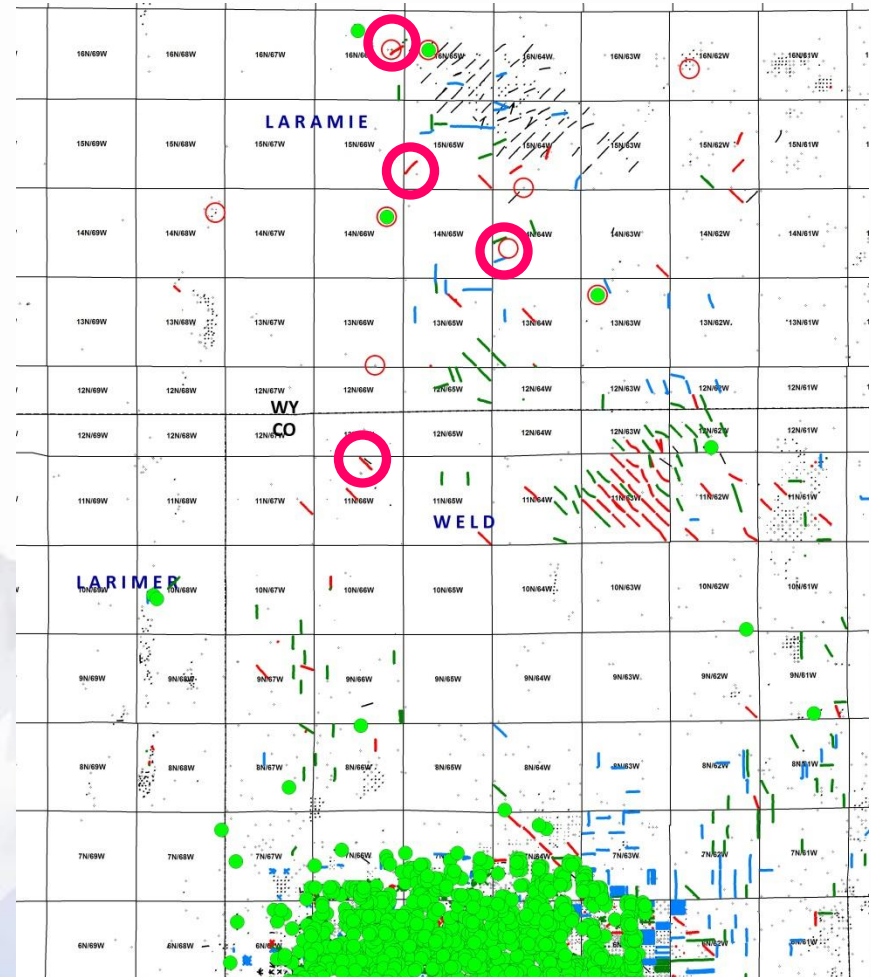
**DST #1 8809-8910' (Mud log depth)**  
**8864-8970' (electric log depth)**



# Codell Cores Taken in 2010

- 3 vertical wells drilled by Noble & Cirque with cores taken in Niobrara & Codell
- 1 vertical well drilled by SM Energy with core in Niobrara & Codell
- Cirque conducted a thorough review of all core data in Codell to determine viability of a horizontal drilling program

○ Wells with core in CODELL SS



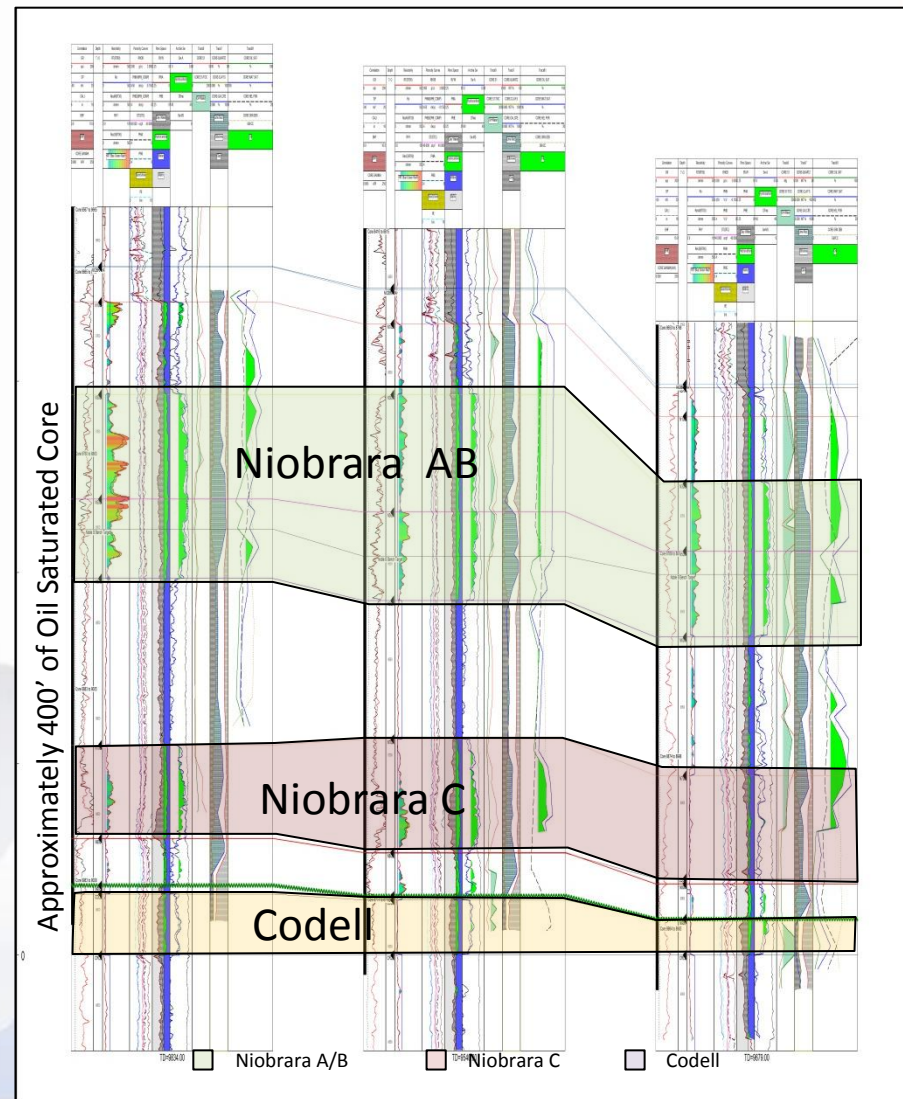
# Core Critical in Reservoir Characterization

- Cirque had three Niobrara/Codell cores taken in 2010.
- All cores show significant **oil saturations** in the Niobrara and Codell
- Core analysis in Niobrara and Codell is critical in calibrating the petrophysical model and understanding the reservoir
- Cirque acquired additional core data in the Codell SS
- Analysis includes XRD, MICP, RCA, Thin Sections, CST, Rock Mechanics

Cirque/Noble Energy  
Berry UN 13-9

Cirque/Noble Energy  
Child VO 30-9

Cirque/Noble Energy  
Lazy D ZN 03-09



# Development History of Codell SS Laramie County, WY

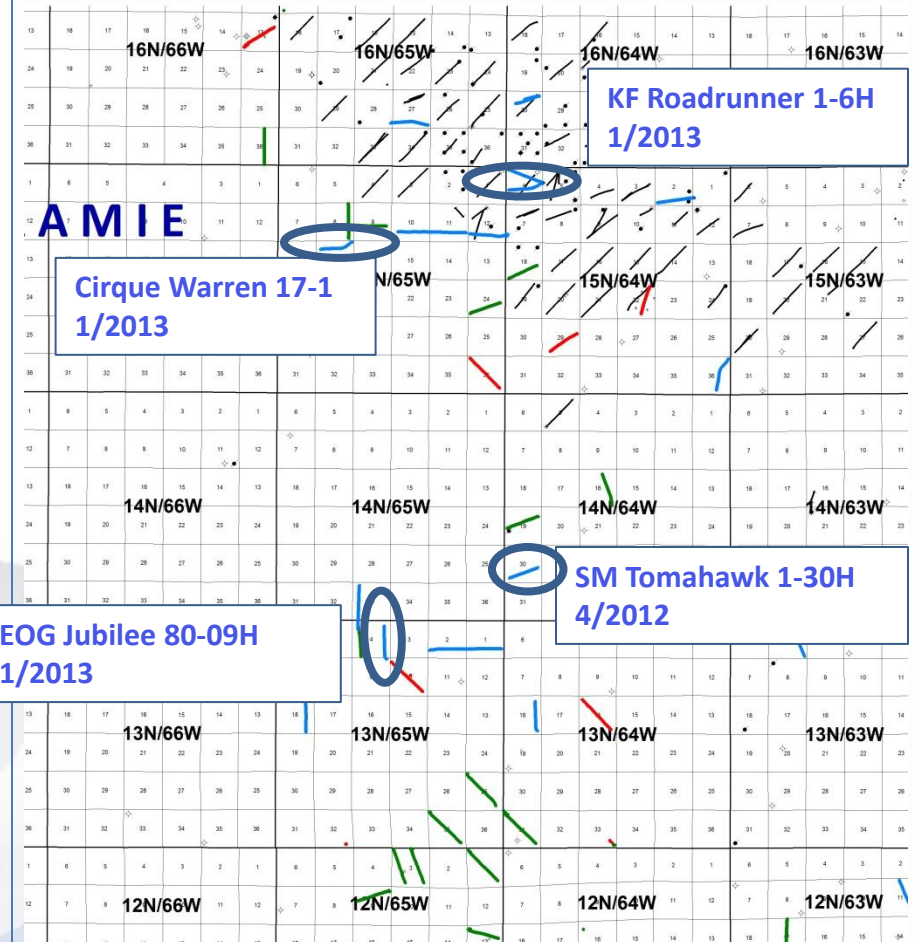
## Initial drilling for Codell Laterals 2012

- First four wells drilled as 640 ac DSU
  - SM Tomahawk 1-30 – SW-NE lateral
  - Kaiser Francis Roadrunner 1-6H - EW
  - Cirque Warren 17-1H – EW lateral
  - EOG Jubilee 80-09H – NS lateral

## Completion Technique

- Cirque and SM & KF used **packers and sleeves**
  - 19 stages in Cirque Warren 17-1H
    - 949 BOEPD IP**
  - 15 stages in SM Tomahawk 1-30H
    - 501 BOEPD**
  - 16 stages in KF Roadrunner 1-6H
    - 485 BOEPD**
- EOG used cemented liner and **Perf & Plug**
  - 19 stages in EOG Jubilee 80-09H
    - 1,855 BOEPD**
    - Put on ESP immediately after completion

## Drilling as of 12/31/2012



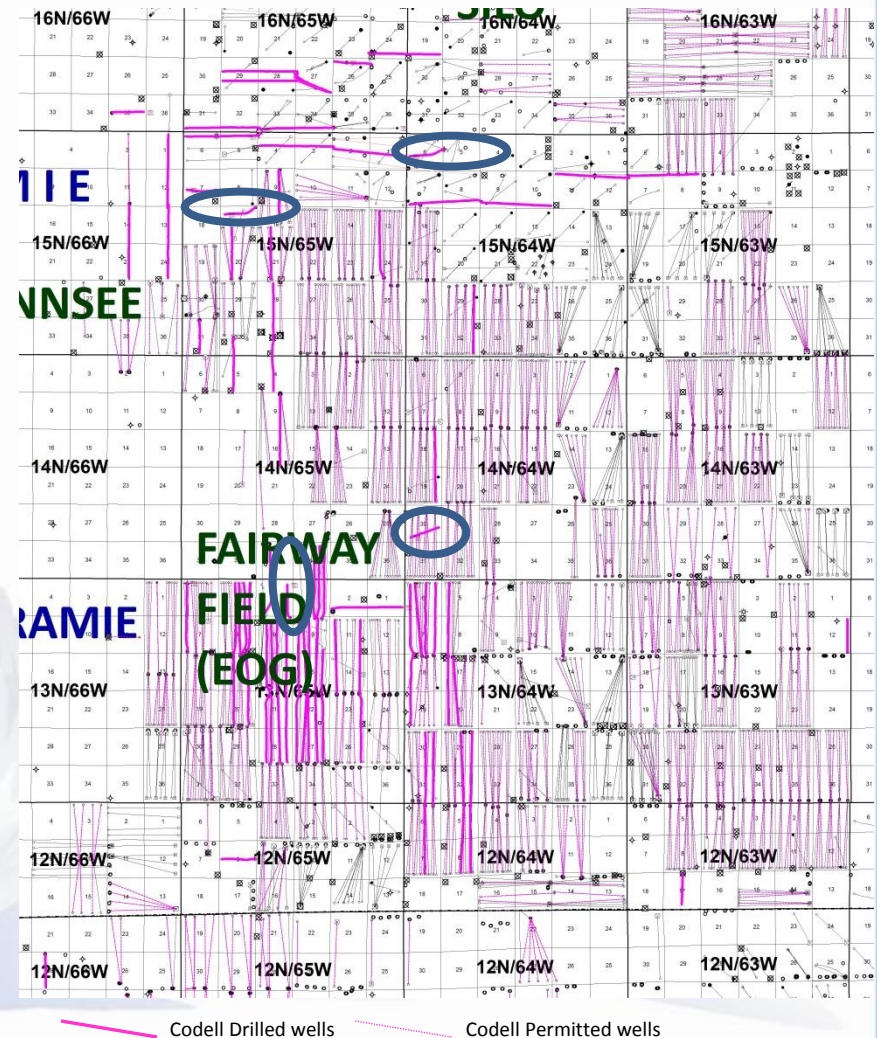
# Development History of Codell SS

## Laramie County, WY

### Several operators permitting large number of wells

- EOG is most active operator in the play
  - Kaiser Francis has drilled many Codell wells in the Silo area
  - Samson Energy has acquired a position in 2015 and is moving forward with new permits and drilling
- 
- 72 Codell wells drilled to date in the play
  - All new drilling is done on 1280 DSU
  - Well Spacing is minimum 4 wells per DSU
    - EOG has experimented with 6 wells per DSU
    - Perf & Plug is typical completion method

### Drilling and permitting as of 1/31/16



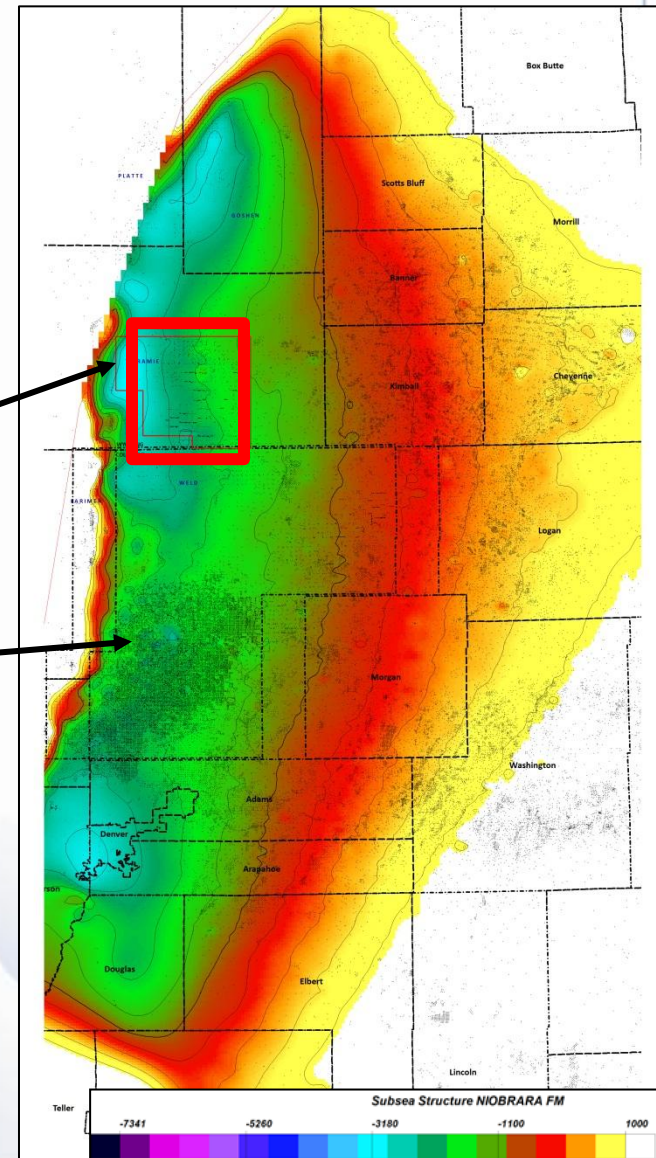
# Regional Structure Map

## DJ Basin Regional Structure on Top of Niobrara FM

- ▶ Asymmetrical basin with thrust contact on the western margin against the Laramide orogeny (Rocky Mountains)
- ▶ Top of Niobrara ranges from 7,200' TVD to 9,100' TVD across the Brennsee/Fairway area

Brennsee/Fairway Area

Wattenberg



# DJ Basin Pay Zone Stratigraphy

## Stratigraphic Column

- Niobrara**

Historically productive at Wattenberg, Silo & several smaller fields

- Oil charged over a wide area with extensive natural fracturing
- Up to 300 ft of fractured calcareous shale reservoir/source rock
- Oil window outside of Wattenberg, GOR ~1,000 scf/bbl

- Codell Sandstone**

- Produced extensively in Wattenberg with some older vertical wells in WY often commingled with Niobrara in vertical wells
- Target of horizontal drilling in both Wattenberg and Brennsee/Fairway area since 2011
- Matrix dominated with some fracture support

- Greenhorn**

- Carbonate rich organic shale with carbonate layers (Lincoln & Bridge Creek LS)
- Gas bearing in Wattenberg with oil shows being noted
- DST in Brennsee area with free oil recovered

- Dakota (D-Sand)**

- Valley fill channel sands & deltaic sands
- Up to 20' thick and with 12% porosity

- Muddy (J-Sand)**

- Widespread marine/fluvial sandstone with one of the most prolific producers in the DJ Basin
- Produces on highs as well as in the center of the basin

- Basal Dakota**

- Widespread marine & fluvial sandstone

The DJ Basin produced over **2.2 Bboe** from Cretaceous reservoirs, primarily from Codell and Niobrara, before horizontal drilling began

System	DJ Basin Formation			Typical Depth	
Upper Cretaceous	Laramie			8,400'	
	Fox Hills Sandstone				
	Pierre Shale	Terry "Sussex" Ss. Mbr.			
		Hygiene "Shannon" Ss. Mbr.			
		Sharon Springs Mbr			
	Niobrara Formation	Niobrara A			★
		Niobrara B			★
		Niobrara C			★
	Fort Hays Limestone Mbr.				8,800'
	Colorado	Codell Sandstone			
Carlile Shale					
Greenhorn		Lincoln Limestone	★		
Graneros Shale		"D" Sandstone			
Lower Cretaceous	Huntsman and Mowry Shales				
	Dakota Group	Muddy ("J") Sandstone		★	
		Skull Creek Shale			
Inyan Kara Group					
Jurassic	Morrison				
	Ralstone Creek				
	Entrada Sandstone				



Producing  
Zones



Potential  
Zones

# Paleogeographic Setting

## *Western Interior Cretaceous Seaway (85 Ma)*

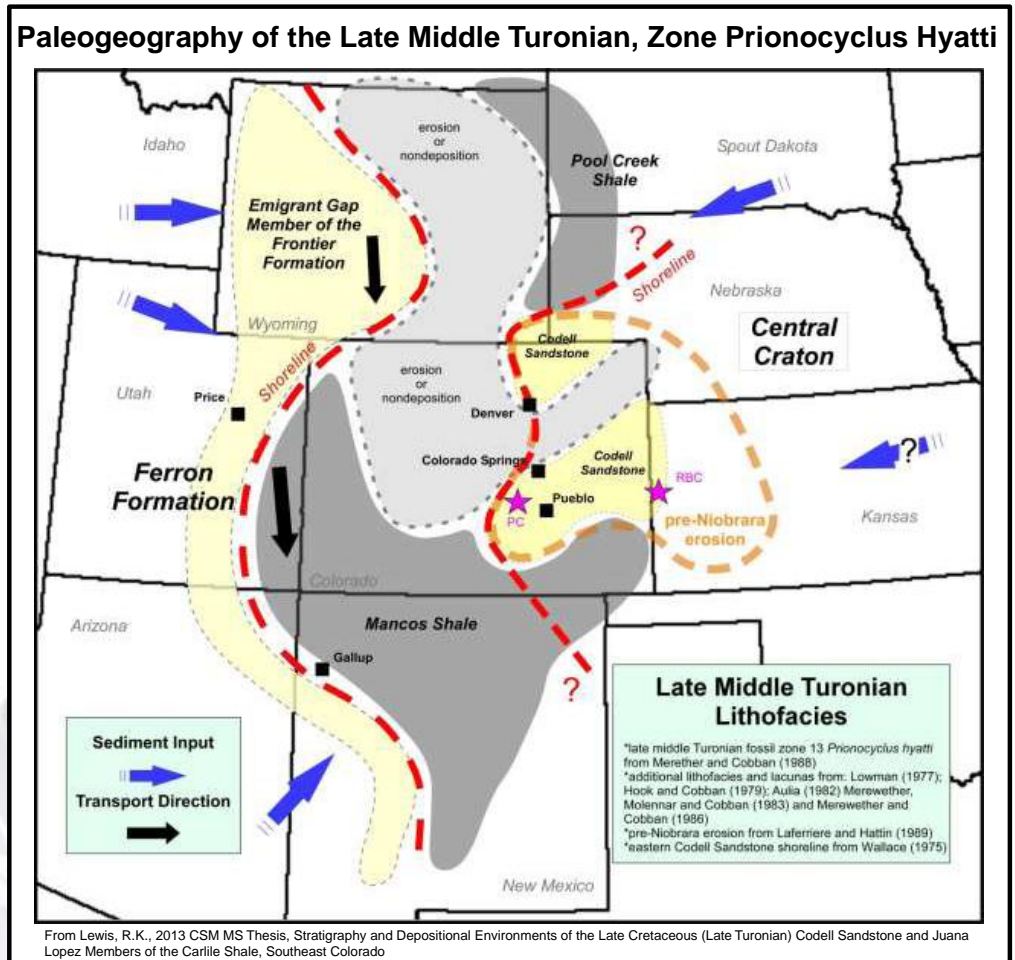
- ▶ Western Interior Cretaceous Seaway (WIC) is asymmetric foreland Cretaceous seaway from Arctic to Gulf of Mexico
  - Following regional Codell Sandstone deposition in low stand conditions, the Niobrara deposition occurred during high sea level conditions resulted in coccolith-rich carbonate sedimentation
- ▶ Niobrara deposition took place over a wide area and was later broken up by the Laramide orogeny into a variety of Rockies Basins: Denver Julesburg, Powder River, North Park, Sand Wash, Piceance, and the Green River Basins
  - Basins to the east were further from the uplifts and received less clastic deposition and more carbonates
- ▶ Niobrara is age equivalent with Austin Chalk.
- ▶ Codell SS/Greenhorn FM is age equivalent to the Eagle Ford Shale.



Colorado Beach 85 Ma

# Codell Paleogeography

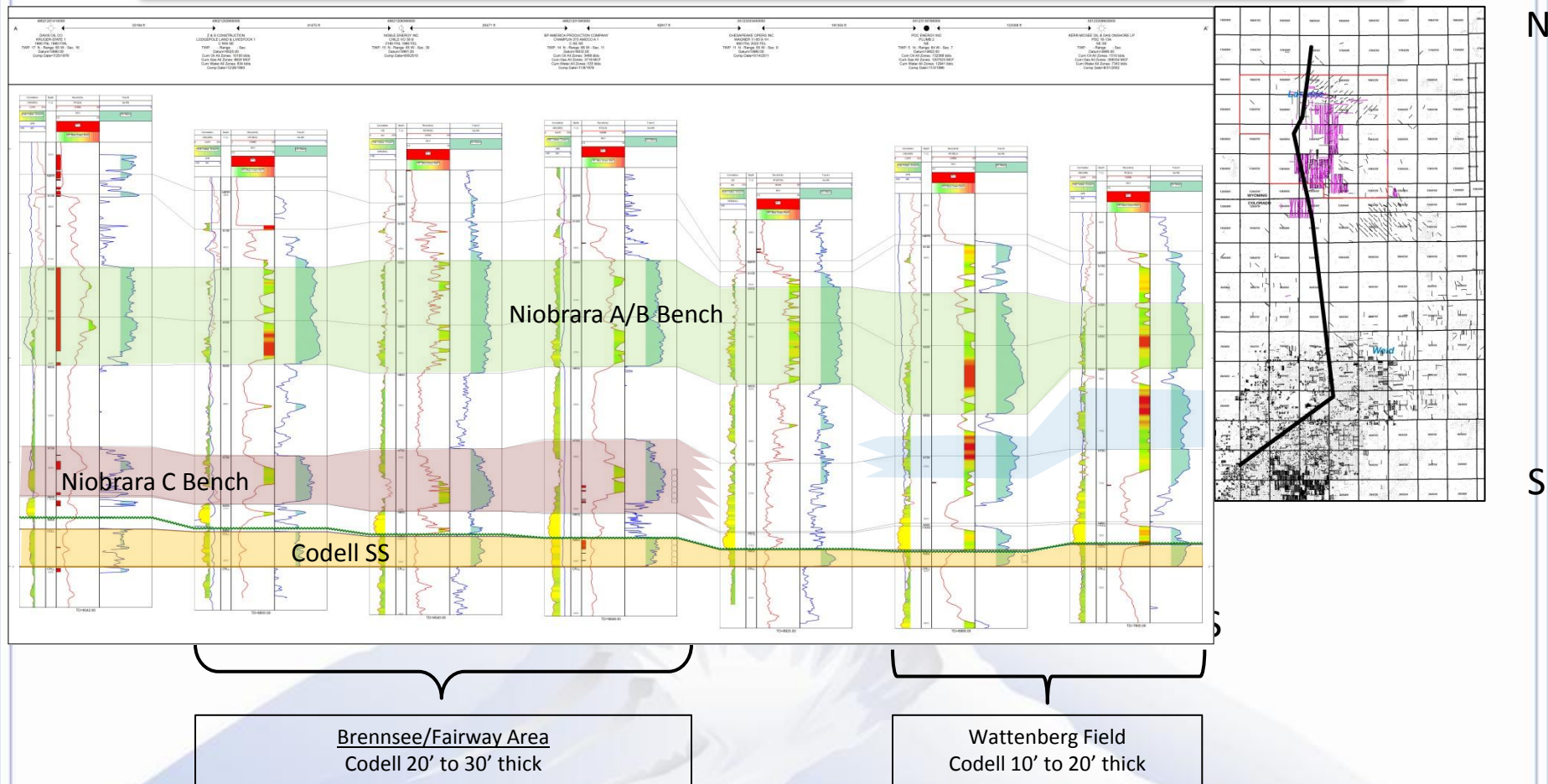
- Deposition occurred along the eastern margin of the Cretaceous Epeiric Seaway
- Represented by sandstones deposited in a shallow marine setting
- Composition is silty, shaly, fine-grained, clay-cemented sandstone
- Common structures include mud drapes, planar horizontal bedding and thin planar cross-bedding and bioturbation
- Thought to be sourced from the North American craton east of the epeiric seaway.

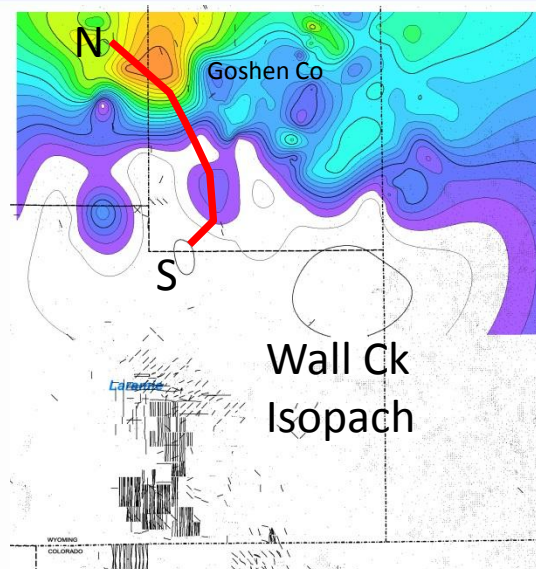
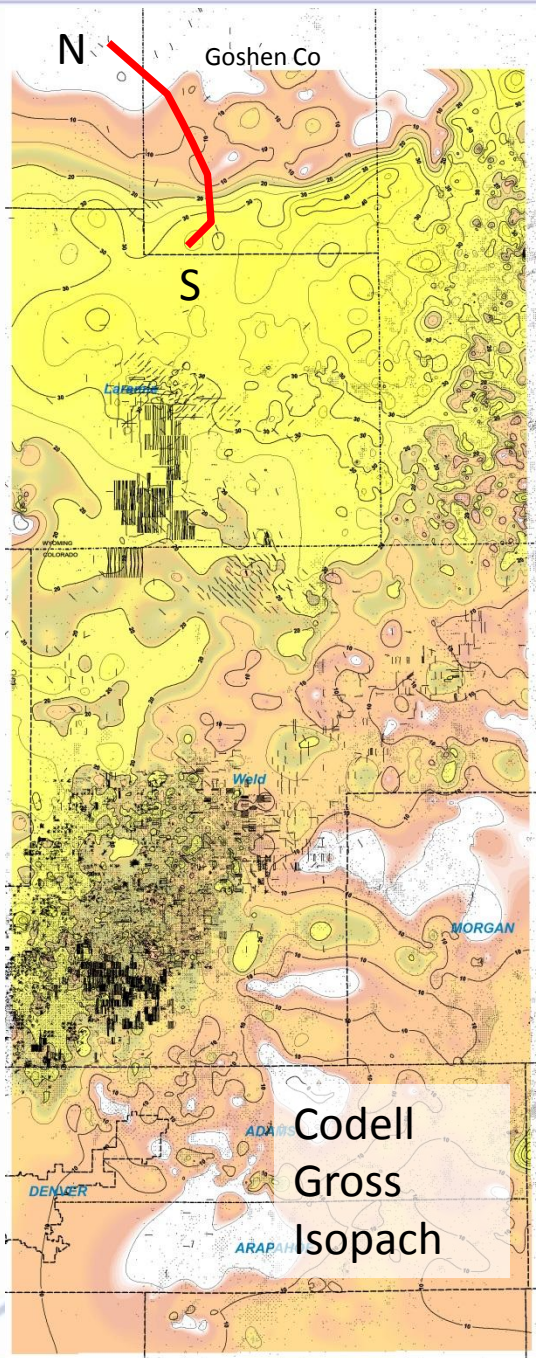


# Regional Codell Sandstone Gross Thickness

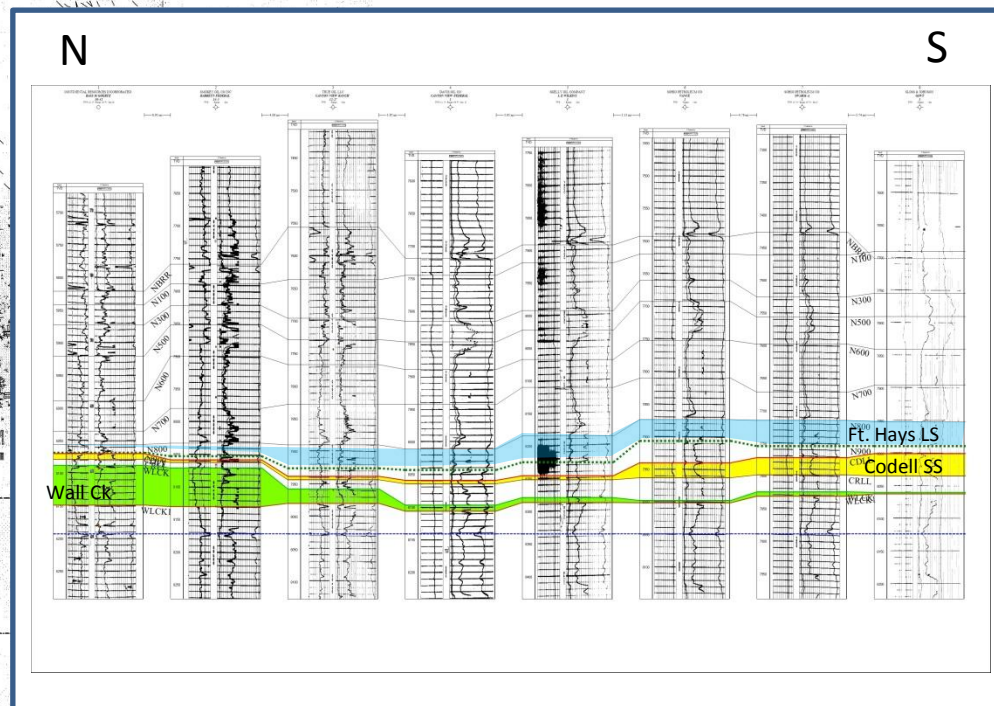
## *N. Wattenberg to Brennsee – Codell Sandstone Thickens to the North*

Codell Sandstone is ubiquitous over a large regional area from Wattenberg Field in Weld County to Laramie County in Wyoming





- Codell SS pinches out in southern Goshen CO, WY
- Wall Ck Member of the Frontier FM develops in Goshen CO and north
- Mistaken for Codell SS in Goshen CO



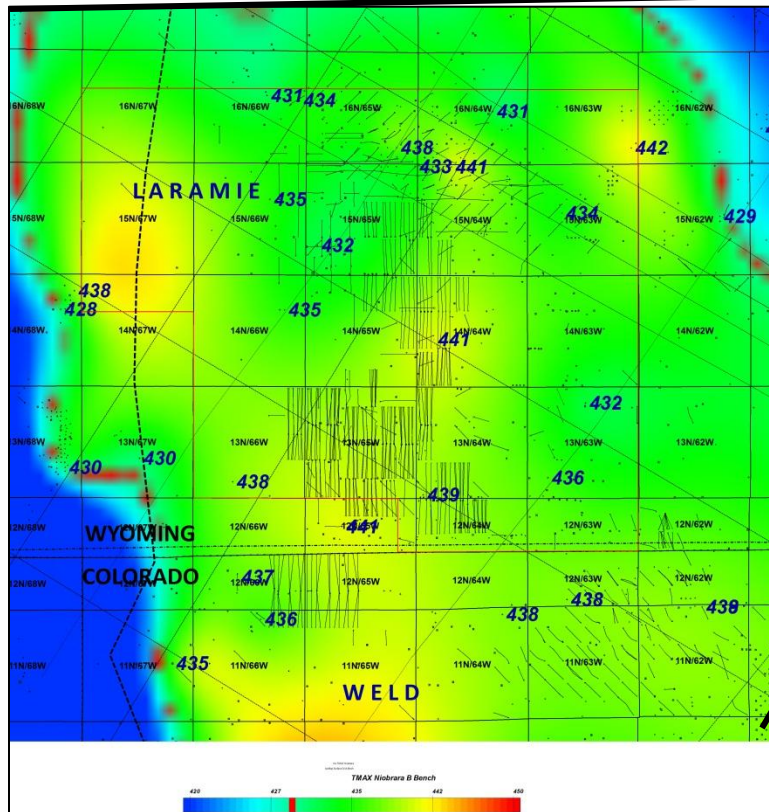
# Regional Thermal Maturity

## Niobrara $T_{max}$ Contours and Burial Histories

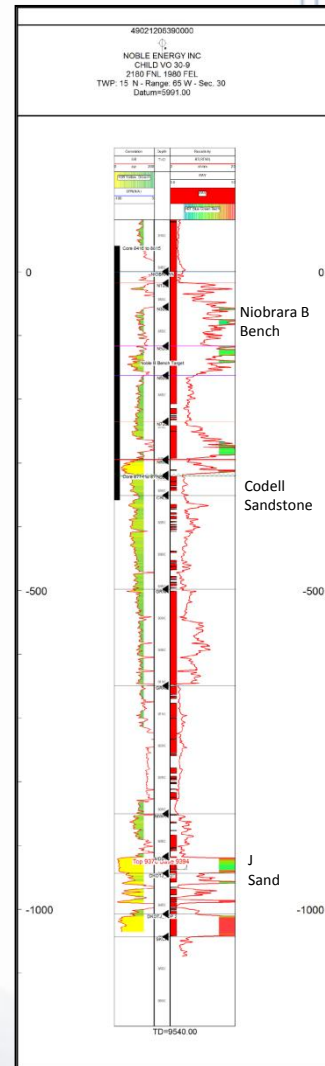
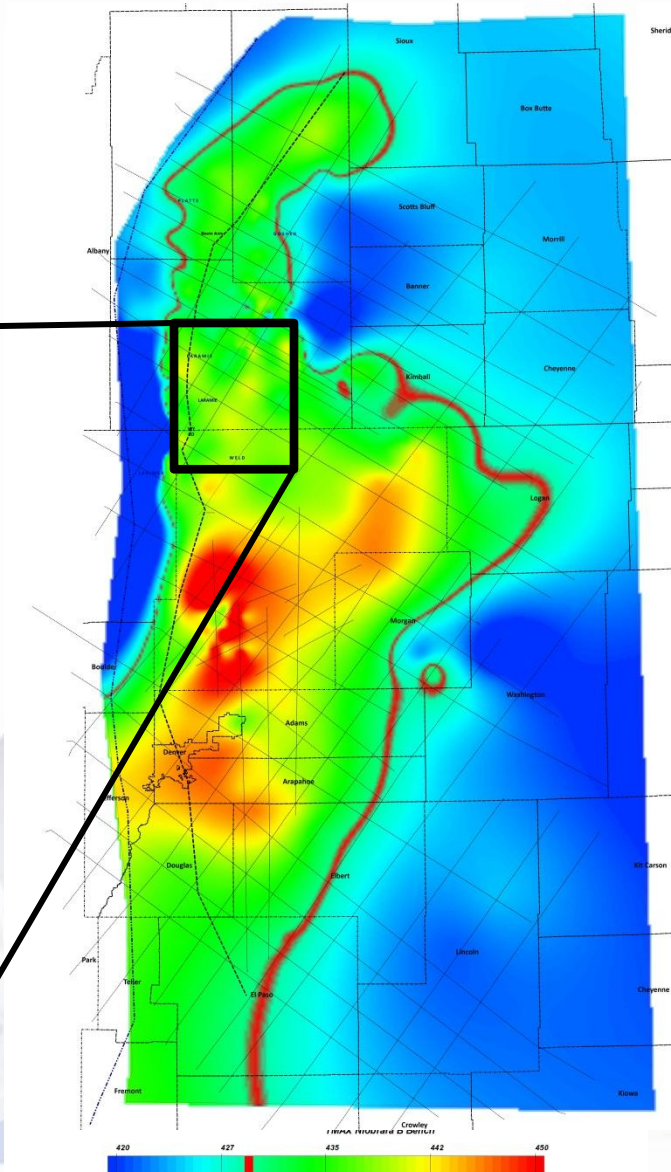
### Type Log

#### Tmax Contours for the Niobrara

- ▶ Brennssee/Fairway area lies within a favorable Thermal Maturity fairway for the Cretaceous petroleum system
- ▶  $T_{max}$  values in Niobrara of 435 to 441 show Thermal Maturity for oil in Project Area in similar structural position as Wattenberg Field



TMAX (color fill) & Basement Lineaments

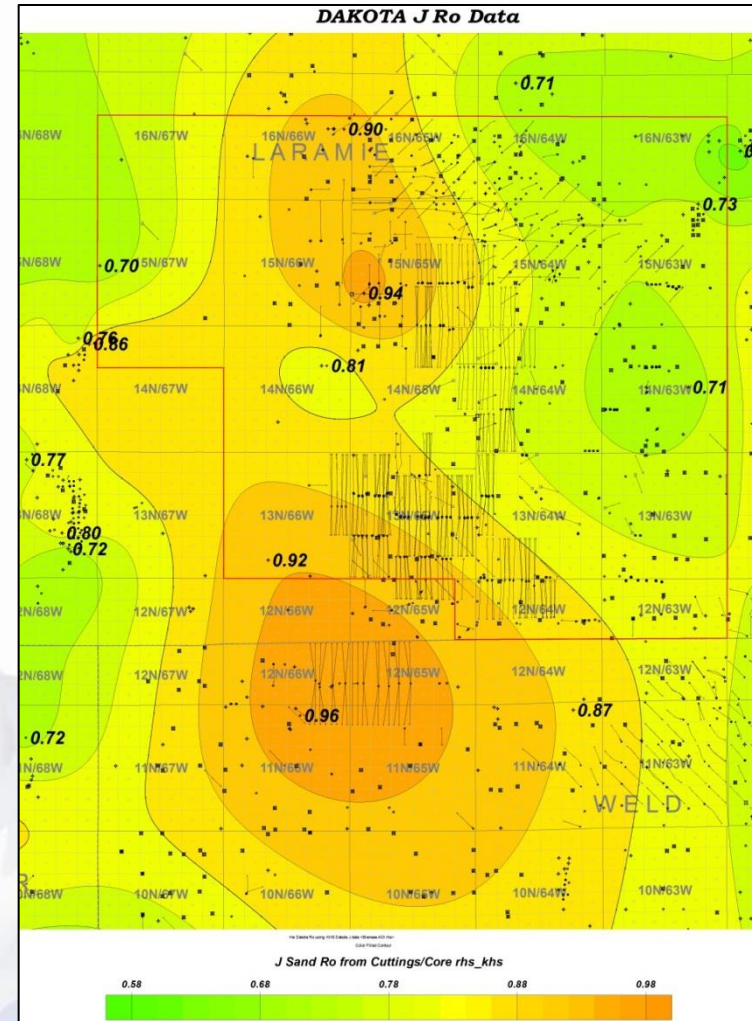


# Regional Thermal Maturity

## *Vitrinite Reflectance (Ro) for J Sand Interval*

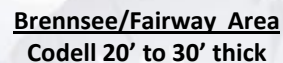
### Overview

- Samples were analyzed using vitrinite reflectance in the J Sand for a view of the thermal maturity of the rocks deeper than the Niobrara



*Maximum Preservation of Codell is in Project Area*

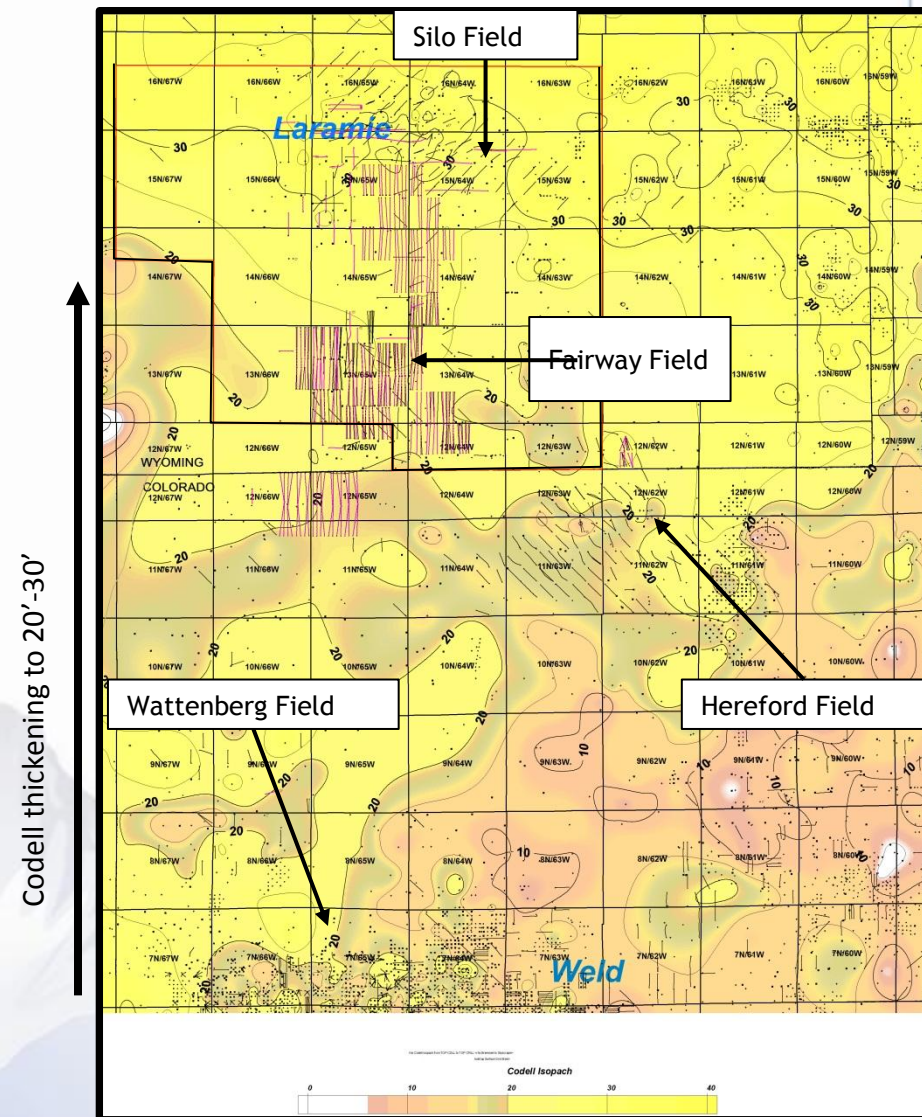
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**Wattenberg Field  
Codell 10' to 20'  
thick**

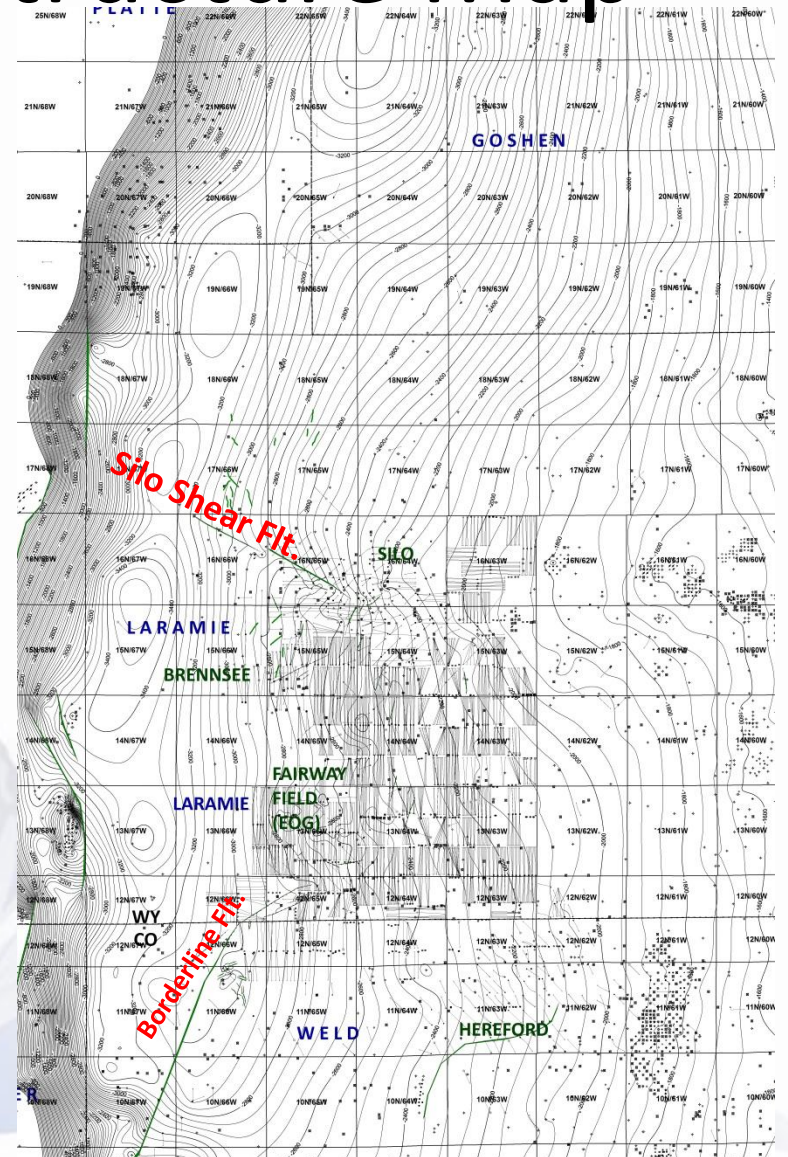
# Codell Isopach in Laramie County, WY

- ▶ Gross Isopach shows Codell thickness ranges from 20' - 30' and is ubiquitous over the Brennsee/Fairway Area
- ▶ Gross sandstone thickness is comprised of:
  - Upper bioturbated
  - Middle section of laminated to hummocky sandstone
  - Lower bioturbated section of the Codell



# Codell Subsea Structure Map

- Faulting in Silo is not as extensive as previously thought based on modern 3D seismic data.
- Faulting away from Silo and the Borderline Fault is minimal
- Codell TVD ranges from 7,800' to 9,400'

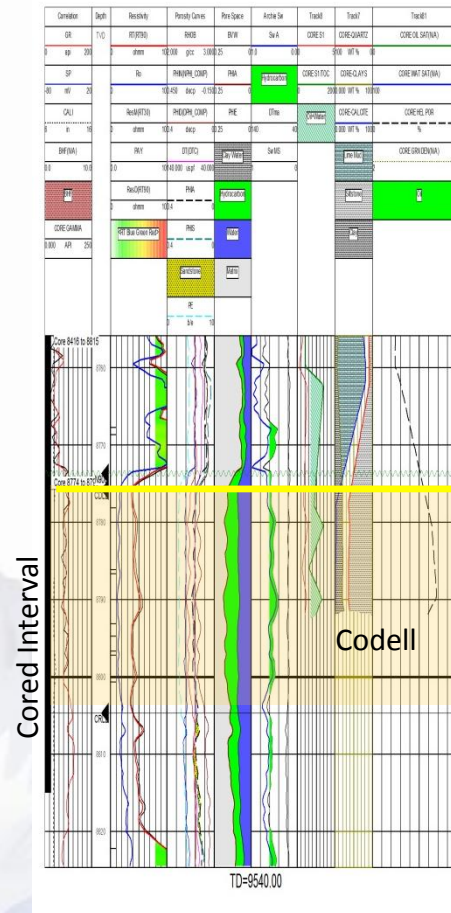


# Codell Core Analysis

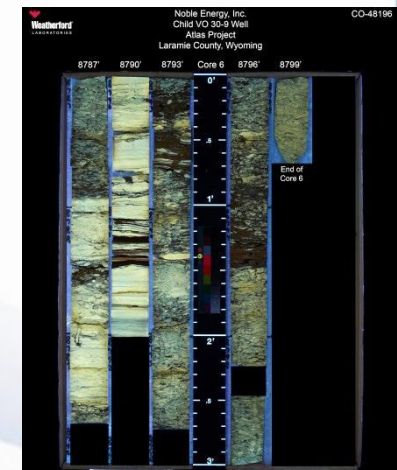
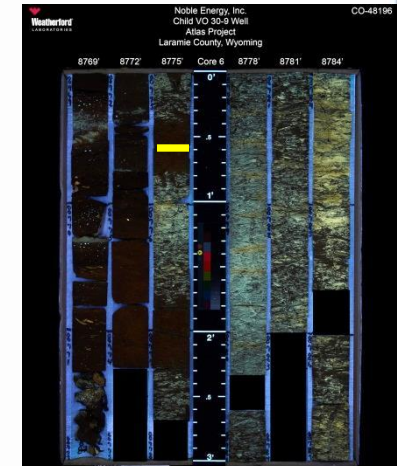
## Distinct Lithologies Within the Codell

Cirque/Noble Child VO 30-09

- **Laminated Facies**
  - Best reservoir characteristics
    - Always saturated with oil
  - Usually in middle of the Codell section
  - Ranges from 2 to 8 feet in thickness
- **Bioturbated facies**
  - Represents a period of lower depositional rates, thus establishing benthic activity that destroyed primary sedimentary fabric
  - Lower permeability and porosity than laminated but significant oil in place and 8.0% to 14.0% porosity
- **Both Facies are charged with oil in Brennsee/Fairway area**
  - Bioturbated facies show s great variability in oil saturation in cores
  - Petrophysics model built using core calibrations



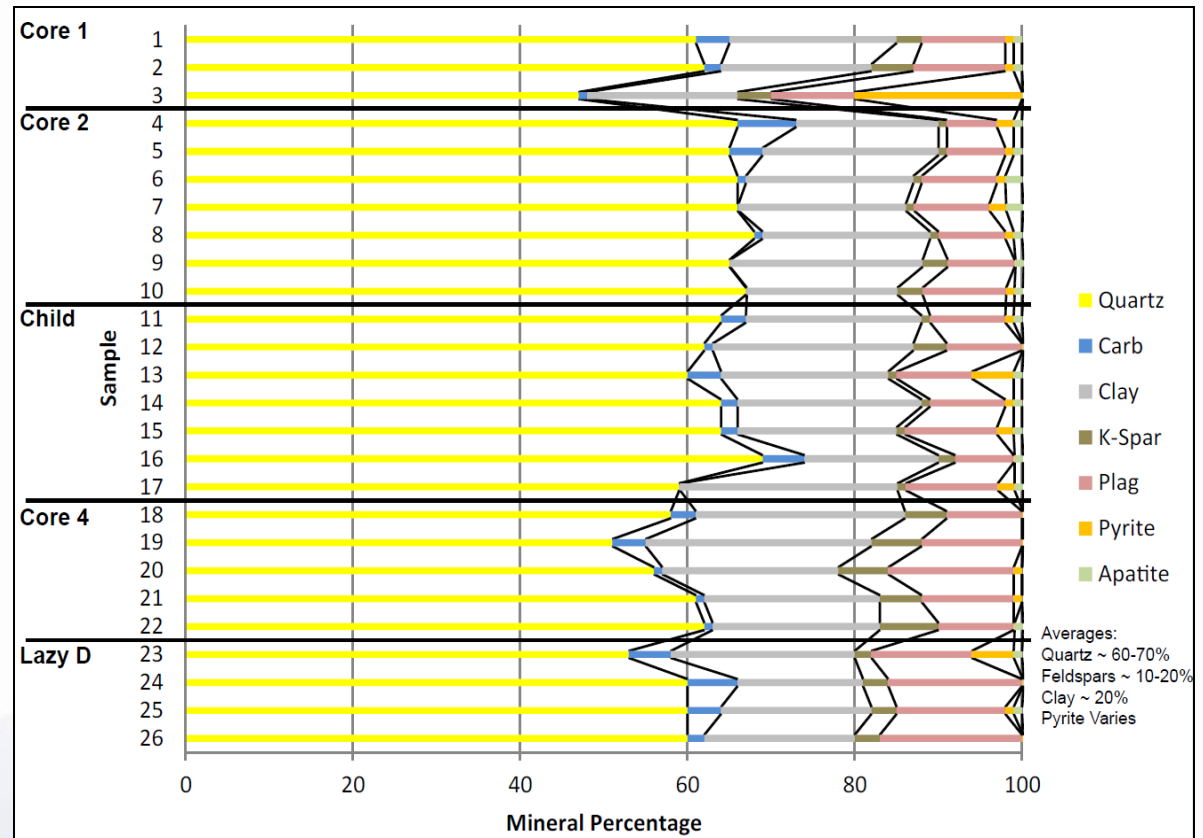
UV Photos of Slabbed Core



# Codell Lithology / X-Ray Diffraction

## Selected Observations

- ▶ Codell sandstone is dominated by quartz with other major minerals being clays and feldspars
- ▶ Minor minerals include Calcite, Apatite, Glauconite, and Pyrite
- ▶ Clays mostly illite with minor mixed layers



**Mineral assemblages are consistent whether in Bioturbated or Laminated Facies**

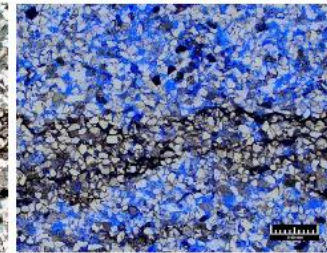
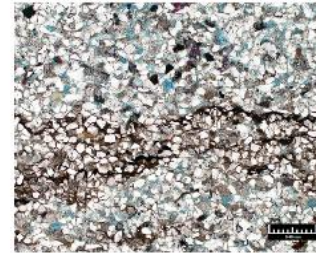
# Codell Thin Section Analysis

- ▶ Thin Sections show porosity in both plain and epifluorescent light
- ▶ Under epifluorescent light intergranular microporosity is apparent in Feldspars
- ▶ Very difficult to differentiate facies in thin section
- ▶ Both facies show comparable amount of porosity in thin section

50x

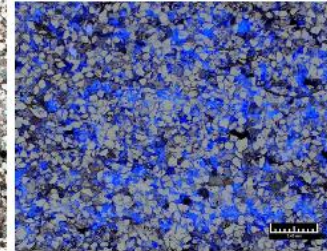
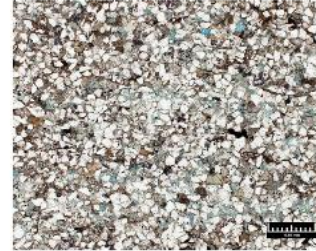
200x

Codell thin section photos show abundant intergranular pores. Epifluorescent light photos show high microporosity accounting for high amounts of bound water in matrix



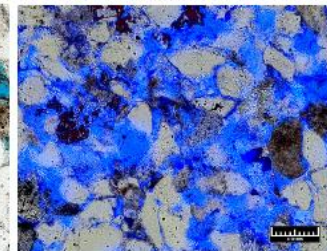
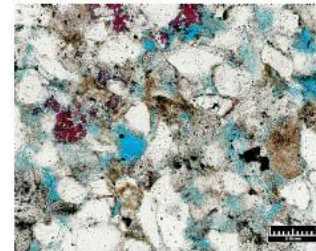
## Laminated

Fine grained to very fine grained sand with interspersed clay. Moderately sorted angular sand grains with intergranular clay



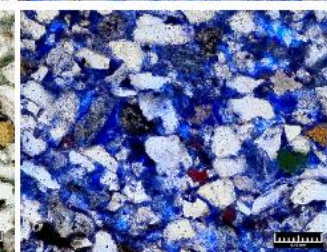
## Bioturbated

Fine grained to very fine grained sand with interspersed clay. Moderately sorted angular sand grains with intergranular clay



## Laminated

Fine grained to very fine grained sand with interspersed clay. Poorly sorted angular sand grains with intergranular clay



## Bioturbated

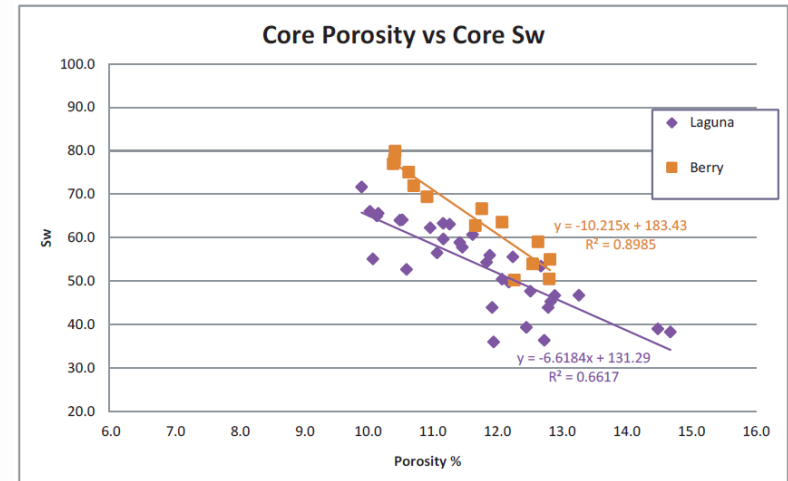
Fine grained to very fine grained sand with interspersed clay. Poorly sorted angular sand grains with intergranular clay

# Codell Porosity and Permeability

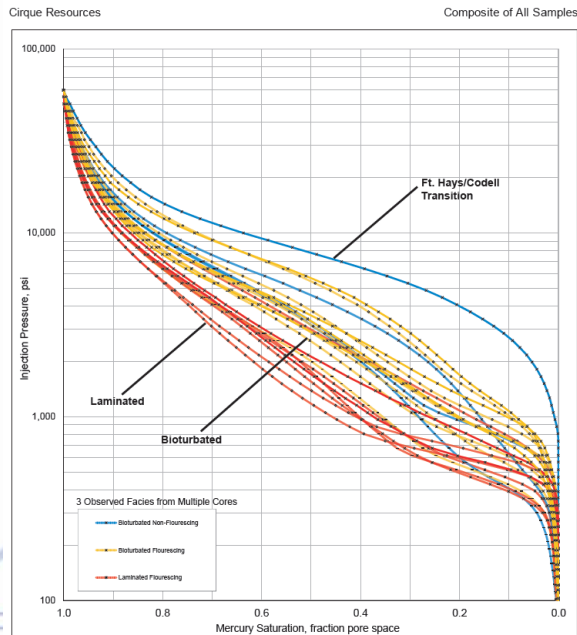
## Selected Observations

- Codell Sw decreases as porosity increases
  - Core data in Sales Area range from 12-14% Phi and 30-50% Sw
- Laminated zone has slightly better reservoir characteristics than bioturbated zone
  - Both facies exhibit good permeability
- Laminated facies is charged initially at lower injection pressures, followed by the bioturbated facies
- In the Sales Area, all of the Codell is oil-charged and both facies contribute to the EUR

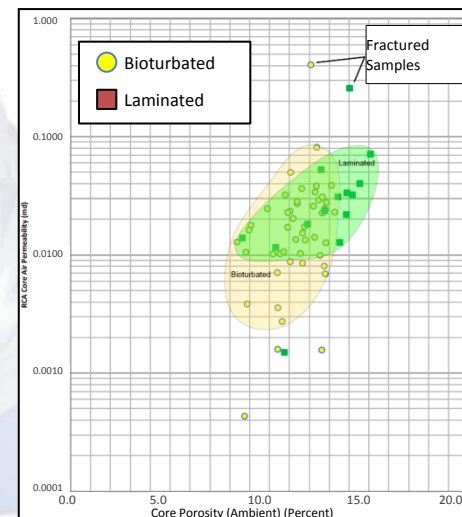
## Core Porosity vs Core Sw



CODELL SANDSTONE Injection Pressure vs Mercury Saturation  
MERCURY INJECTION CAPILLARY PRESSURE



## Core Porosity vs Permeability



- Laminated
- Bioturbated

Laminated and bioturbated facies show largely similar porosity and permeability

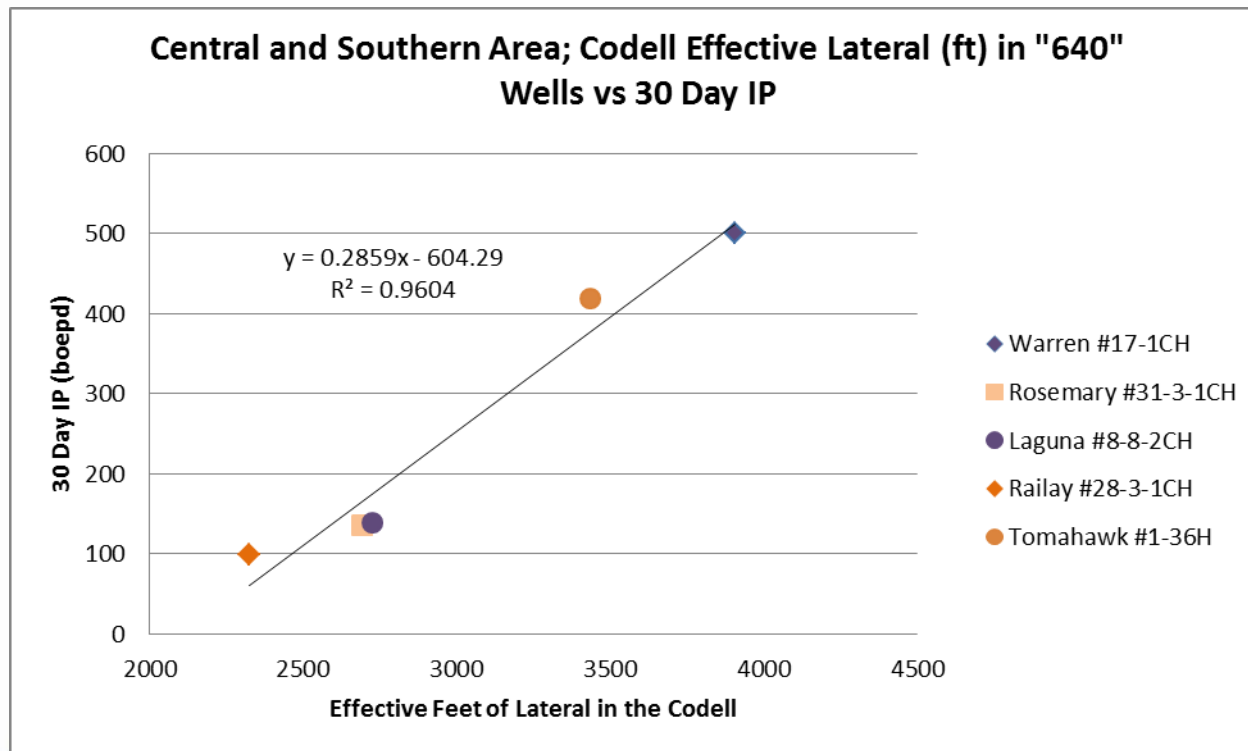
# Fluid Analysis

- Oil gravity = 38° API
- GOR = 900 scf/bbl average
- Water cut ranges from a low of 20% to a high of 45%
- Reservoir pressure has not been directly measured by bottom hole pressure but DFIT & DST indicates a range of .51 to .58 psi/ft gradient



# It is important to be “In Zone”

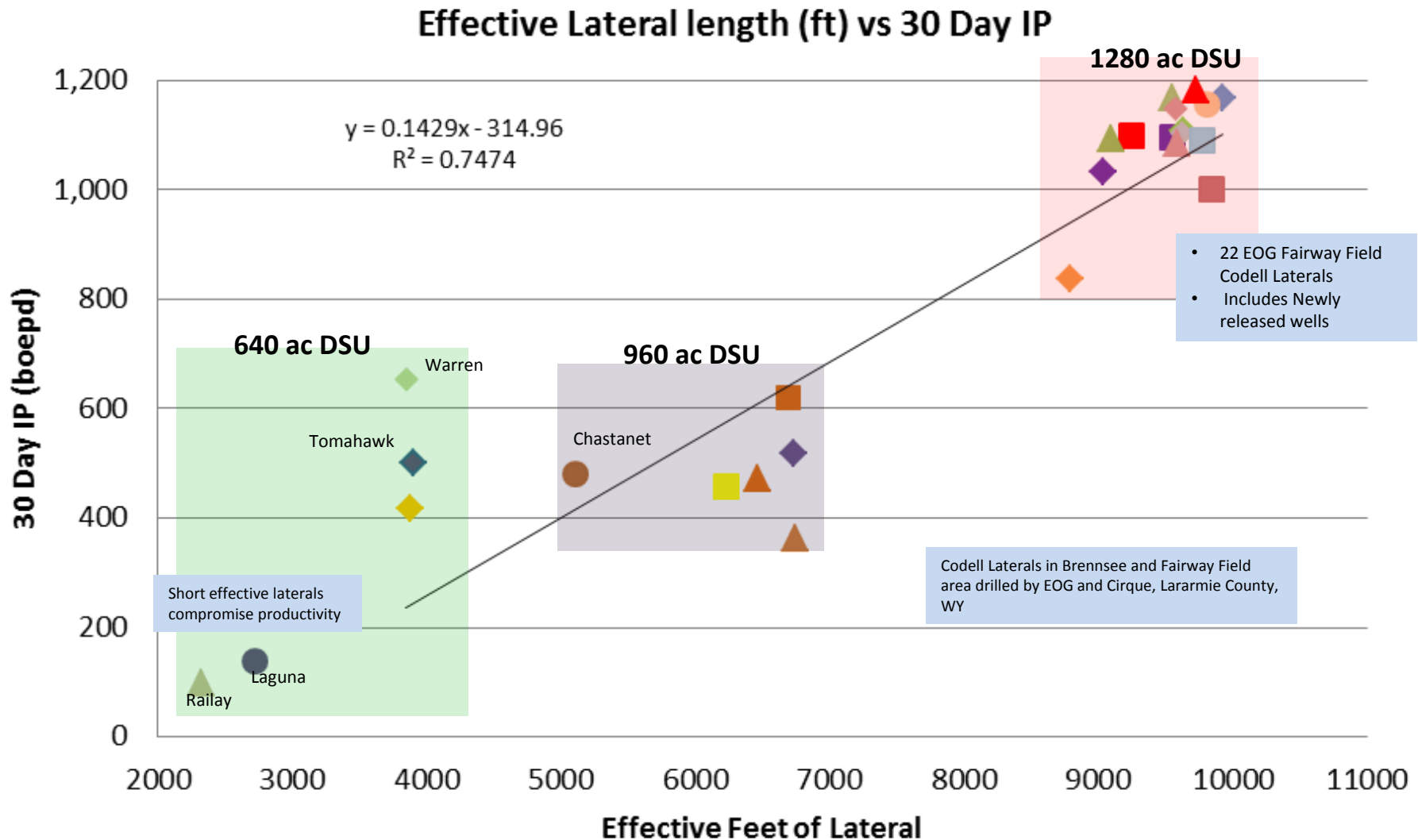
- 640 acre spacing lateral effective lateral lengths need to exceed 3,500' to yield favorable results



Effective Lateral length refers to the amount of lateral actually residing within the Codell Sandstone

# Lateral Length Matters in the Codell!

All new wells are drilled on 1280 ac DSU's



# C Bench Niobrara



# Oil Generation Occurs in C Marl and C Chalk

A

Globe News Pub  
Warren Livestock 11-1

New London Oil  
Jordan 23-6

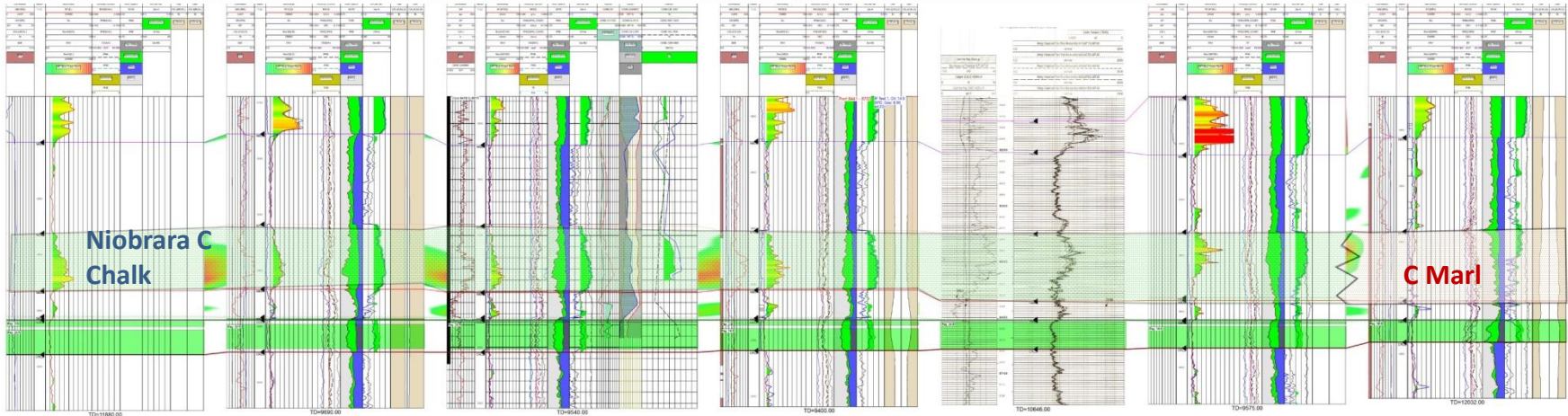
Noble Energy  
Child VO 30-9

Petro-Canada Resources  
Child Ranch 30-1

EOG  
Big Sandy 132-33M

Anadarko  
Shatto 13-65-10-7

Wolverine  
Childers 13-71



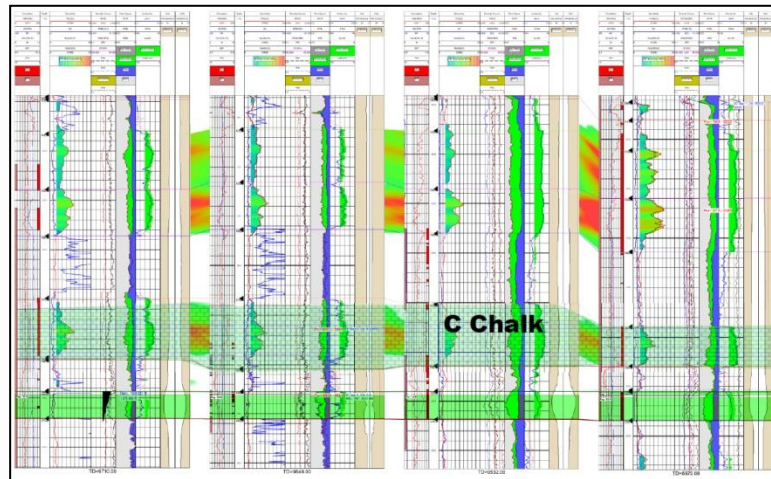
A'

Trans-Texas  
Child Ranch 1-11

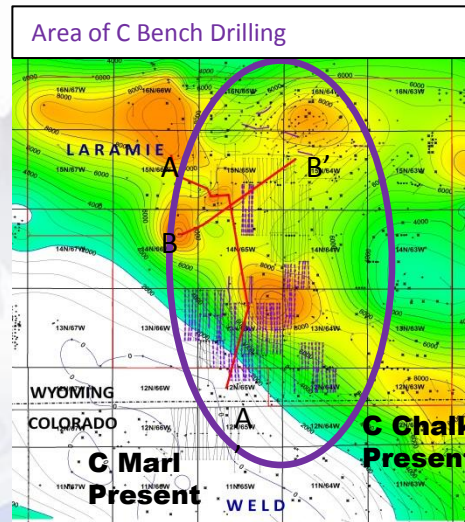
BP  
Champlin 373 Amoco A1

Trans-Texas  
Alexander 1-7

UniOil  
State 1



B'



Cross sections confirm the continuity of the Niobrara C reservoir facies across the Project area.

# Petrophysics / Log Analysis Niobrara C

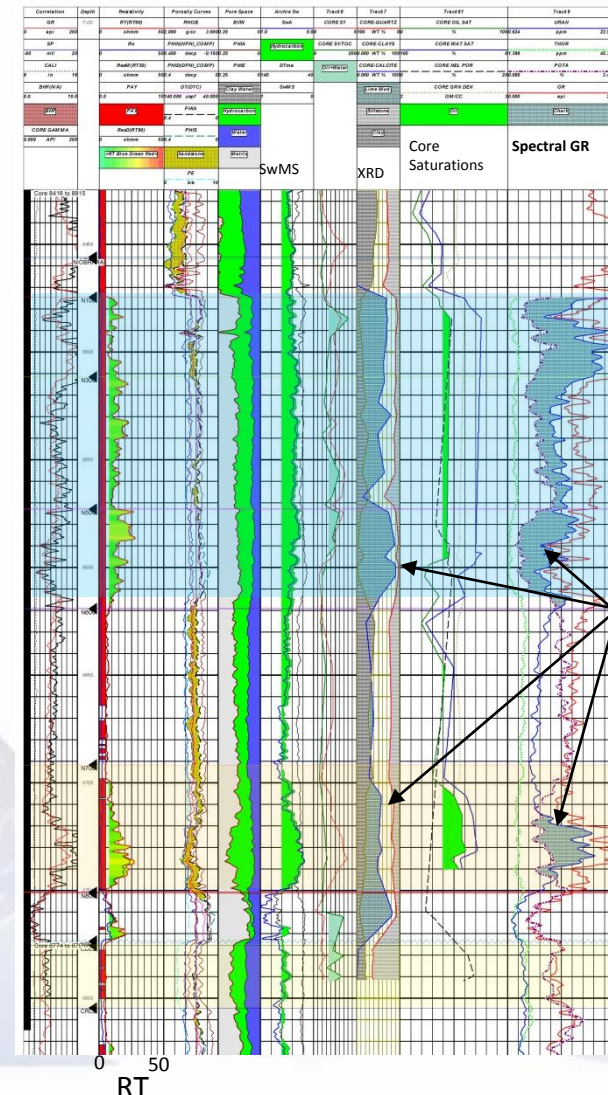
## Analysis Assumptions

- Used Modified Simandeaix due to clay content within chalk
- Porosity calibrated to core measurements
- TOC data makes wireline porosity calculations inaccurate
- **Spectral Gamma Ray confirms XRD in core data for Chalk content in C Bench**
  - Resistivity > 10 ohm is proxy indicator for chalk content

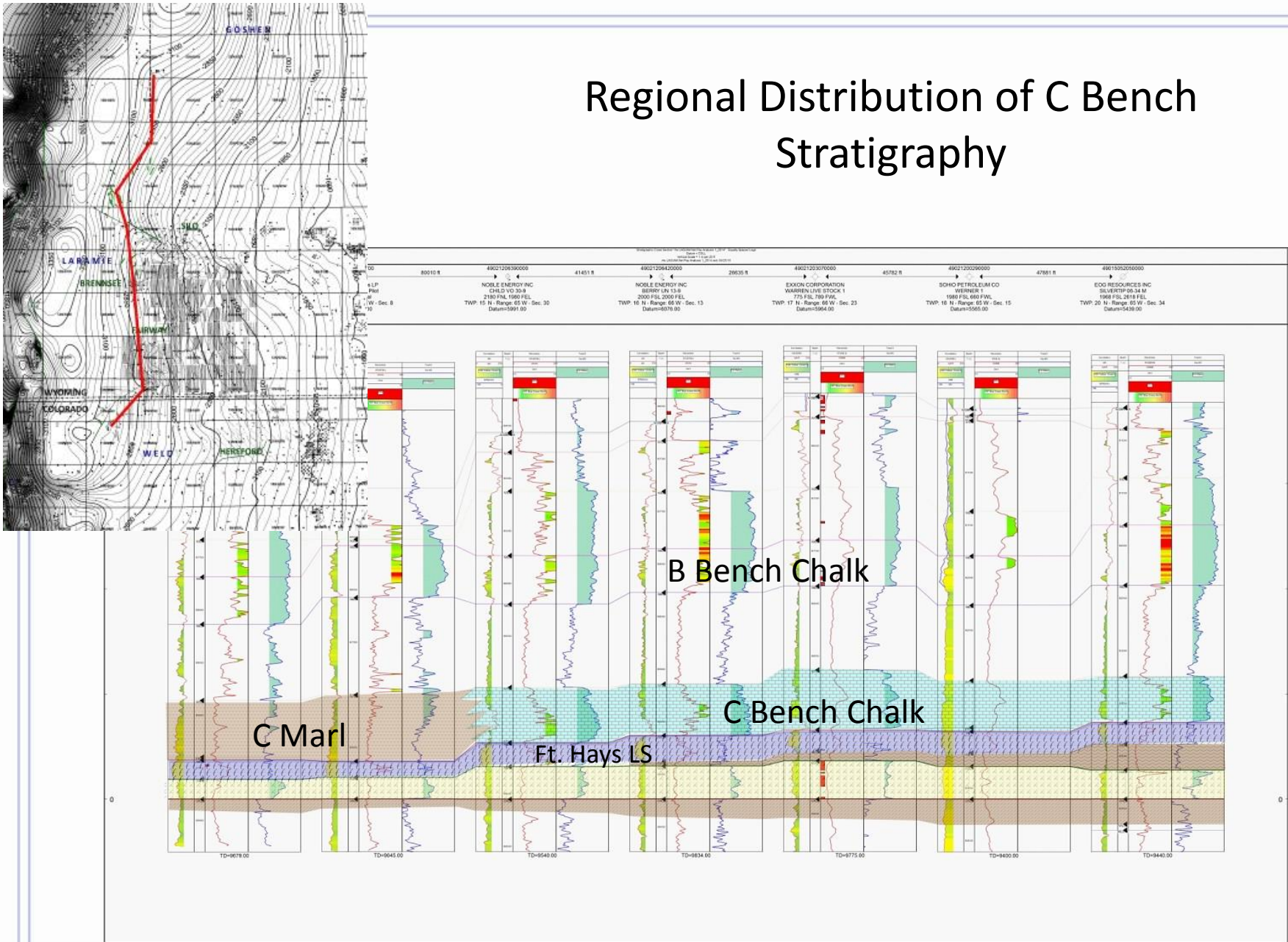
## Modified Simandeaix Equation

$R_w = 0.055$  (48K ppm 200 deg F)  
 $R_{sh} = 1.2$  ohm  
 $Mat\ Den = 2.70$   
 $m = 1.85$   
 $n = 1.87$

## Noble Energy: Child VO 30-9

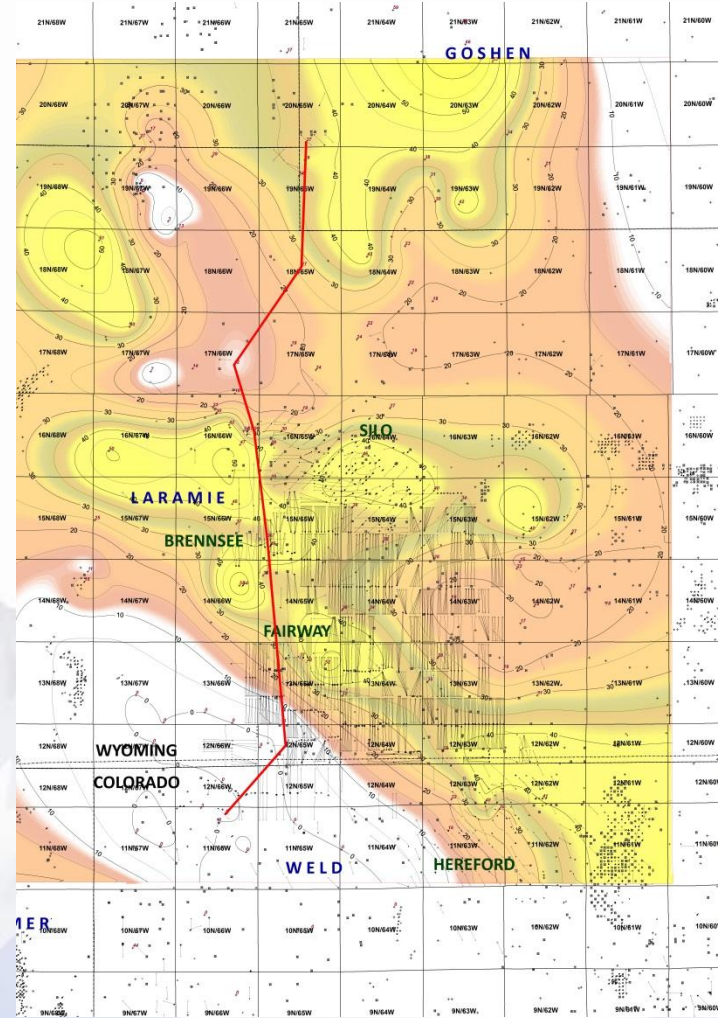
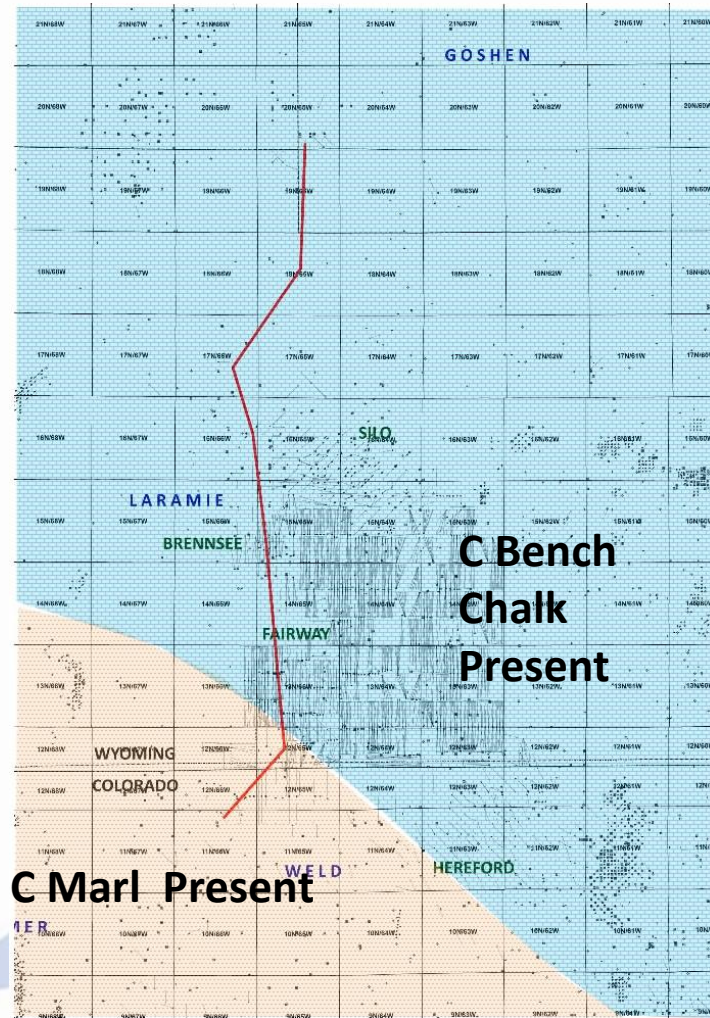


# Regional Distribution of C Bench Stratigraphy



# Distribution of C Chalk

Net Isopach of C Bench > 10 ohm-m



# Oil Sourcing, Generation & Migration



# Codell Oil is from the Niobrara FM.

## Geochemical Synopsis

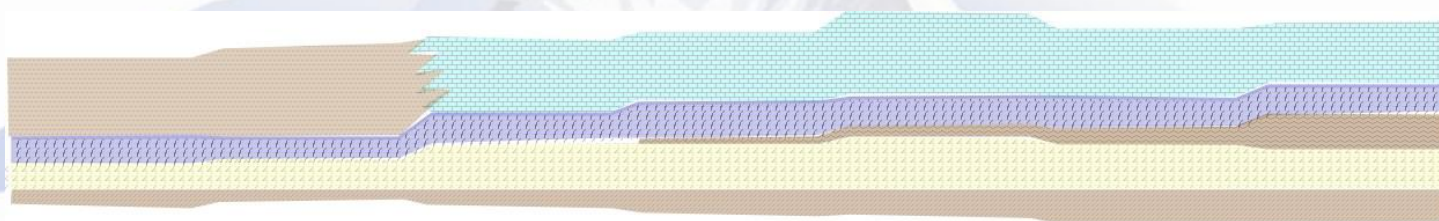
- In GeoMark's Mowry/Niobrara Oil & Source Rock Study (2011), 1600 Rocky Mountain oils were grouped into families which share common sources based on genetic-specific biomarkers and stable carbon isotope compositions using multivariate statistics (for methodology see Zumberge et al., 2005, AAPG Bul., 89, 1347). Oils generated from the Mowry and Niobrara comprise sub-families of the major Cretaceous Marine Shale Family 1 as suggested by their respective reservoir occurrence.
- In a previous Cirque Study (May 15, 2014), four Codell-reservoired oils from Cirque Resources (Dewey 7-9-1CH, Rosemary 31-3-1CH, Rimrock 33-4-6-2CH, & Gaviota 35-12-1CH) were similarly analyzed and statistically compared to oils in the Mowry/Niobrara study. In the present study, another two (2) Codell-reservoired oils are compared (Railay 28-3-1CH & Laguna 8-8-2CH). The Geochemical Summary Sheets are shown in the Appendix and an Access database provided with all geochemical analyses.
- When added to the statistical 'mix', the two new Codell Cirque oils type as Niobrara Family 1.2.
- A number of thermal maturity sensitive biomarker ratios (C27 & C29 terpane Ts/Tm, C30 diahopane/hopane, C27 diasterane/regular sterane & triaromatic steranes), not used in the genetic-based statistics, were converted to the primary principal component then assigned a vitrinite reflectance value (VRE) to each oil sample. The Laramie Co. Laguna oil is slightly more mature than the Weld Co. Railay oil (0.80% vs 0.76% VRE, respectively).
- Neither of the new oils contain abundant high molecular weight n-paraffins (C37+) with an even over odd carbon number preference indicative of bacterial waxes.

SampleID	County	Field	Well	% VRE	SR Family	Reservoir	Lat	Long	API#
WY1317	Laramie	Wildcat	Dewey 7-9-1CH	0.79	Niobrara 1.2	Codell	41.2817	-104.6944	49021210020000
WY1318	Laramie	Atlas	Rosemary 31-3-1CH	0.81	Niobrara 1.2	Codell	41.2312	-104.7300	49021210180000
WY1319	Laramie	Wildcat	Rimrock 33-4-6-2CH	0.88	Niobrara 1.2	Codell	41.2247	-104.6649	49021210660000
WY1320	Laramie	Wildcat	Gaviota 35-12-1CH	0.78	Mowry 1.1	Codell	41.3119	-104.7479	49021210040000
CL0916	Weld	Wildcat	Railay 28-3-1CH	0.76	Niobrara 1.2	Codell	40.9852	-104.7831	51233986300000
WY1403	Laramie	Wildcat	Laguna 8-8-2CH	0.80	Niobrara 1.2	Codell	41.0221	-104.6757	49021211760000

GeoMark

2 Codell Oils Laramie Co

24 March 2015

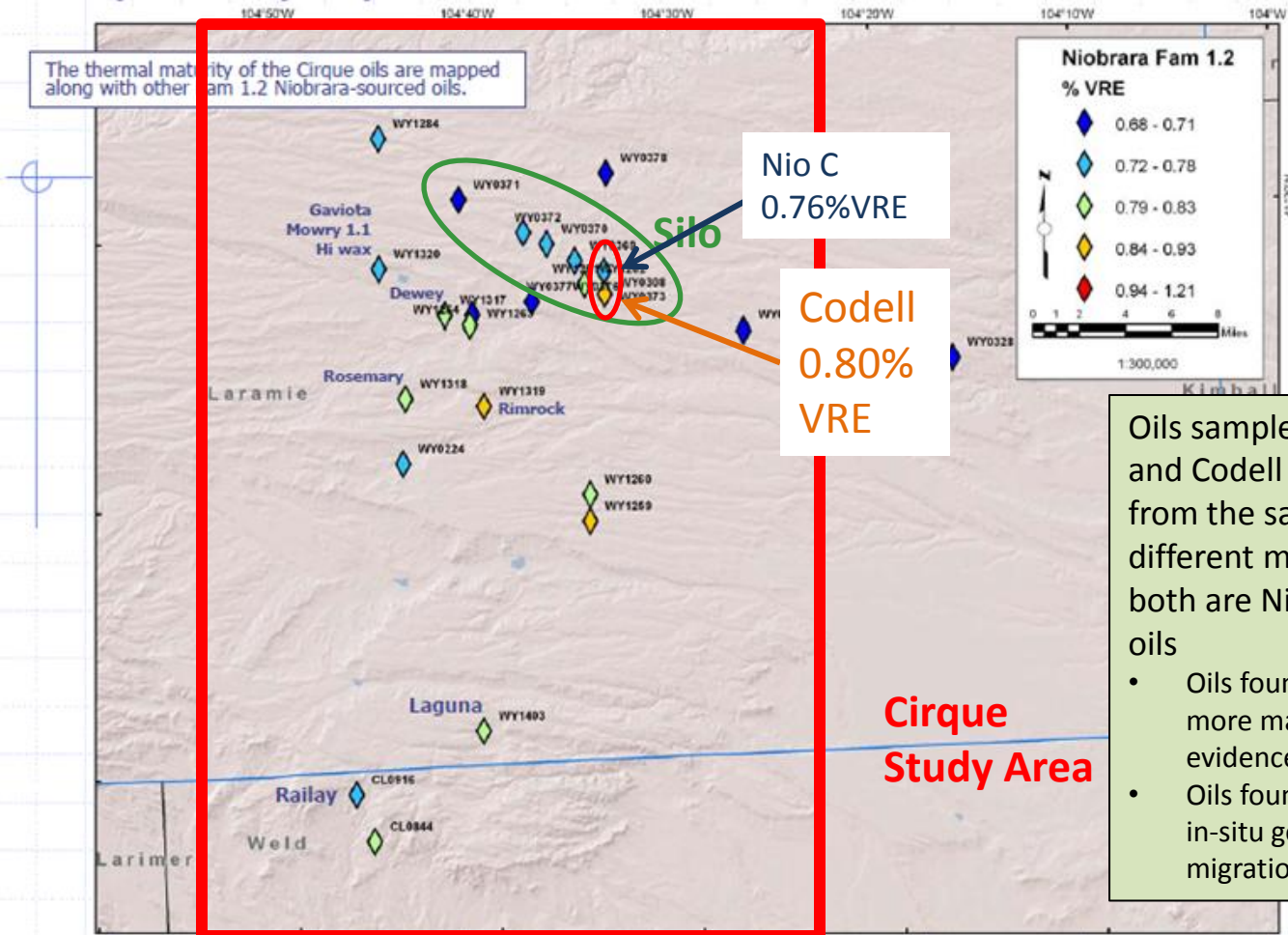


# Distribution of Oil Maturities from Niobrara Sourced Oils

Oil found in Codell SS is generally higher maturity than oil found in Niobrara, though all sourced from Niobrara

## Oil Family Maturity Map

The thermal maturity of the Cirque oils are mapped along with other Fam 1.2 Niobrara-sourced oils.

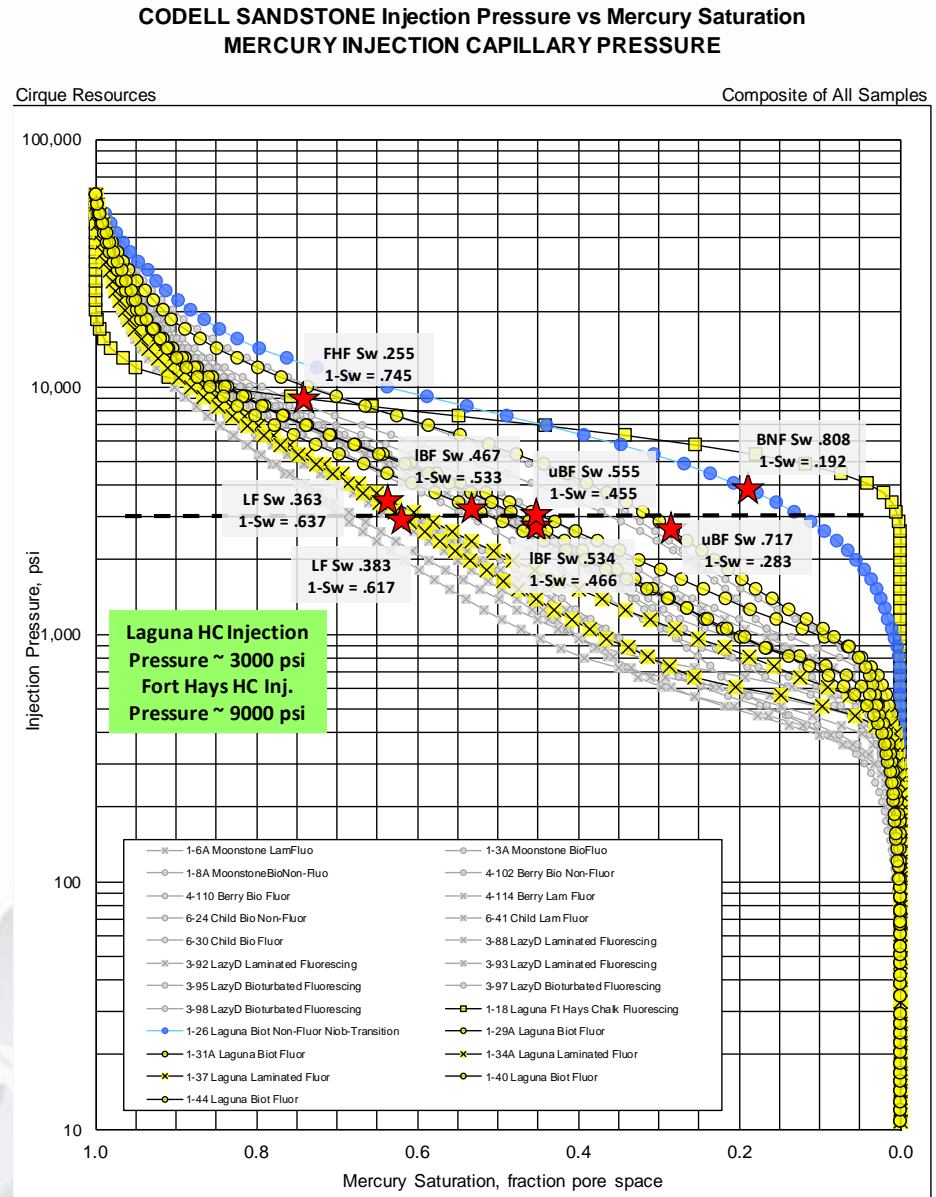


Oils sampled from a Niob C and Codell well drilled from the same pad have different maturities though both are Niobrara-sourced oils

- Oils found in Codell are more mature and show evidence of migration
- Oils found in Nio C indicate in-situ generation and no migration

# Mercury Injection Capillary Pressure as a proxy for oil saturation

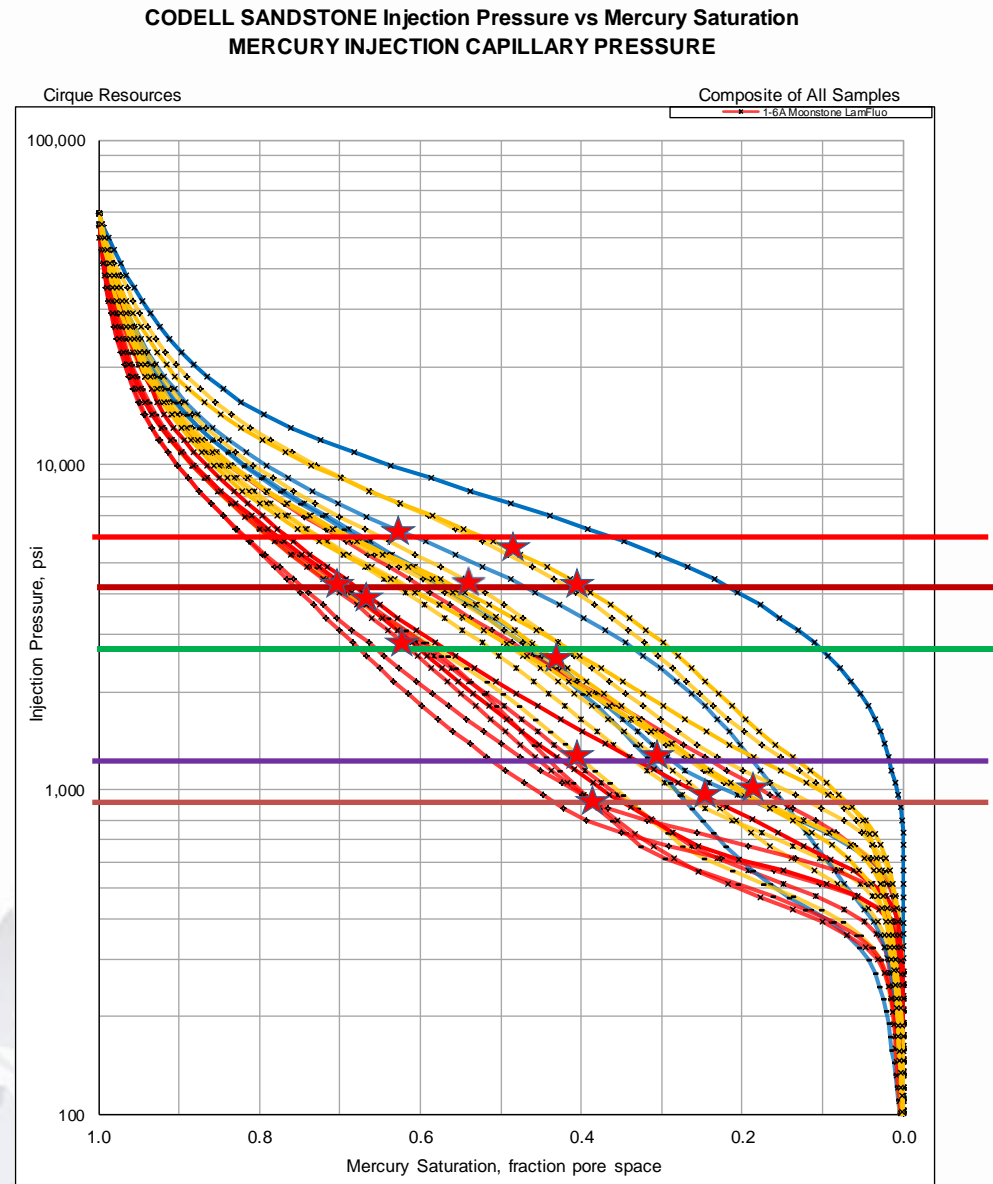
- Plot (1-Sw) from RCA analysis along the capillary pressure curve for each sample
- Note the pressure line that most of the data points relate to
  - Pressure is determined through mercury injection to reach any given mercury saturation
  - A proxy for oil migrating into the rock displacing movable and capillary bound water
  - The higher the pressure wave of oil being injected into the rock the higher the oil saturation of the rock will ultimately become



# Plotting 1-Sw regionally suggests an oil migration history for the Codell SS

	Avg Inj Press
Well #1 –	5300 psi
Well #2 –	3000 psi
Well #3 –	2500 psi
Well #4 –	1200 psi
Well #5 –	900 psi

Higher Injection Pressure correlates with higher So for any given well.

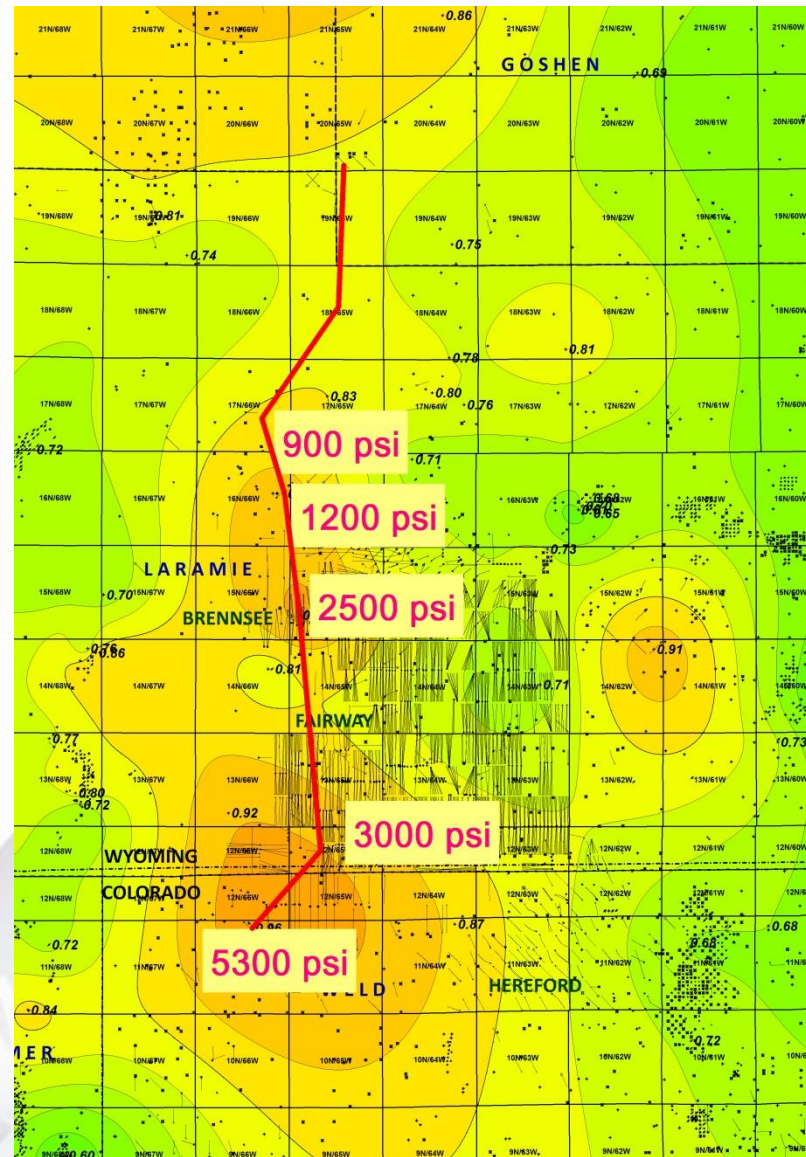


★ RCA 1-Sw data points

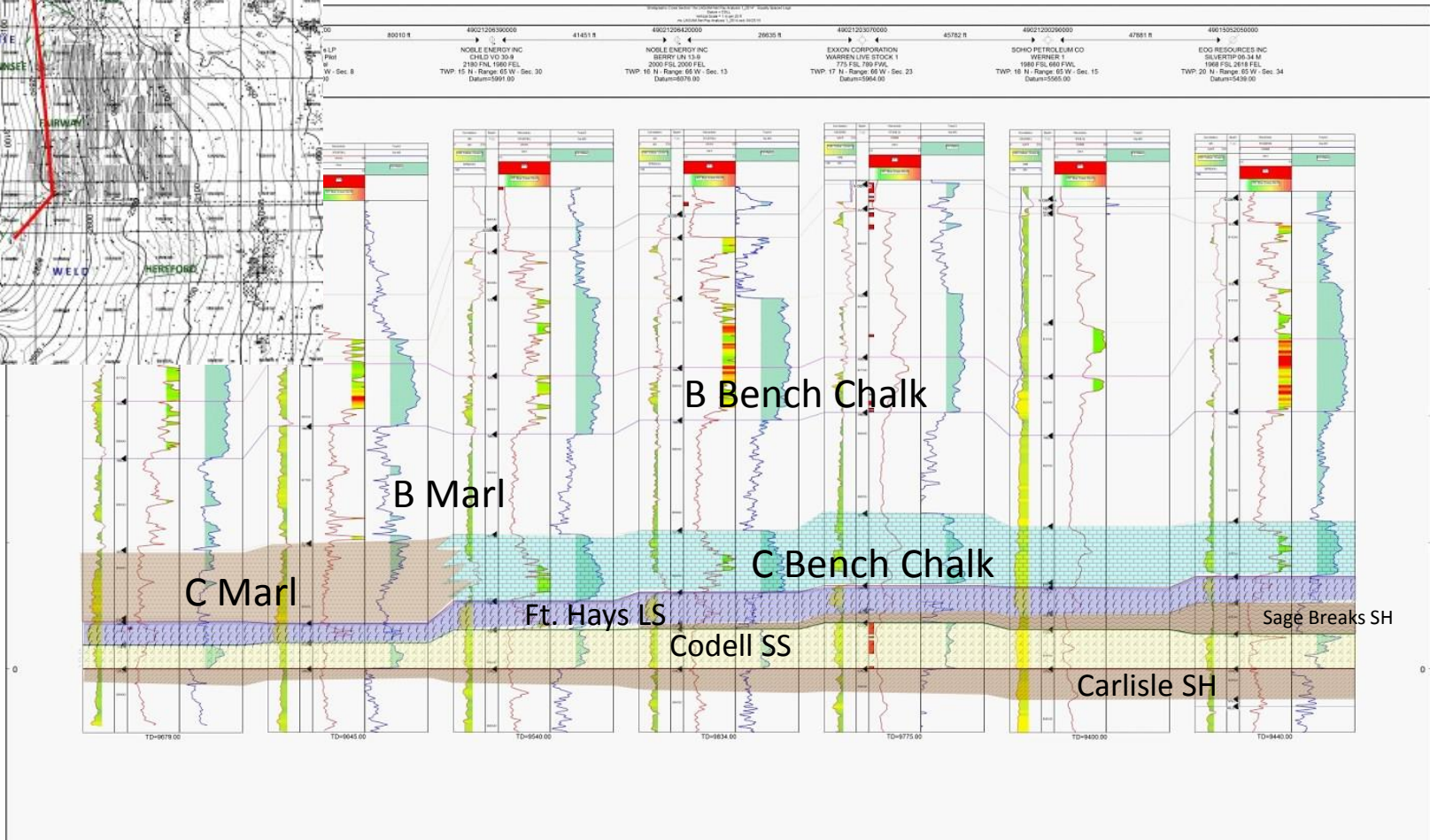
RCA= Routine Core Analysis

# Thermal Maturity Vitrinite Reflectance in the J Sand

- More variability in the J Sand Ro
- Highest thermal maturity in the area near the state line
- Injection Pressures from MICP data are listed next to the wells cores were taken from

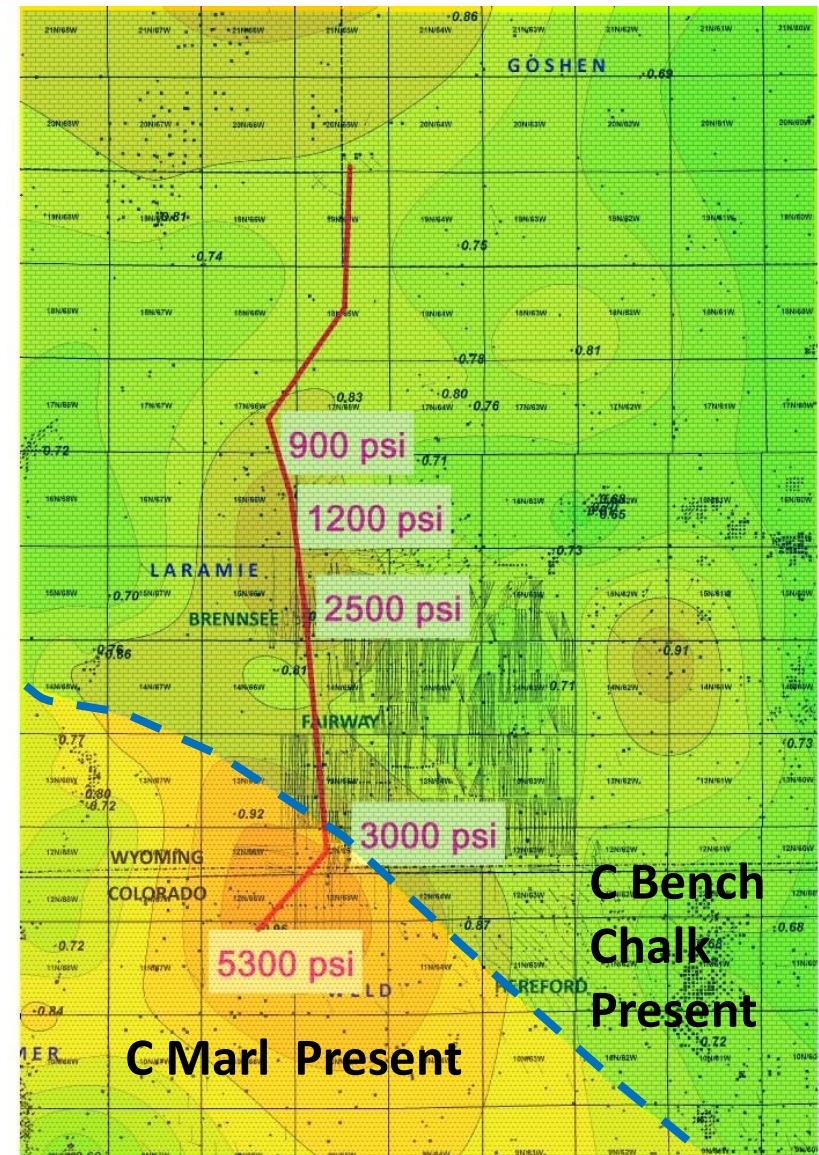


A topographic map of the Fort Collins area in Colorado. The map features a grid of latitude and longitude lines. Contour lines are drawn at 100-foot intervals, with major contours labeled every 500 feet (500, 1000, 1500, 2000, 2500, 3000, 3500). A red line is drawn across the map, starting near Goshen in the northeast, going south, then west, then south again, and finally west towards Herndon. The line passes through or near Larimer, Weld, and Herndon. The map also shows the Fort Collins city area, including the airport and various roads. The state boundary between Wyoming and Colorado is indicated by a dashed line.



## Niobrara C Chalk Distribution relative to J Sand Ro Thermal Maturity

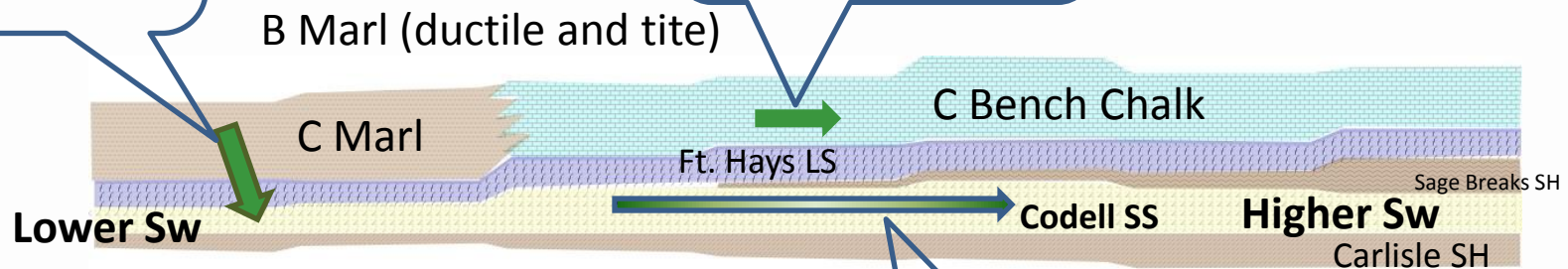
- Well with highest oil saturations and highest MICP injection pressures is located where the C Chalk is not present
- C Marl is organic-rich
  - Catagenesis without an adjacent chalk to “inject” into
  - Oil works through fractured Ft. Hays Limestone into the Codell



# Generation and Expulsion Model

Oil Generation in the C Marl  
Oil is expelled through fractured Ft. Hays into Codell SS

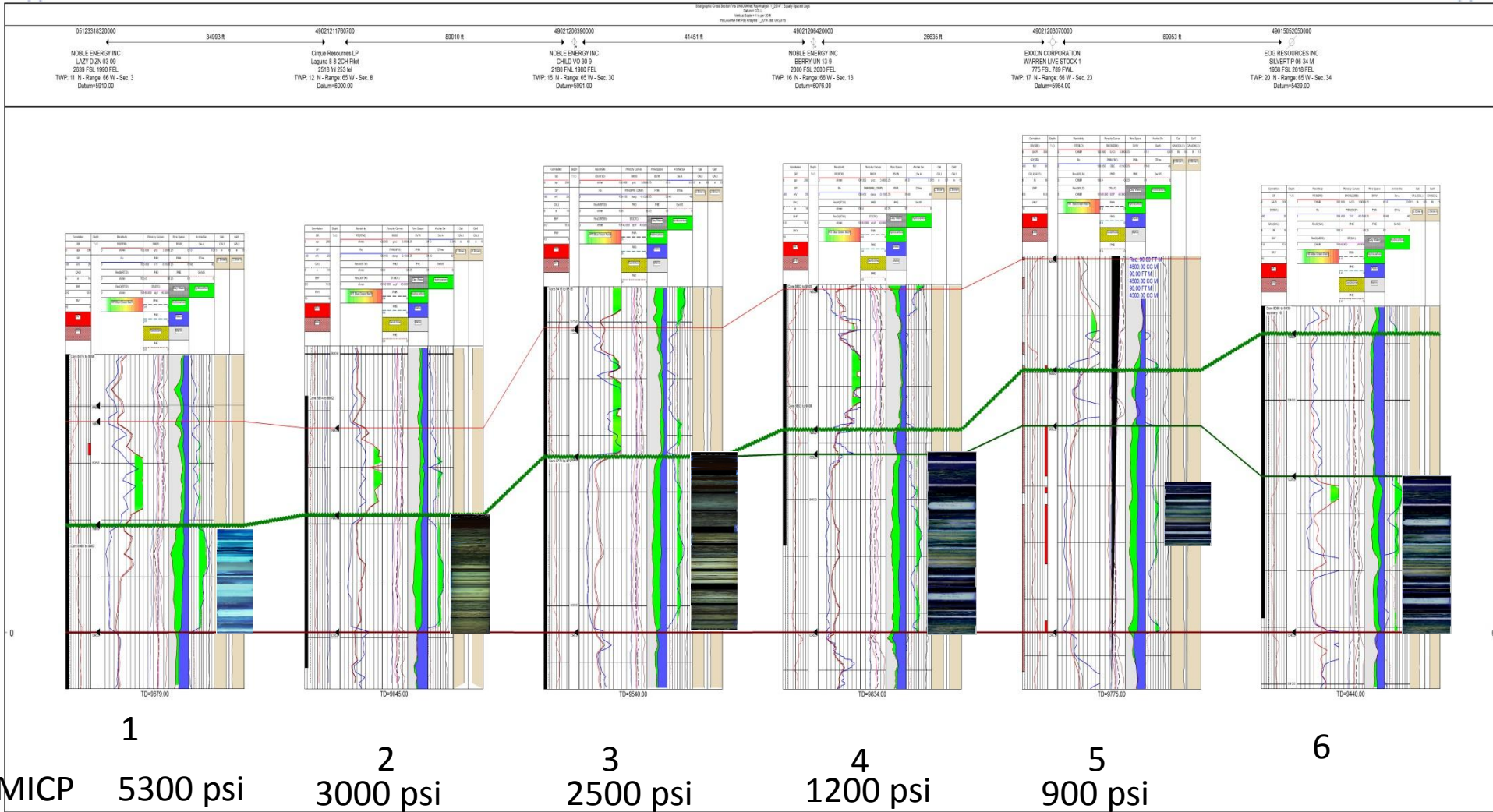
Oil generated in C Chalk finds porosity to occupy in the Chalk, thus less is expelled into Codell SS.



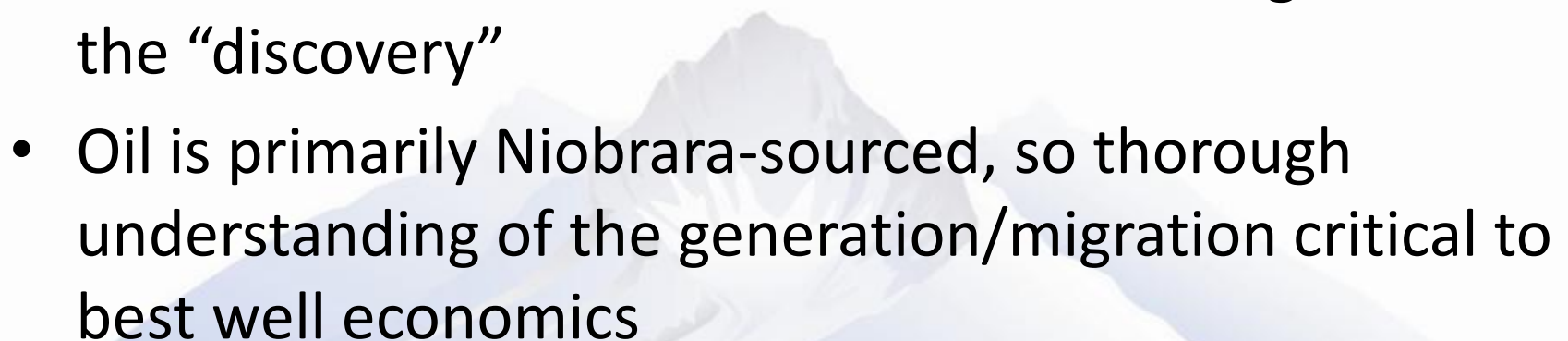
Niobrara oil migrates in Codell SS from the area of "excess" generation into lower pressure areas

# Cross Section showing logs with UV Core Photos

## Lower Oil Saturation with lower MICP



# Summary

- A new “*Sweet Spot*” has been found in Laramie County, Wyoming
  - Codell SS is primary driver of the play
    - C Bench is being actively developed
    - AB Bench wells are planned
  - Careful correlation of core data and well logs led to the “discovery”
  - Oil is primarily Niobrara-sourced, so thorough understanding of the generation/migration critical to best well economics
- 

# Acknowledgements

- Cirque Resources LP
- Weatherford Labs & Mudlogging
- Noble Energy
- GeoMark
- Triple O Slabbing

