Codell Sandstone, DJ Basin*

Kevin H. Smith[1]

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*Adapted from oral presentation at Short Course 17, Tight Oil Sandstone Reservoirs, Wyoming and Colorado: Denver Core Workshop, June 4, 2015, in conjunction with AAPG Annual Convention and Exhibition. Please refer to related poster presentation at the convention, Codell Sandstone, Northern DJ Basin, Wyoming and Colorado: Reservoir Characteristics in a Tight Oil Play Search and Discovery Article #10761 (2015); also Reservoir Characteristics of the Codell Sandstone Tight Oil Play, Northern DJ Basin, Wyoming and Colorado: Extension of Wattenberg into the Oil Window, Search and Discovery Article #20262 (2014) .

[1]Cirque Resources, Denver, CO (kevinharleysmith@gmail.com)

Summary

- Codell has historically been a major contributor in the DJ Basin. The “First Burrowed SS Play”!
- Codell SS is primary driver of Wattenberg being extended to the North into Laramie County, WY.
- We believe the Codell is eastern sourced but do not have a good handle on depositional environment.
- Unconformity at the Base of Ft. Hayes LS is primarily responsible for Codell thinning.
- Core Data is essential to understanding the Codell Play due to poor log response. NMR Logs are the next best thing.
- Clays are not the only minerals that bounds water in the Codell.
- Log density porosity is a good match to core porosity.
- MICP is essential to understanding pore throat distribution and injection pressures.
- Don’t forget about thermal maturity and charge!
- Oil has been typed back to Niobrara source

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Codell Sandstone
DJ Basin

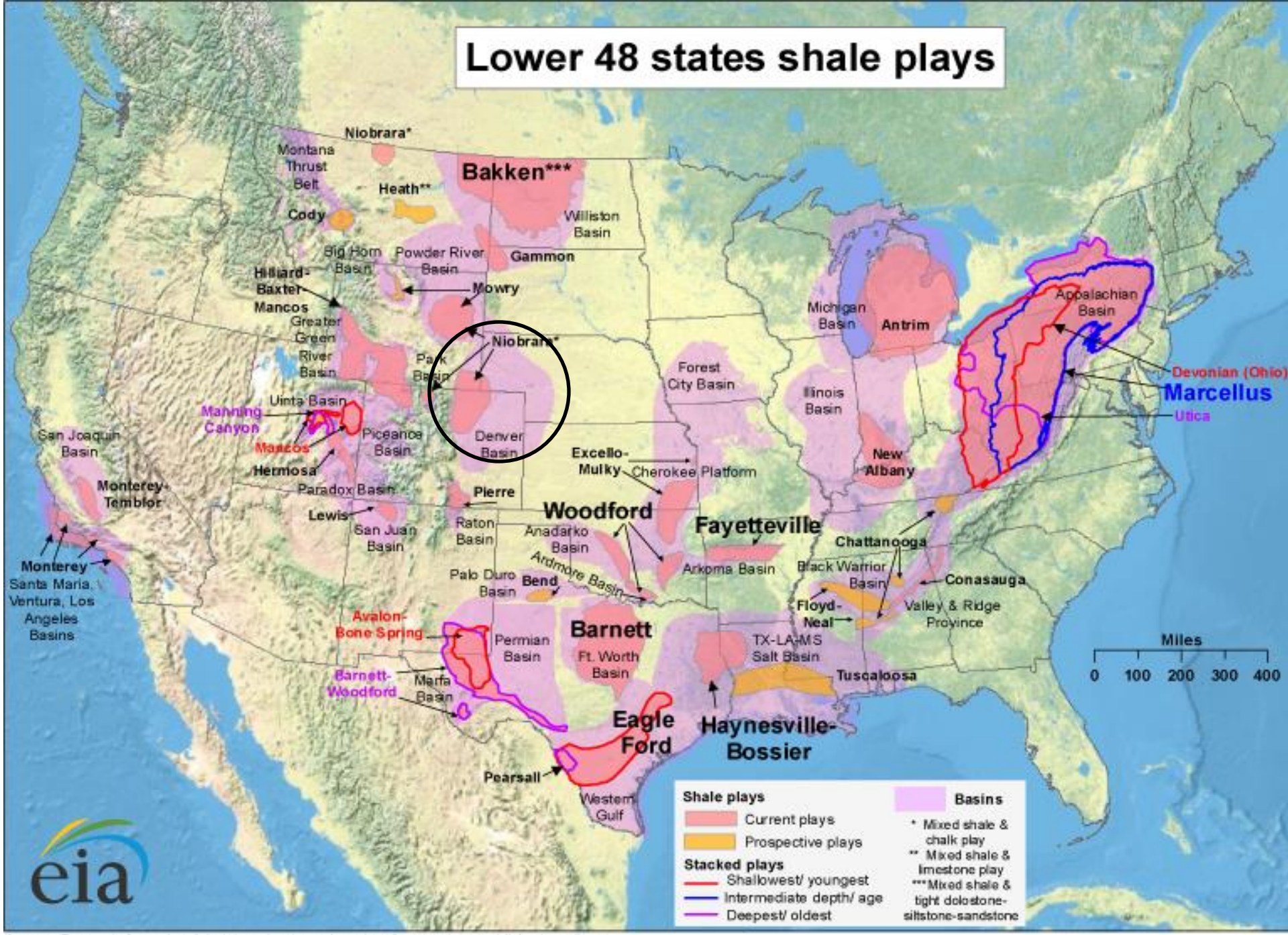
Kevin H. Smith

Paleogeographic Setting

Western Interior Cretaceous Seaway (85 Ma)

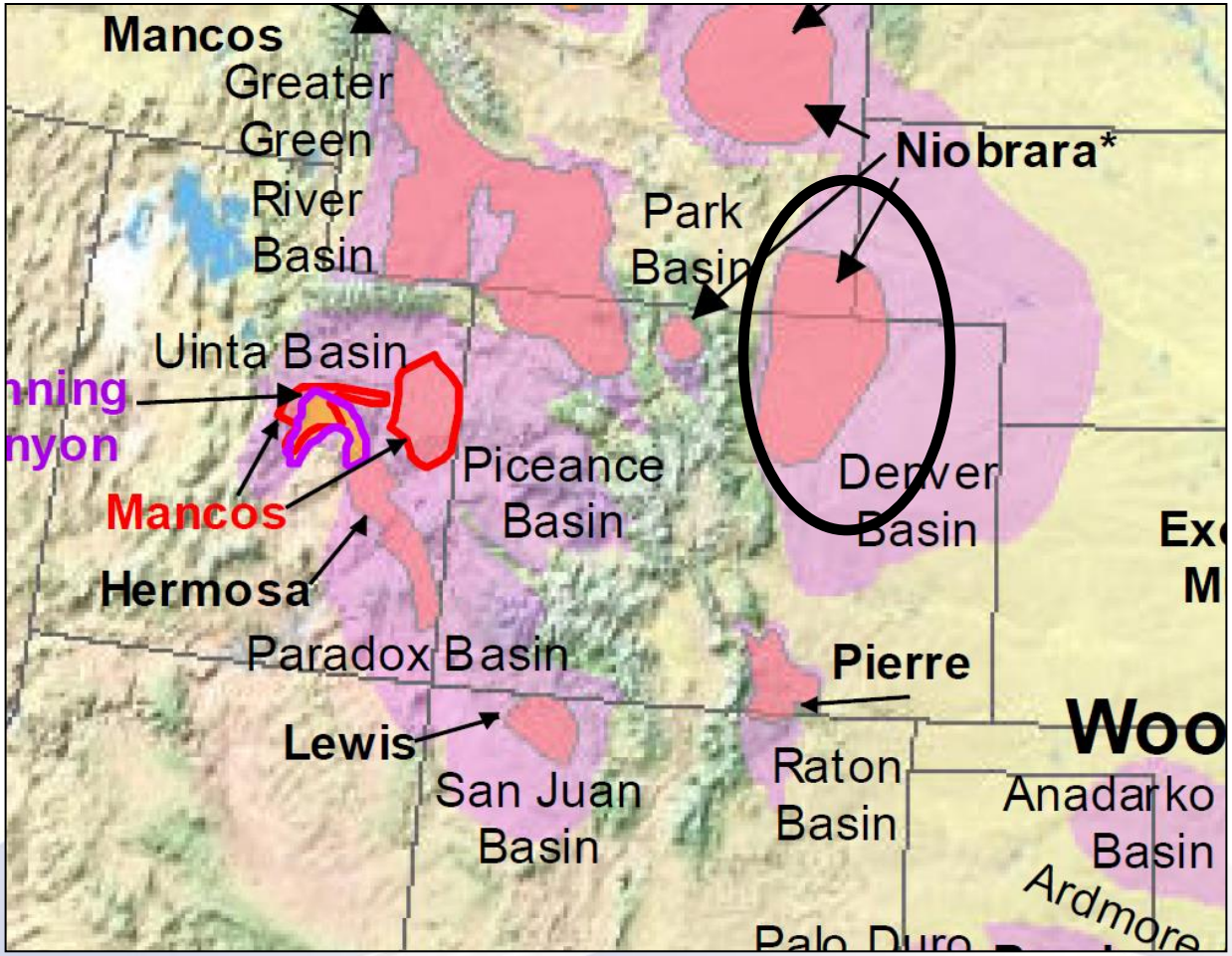
- Western Interior Cretaceous Seaway (WIC) is an asymmetric foreland Cretaceous seaway from Arctic to Gulf of Mexico
  - Following regional Codell Sandstone deposition in low stand conditions, the Niobrara deposition occurred during high sea level conditions resulted in coccolith-rich carbonate sedimentation.
- Codell deposition took place in the eastern portion of the seaway and is preserved today in the northern and southern DJ Basin.
- Codell SS/Greenhorn FM is age equivalent to the Eagle Ford Shale.

Source: Blakely, Rocky Mountain Association of Geologists. Modified from Longman et al., 1998.



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

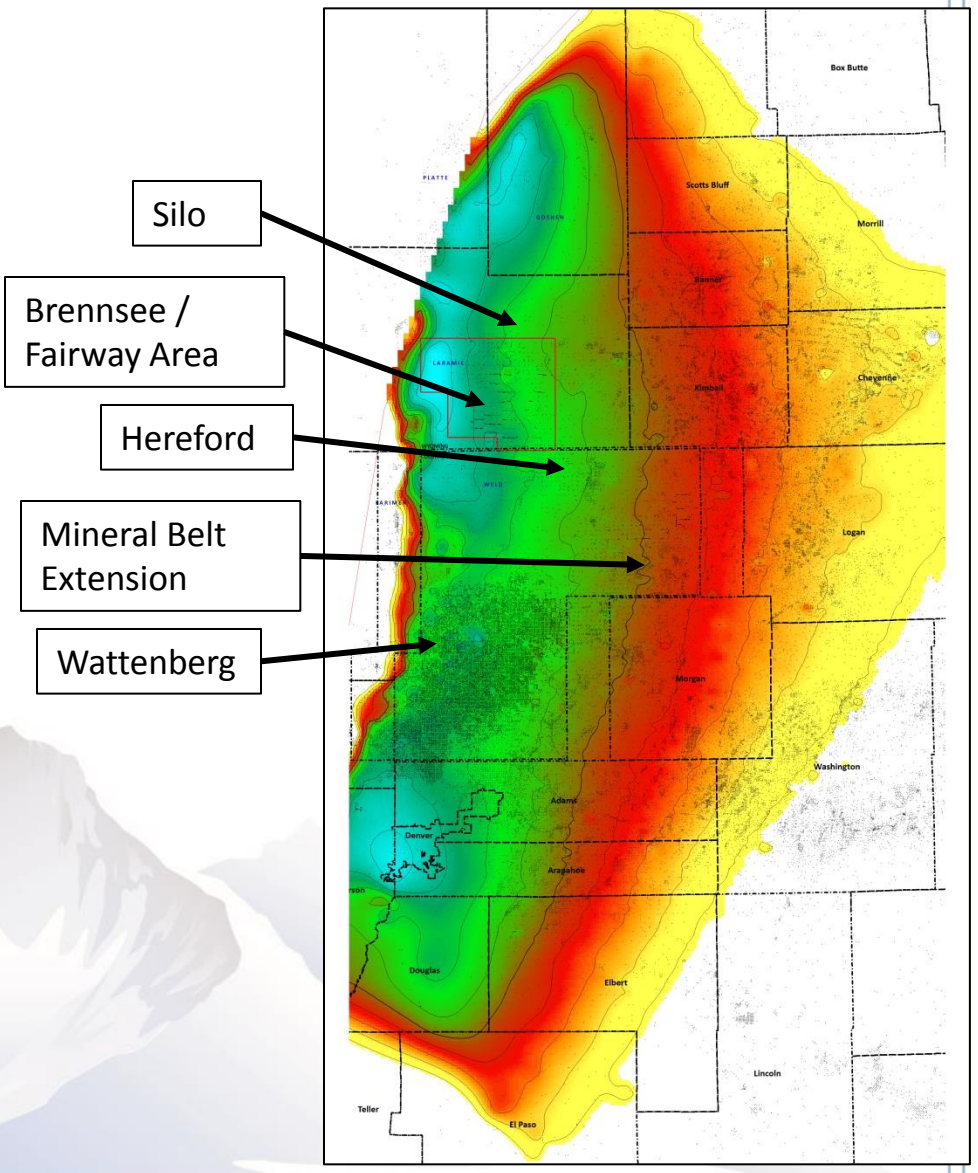
Rocky Mtn Shale Basins



Regional Structure Map

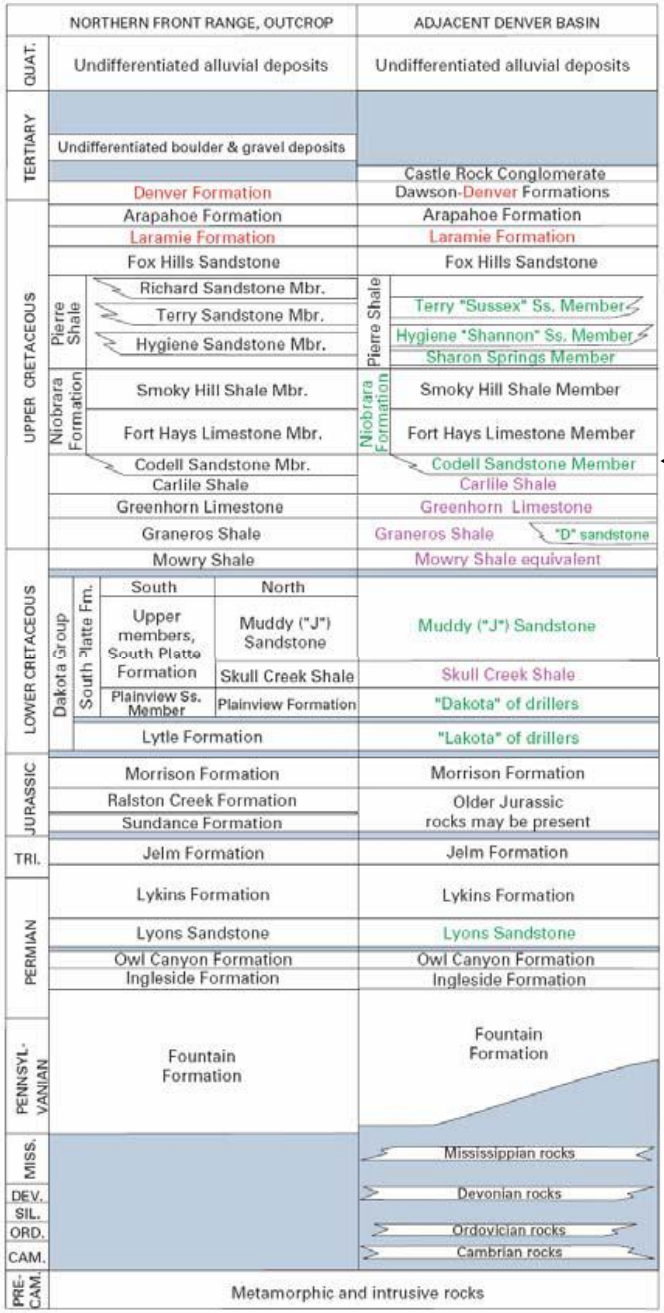
DJ Basin Regional Structure on Top of Niobrara FM

- Asymmetrical basin with thrust contact on the western margin against the Laramide orogeny (Rocky Mountains)
- Steep western dip and gentle eastern dip.
- Top of Codell ranges from ~6,000’ TVD to ~9,000’ TVD across productive area



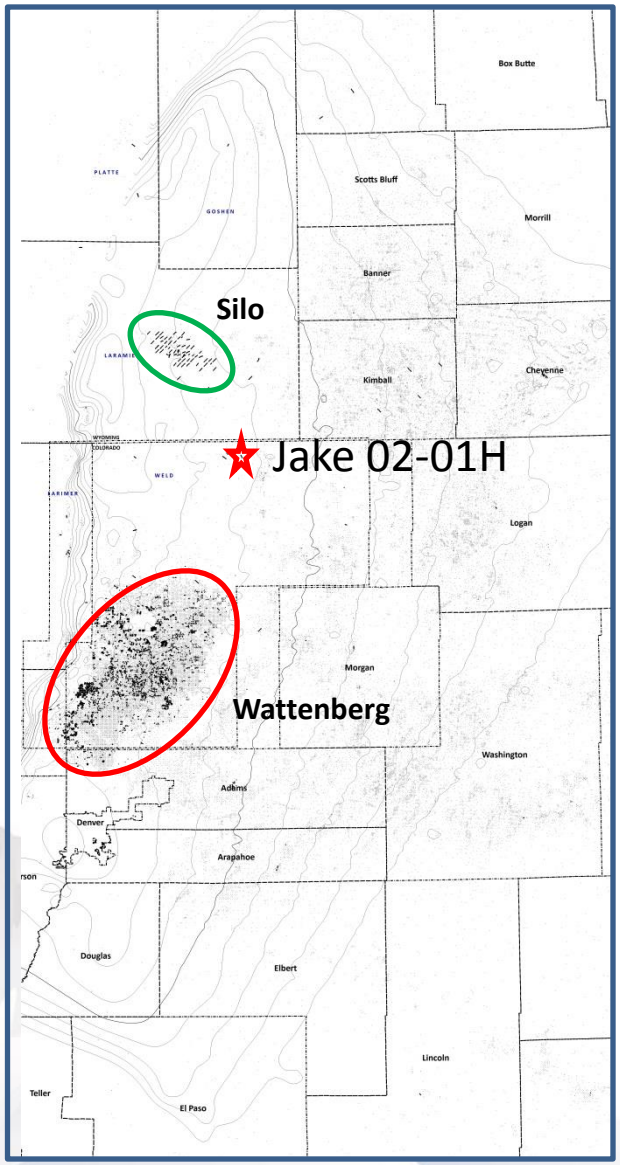
DJ Basin Stratigraphy

- Cretaceous Petroleum System is most prolific
- Niobrara/Codell is the focus of present day activity by most operators in DJ Basin
- Originally drilled as tightly spaced vertical wells with fracs and refracs
  - Refrac and downspacing built many mid-cap companies in the late 1990's:
    - Snyder
    - HS Resources
    - Kerr McGee
- Present day horizontal and multi-stage frac has revitalized the play



DJ Basin Drilling as of 2009

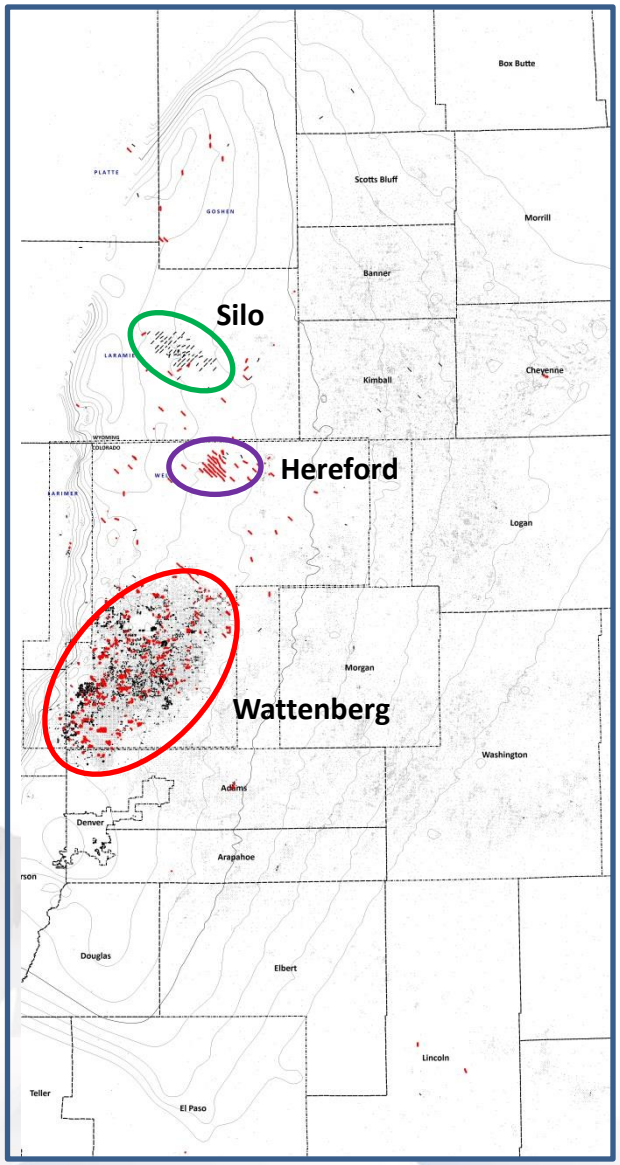
- Wattenberg had been primarily a vertical Niobrara/Codell play with down spacing and refracing
- Silo Field had been drilled with horizontal Niobrara B Bench wells in the early 1990's with open hole, unstimulated completions
- Noble drilled a horizontal Niobrara B Bench well in Wattenberg
- Encana drilled two horizontal Niobrara B Bench and two horizontal Codell laterals from a common pad.
- EOG drilled the Jake 02-1H resulting in the discovery of the Hereford Field and setting off the Niobrara "boom" outside of core Wattenberg



DJ Basin
2009 - 2010 Drilling

5 Horizontal Rigs running

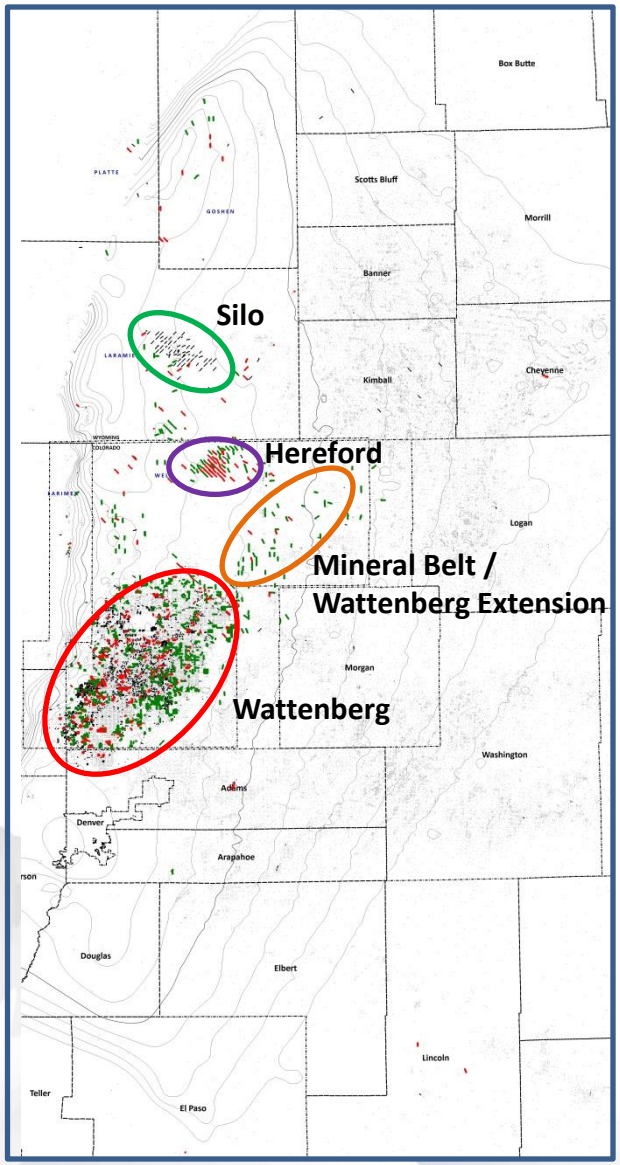
- Hereford Field begins to get developed (Niobrara)
- Several Niobrara Wildcats drilled north and northeast of Wattenberg Field
- Wattenberg Horizontal Niobrara programs take off



DJ Basin
2009 - 2011 Drilling

~10 horizontal rigs running

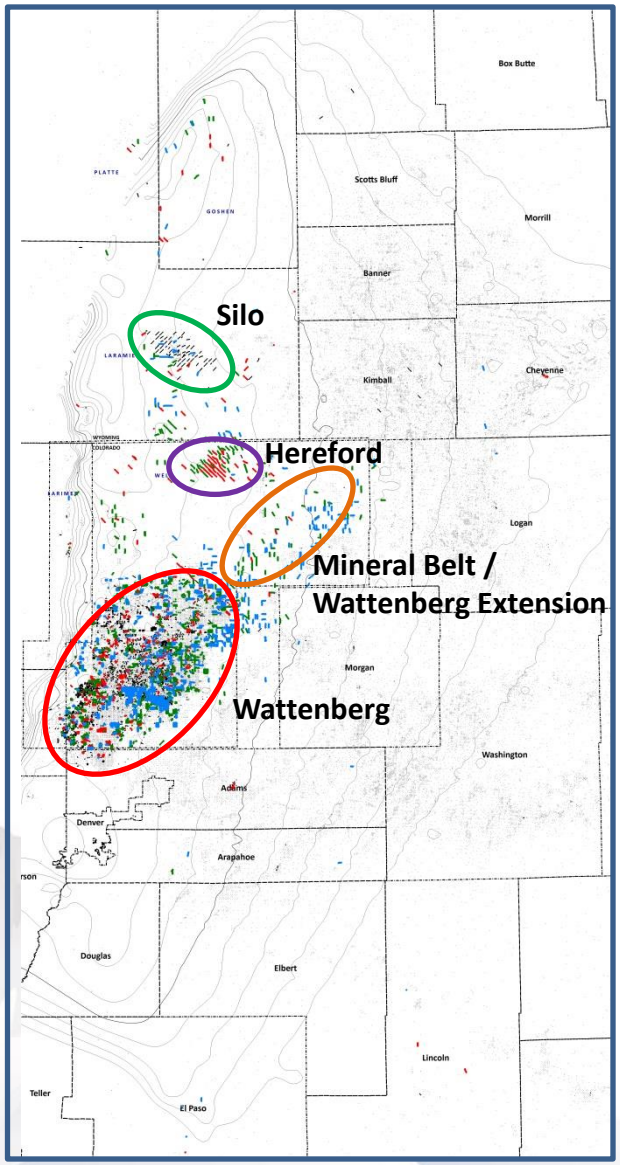
- Hereford Niobrara Field development continues
- Mineral Belt/Wattenberg extension begins to develop
- Fringe Wattenberg begins to take off



DJ Basin
2009 - 2012 Drilling

~20 horizontal rigs running

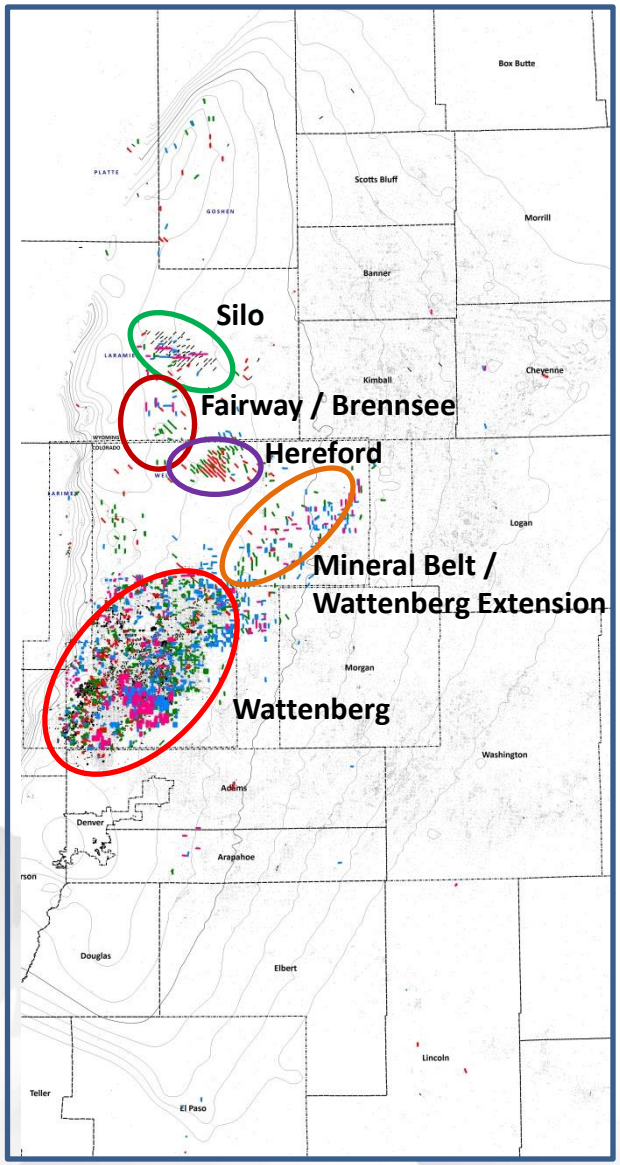
- Mineral Belt/Wattenberg extension development continues
- Fringe Wattenberg development continues
- First Horizontal Codell wells are drilled between Silo and Hereford Fields outside of Wattenberg



DJ basin
2009 - 2013 Drilling

> 25 horizontal rigs running

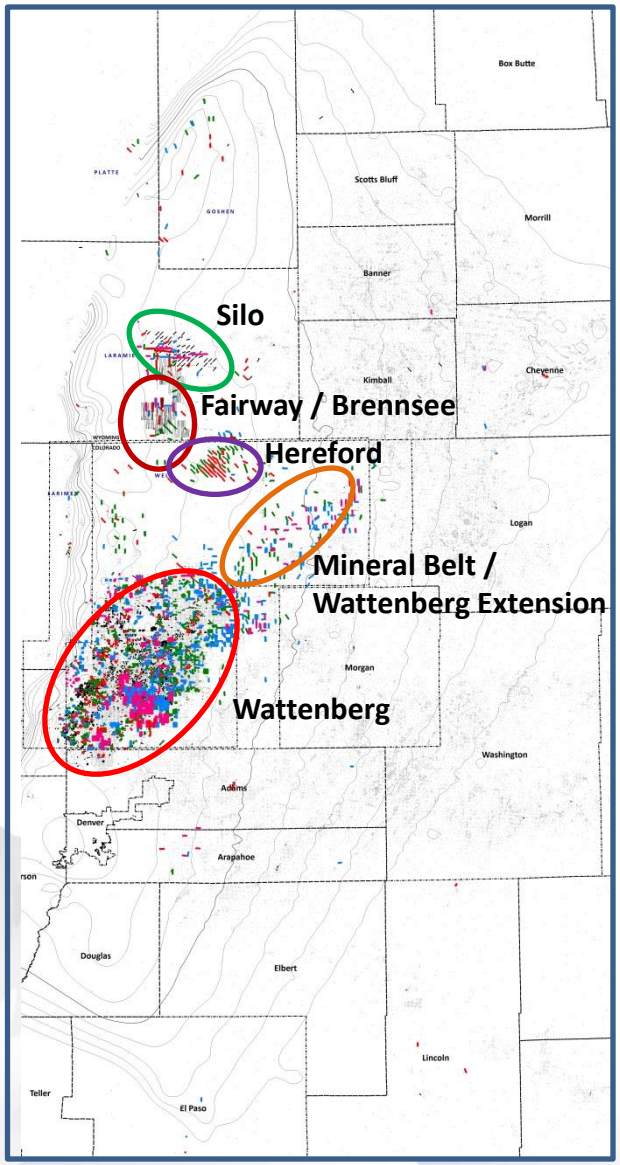
- Mineral Belt/Wattenberg extension development continues
- Fringe Wattenberg development continues
- Fairway/Brennsee Codell Field development starts



DJ Basin

2014 Drilling and Permits

- ➢ 30 Horizontal rigs running
- Brennsee and Fairway Codell Fields defined between Silo and Hereford Fields
- Mineral Belt/Wattenberg extension development continues
- Fringe Wattenberg development continues
- Codell, Niobrara C, Niobrara A & B are all exploration targets north and northeast of Wattenberg

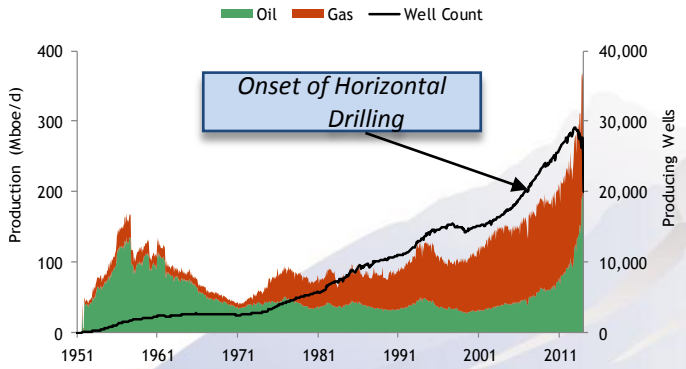


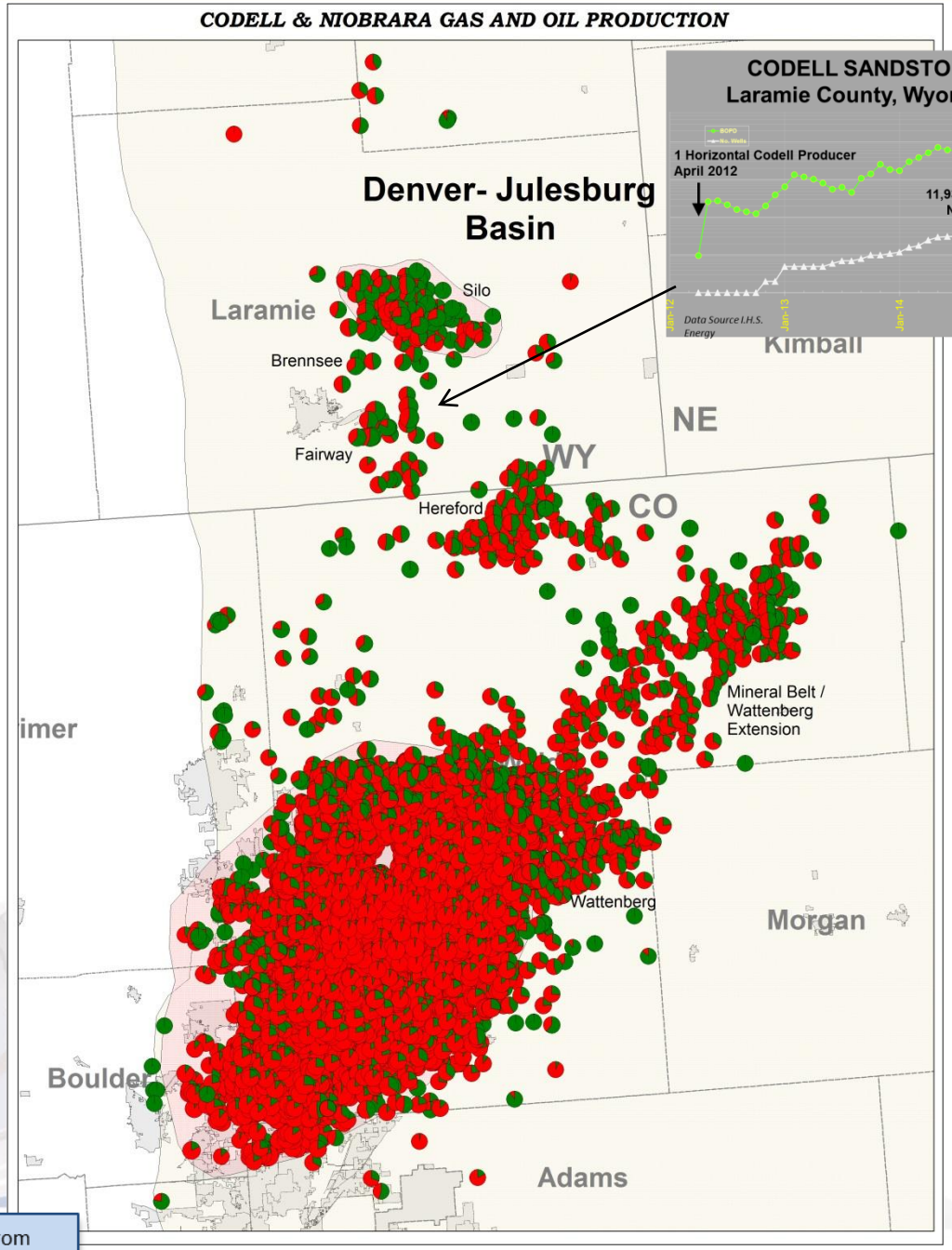
2015?

DJ Basin

- Gas Oil ratio shown on wells
- Gas window in center of Wattenberg Field
  - Historically Vertical Wells
- Edge of Wattenberg Field wells get into Oil Window
  - Horizontal Wells
- Silo, Hereford, Mineral Belt/Wattenberg Extension, Fairway/Brennsee in Oil Window
  - Horizontal Wells

- Historical DJ Basin Production



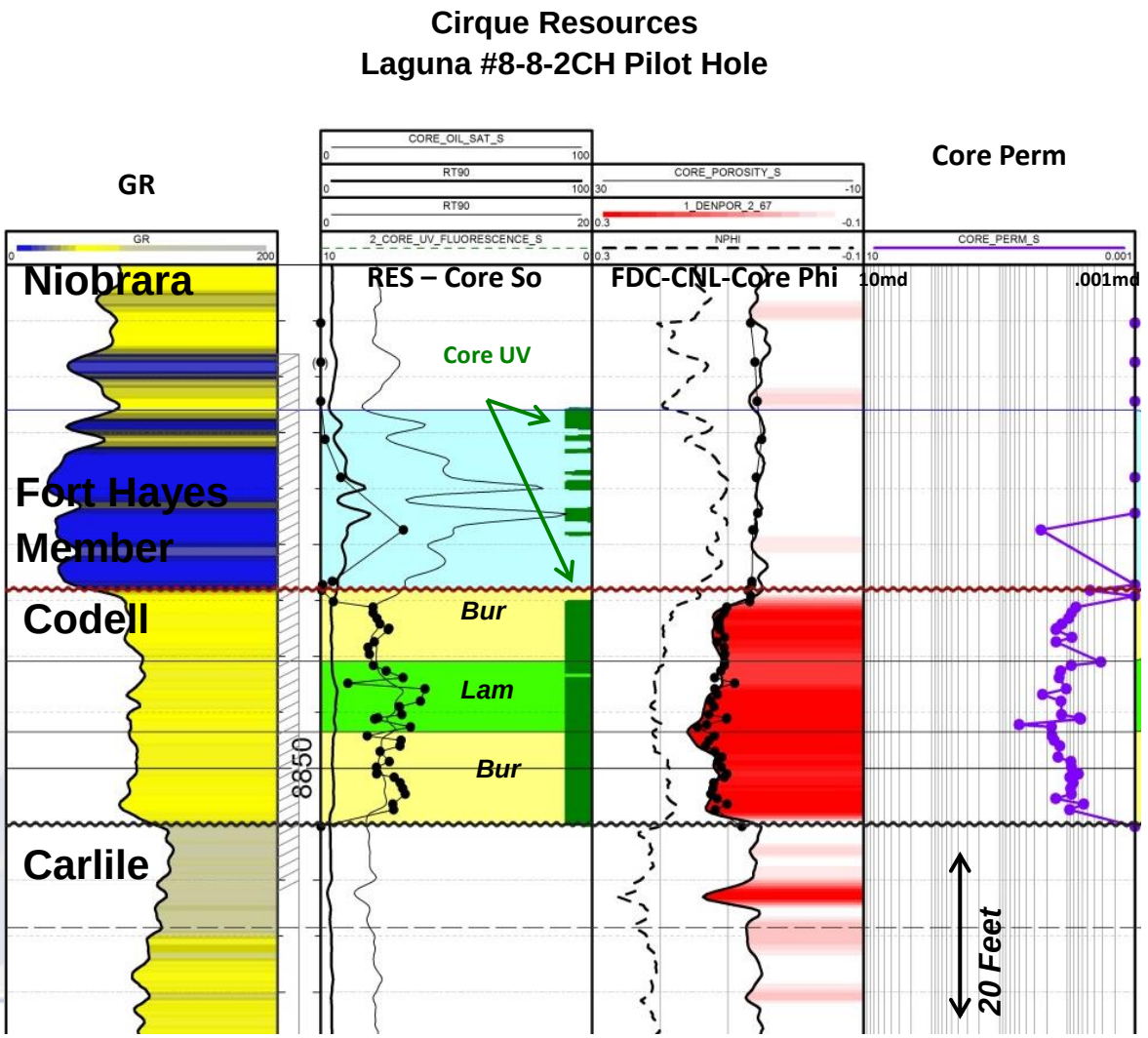


The DJ Basin produced over **2.2 Bboe** from Cretaceous reservoirs, primarily from Codell and Niobrara, before horizontal drilling began

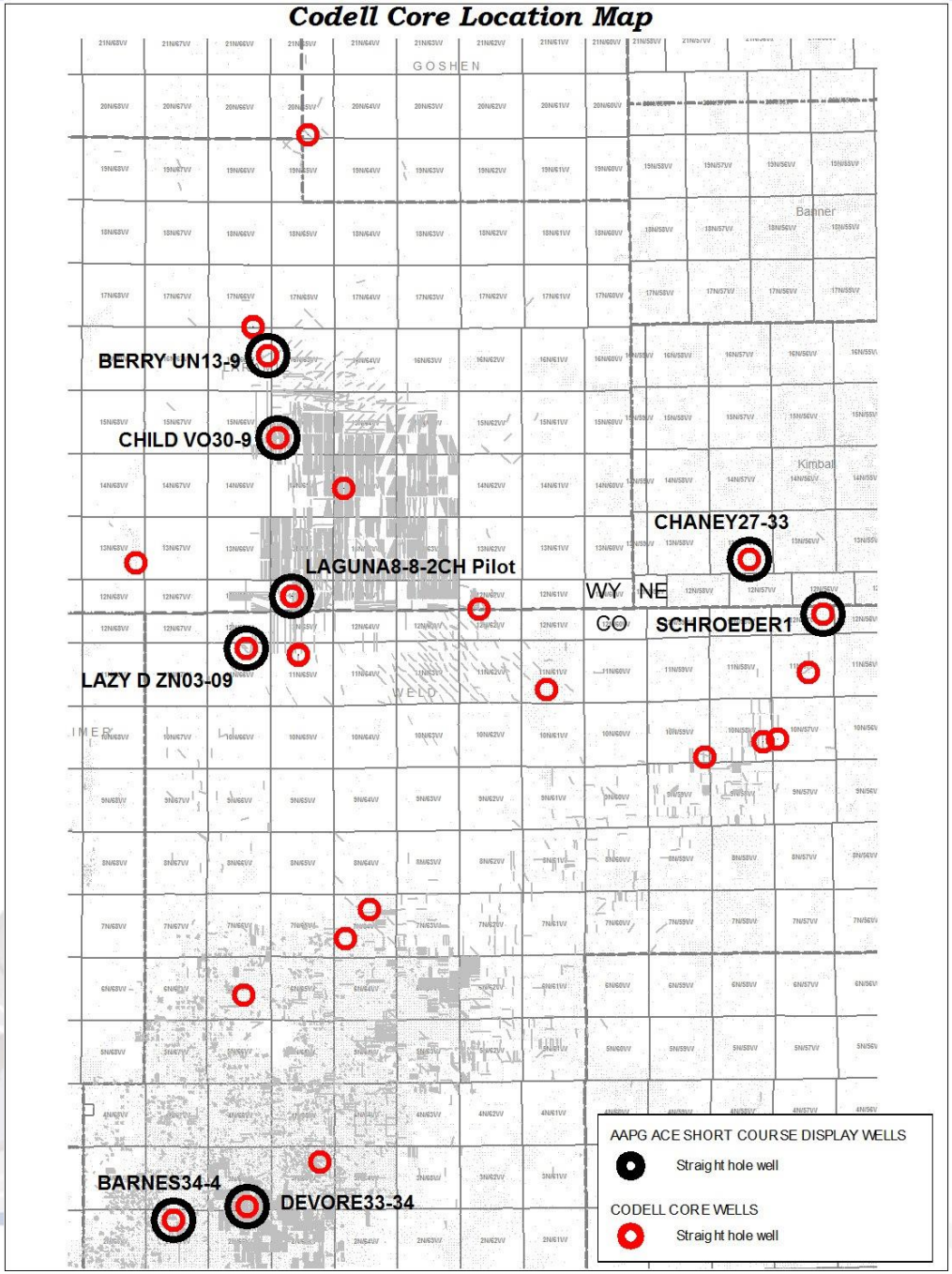
Codell Sandstone- DJ Basin

Where Burrowed SS Pay Was Found!

- Codell Type Log
  - Gamma looks like a dirty sand / shaley
  - Resistivity usually between 4 and 6 ohmms
  - Porosity 12% to 16%
  - Perm generally increases to greater than 0.01md
  - Oil saturation increases



- 23 Codell Cores identified in study area
  - Some at CRC and some proprietary
- 8 Codell Cores laid out today
  - 4 in the Fairway/Brennsee Field Area
  - 2 on the far end of the Mineral Belt/Watteneberg Trend
  - 2 in Wattenberg Field



Break to Look at Core

Things to think about:

- Depositional Environment?
- Key Surfaces – Unconformities, Etc…?
- Porosity Distribution?
- Permeability Distribution?
- Facies Changes?

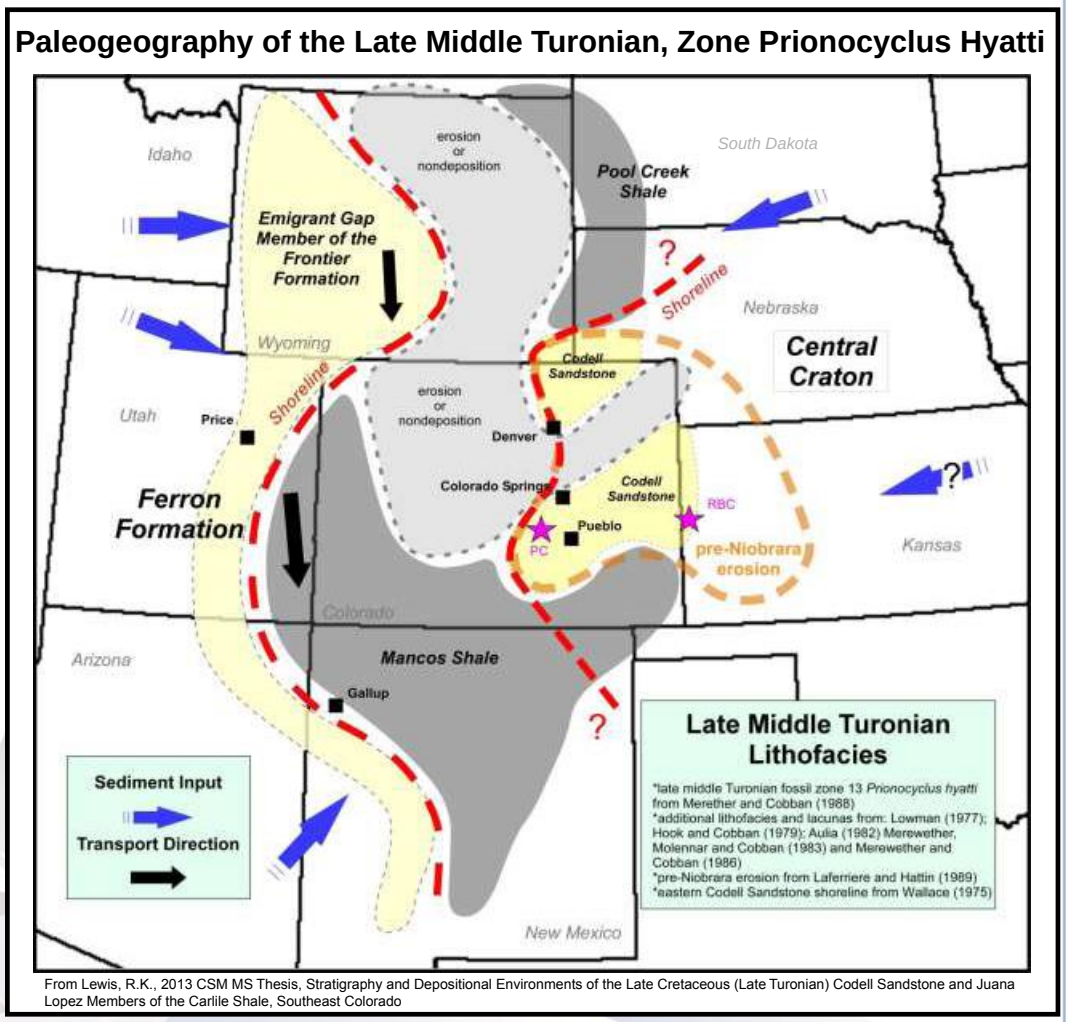
Codell Depositional Environment

- Shallow water?
- Bioturbation
  - Paleontologist are resistant to pigeon hole trace fossils into water depth and specific environments now!
- Hummocky Cross-Strat = Storm beds
- Does not follow a typical shore face model

We don’t have it figured out yet.
Anyone want to go to Kansas?

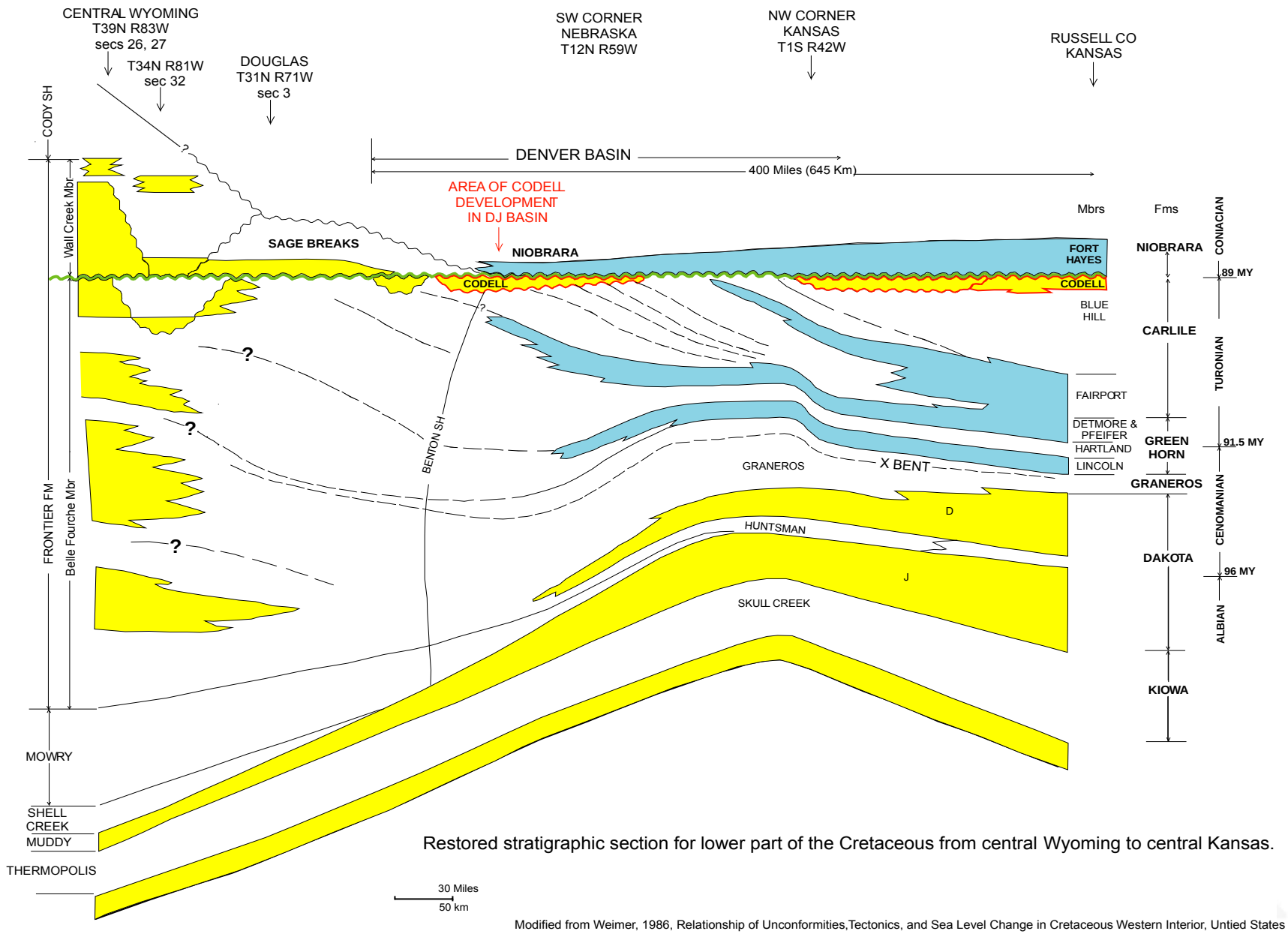
Codell Paleogeography

- The DJ Basin is bound by the Front Range of Colorado, Laramie Range of Wyoming, Chadron Arch and Las Animas Arch
- **Codell**
  - 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 to hummocky cross-bedding and bioturbation
  - Thought to be sourced from the North American craton east of the epeiric seaway.



From Lewis, R.K., 2013 CSM MS Thesis, Stratigraphy and Depositional Environments of the Late Cretaceous (Late Turonian) Codell Sandstone and Juana Lopez Members of the Carlile Shale, Southeast Colorado

Codell Stratigraphic Section Showing Eastern Sourced Sands

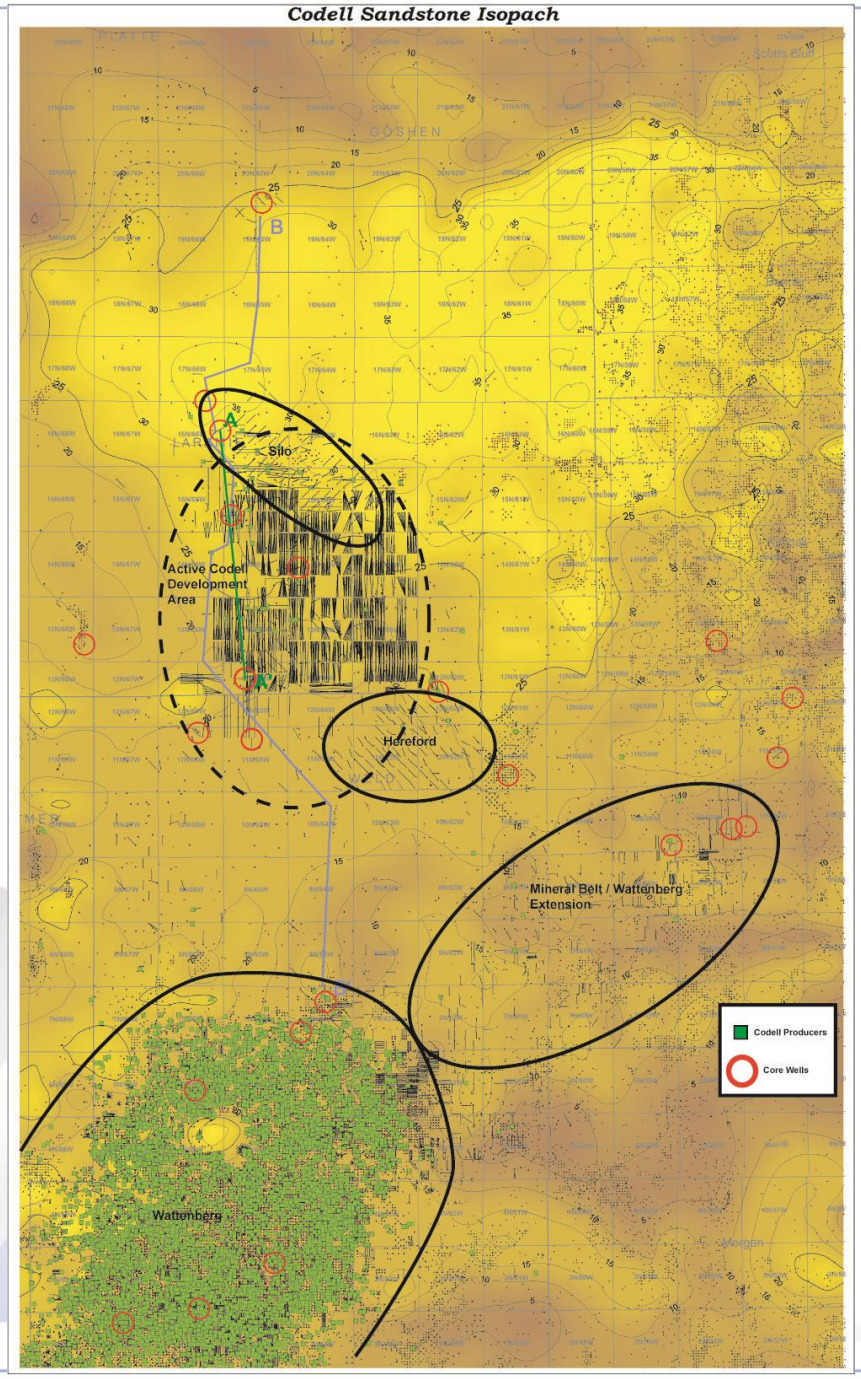


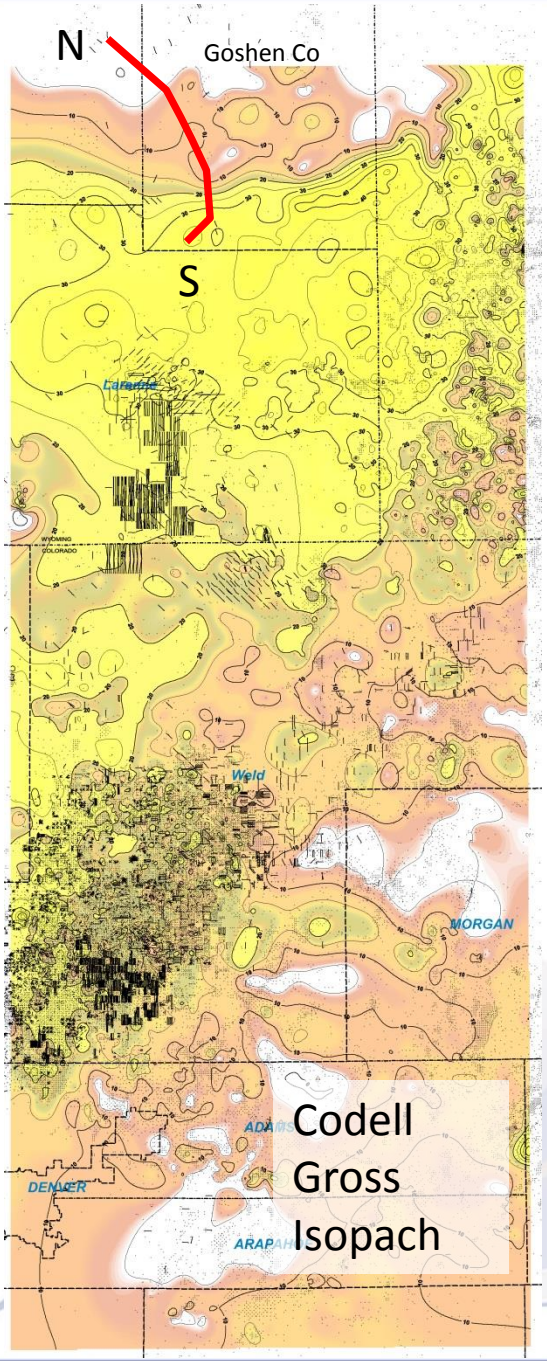
Restored stratigraphic section for lower part of the Cretaceous from central Wyoming to central Kansas.

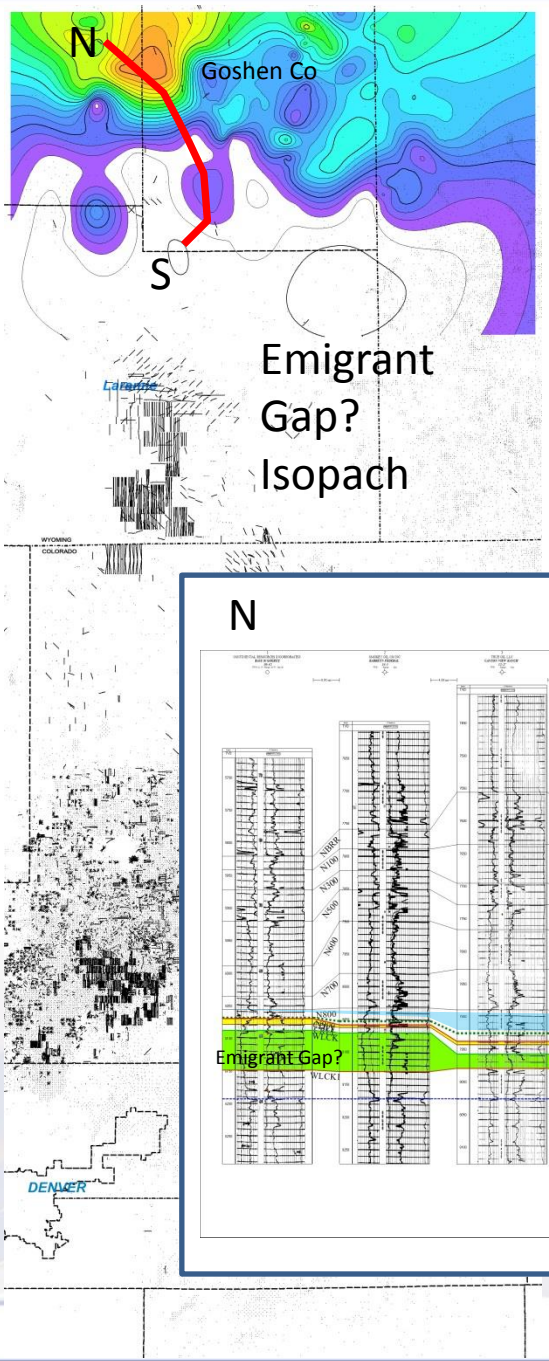
Modified from Weimer, 1986, Relationship of Unconformities,Tectonics, and Sea Level Change in Cretaceous Western Interior, Untied States

Codell Sandstone

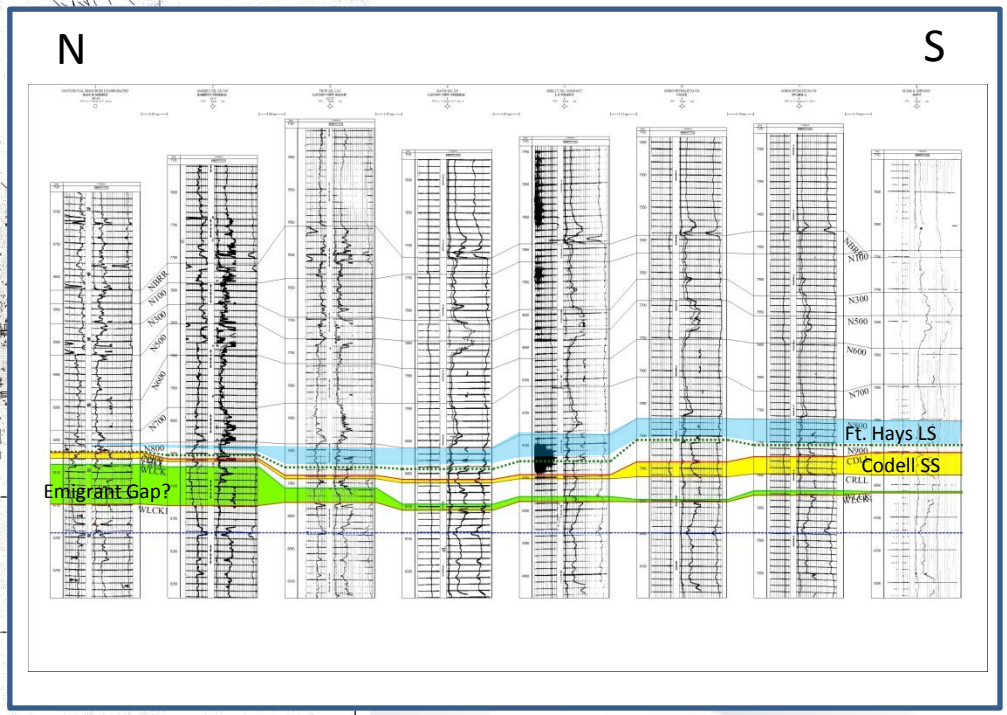
- Sourced from the East found throughout the Northern Colorado and Southern Wyoming
- The heart of Codell is 25 to 30 feet thick
- Codell gets less than 5 feet and pinches out to the north and south east
- Average depth ~8,500' and porosity between 12% and 17% in productive trend



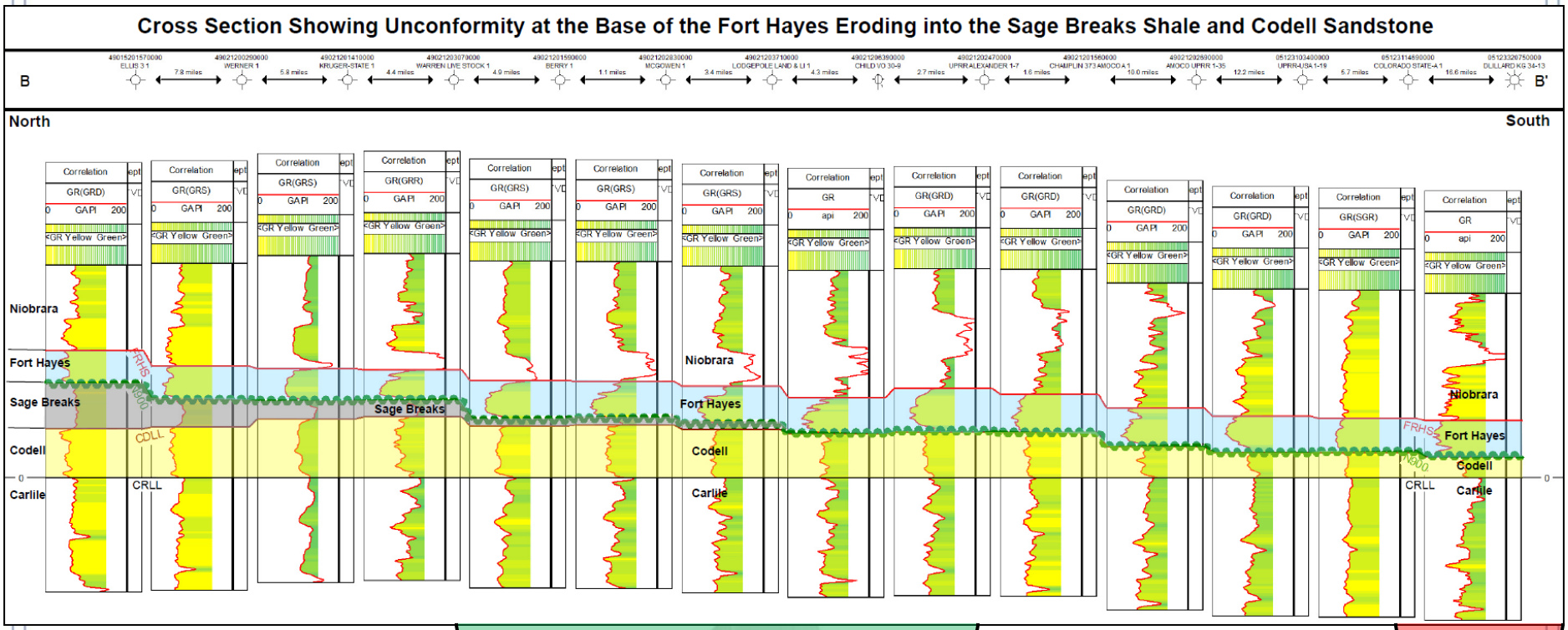


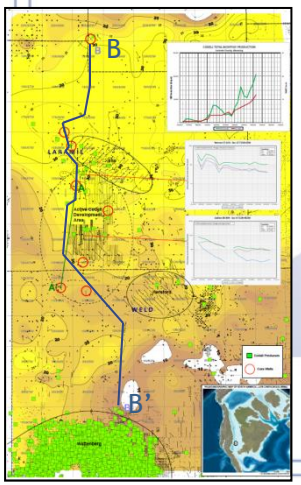


- Codell SS pinches out in southern Goshen Co, WY
- Emigrant Gap? Member of the Frontier FM develops in Goshen County
- Mistaken for Codell SS in Goshen Co



Regional Unconformity in the Codell





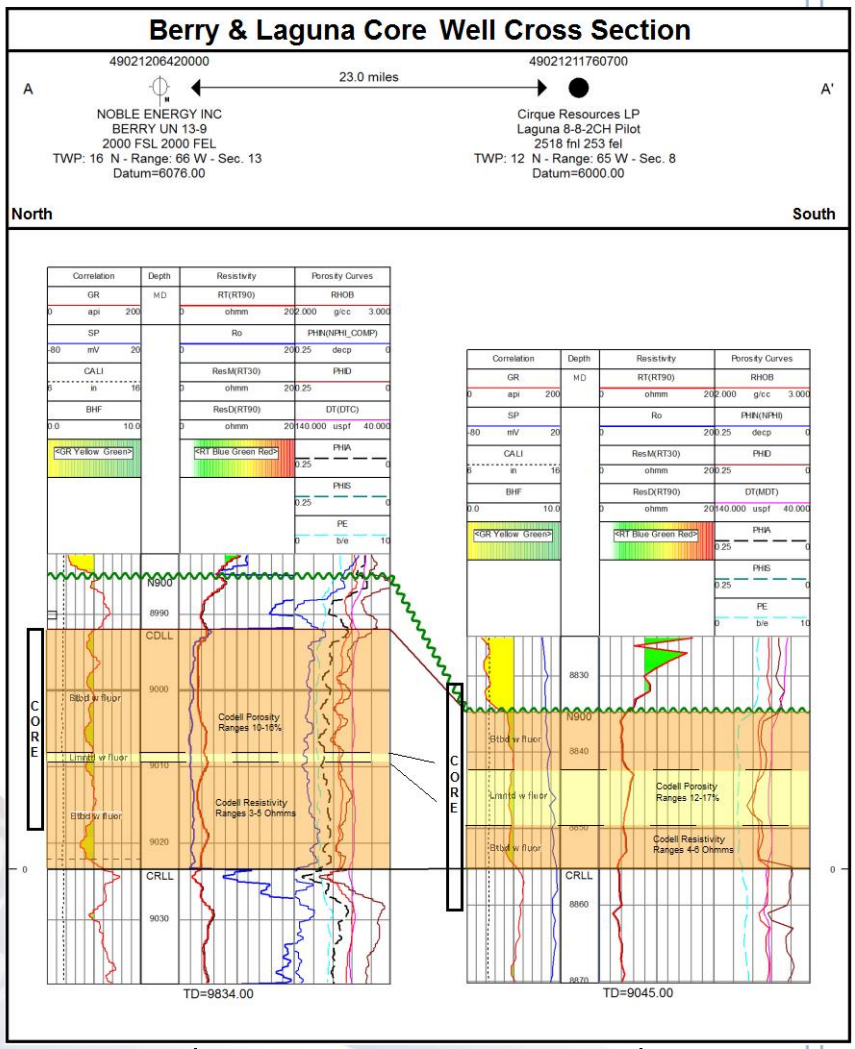
Brennsee/Fairway Area
Codell 20' to 30' thick
Oil Window

Wattenberg Field
Codell 10' to 20' thick
Gas Window

- Sage Breaks preserved to the North
- Unconformity at base of Ft Hayes cuts out Sage Breaks and eventually erodes into Codell as you go south
- Basal Ft Hayes unconformity is the primary reason for thinning in the Codell
- The farthest north cores actually have ~1' of Juana Lopez preserved

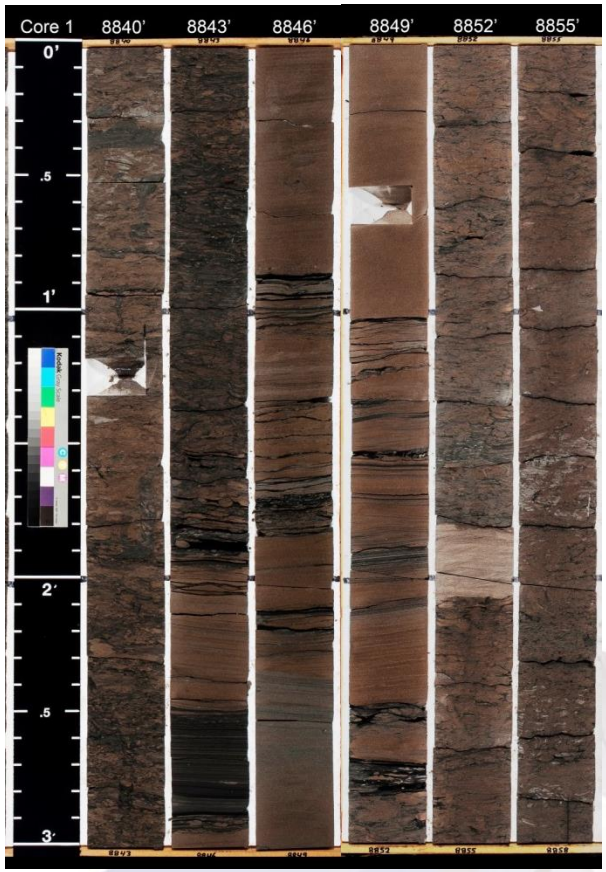
Facies Changes

- **Laminated Facies**
  - Best reservoir characteristics
  - Usually in middle of the Codell section
  - Ranges from <1 to 8 feet in thickness
  - Not apparent on logs
- **Bioturbated facies**
  - Lower permeability than laminated but significant oil in place and 8.0% to 14.0% porosity

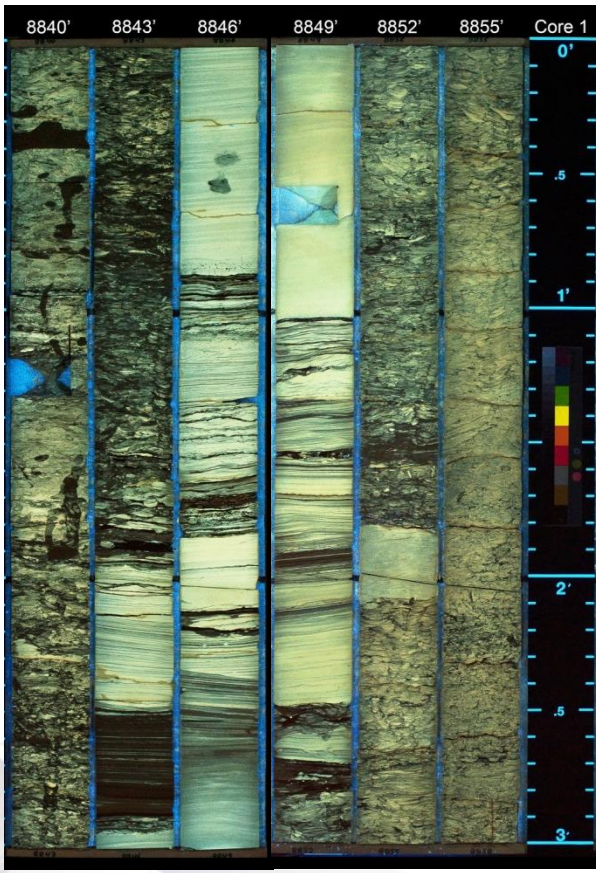


Codell Sandstone, Laguna 8-8-2CH, DJ Basin

PLAIN LIGHT

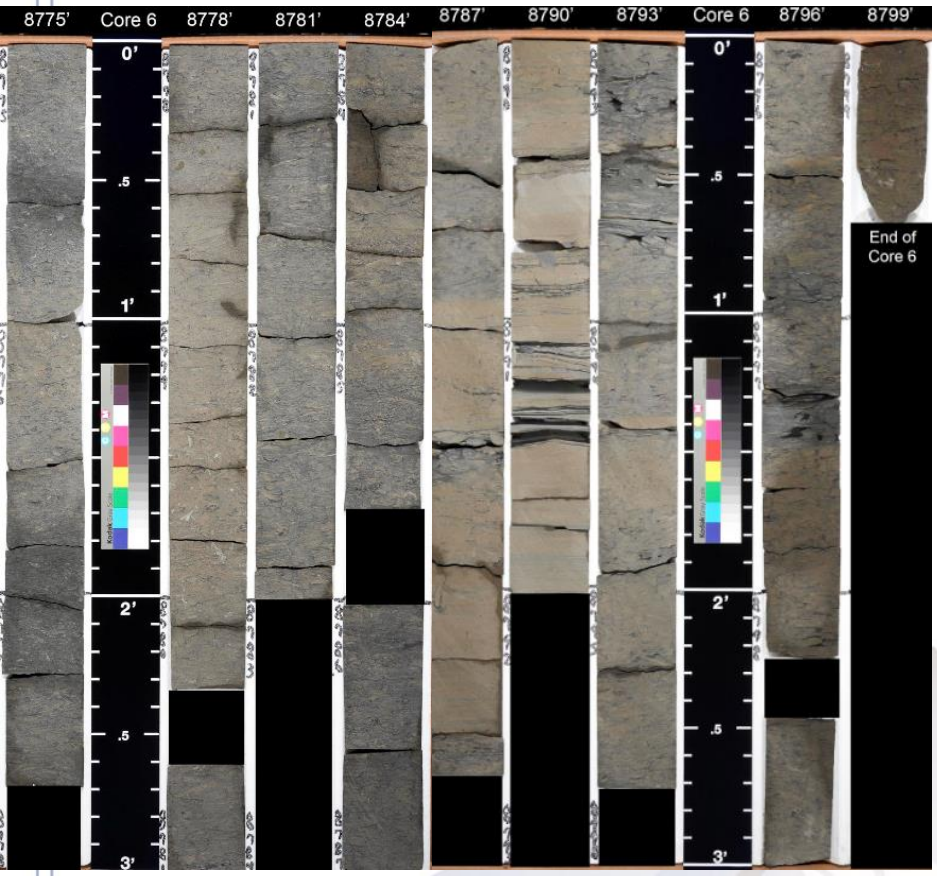


UV LIGHT

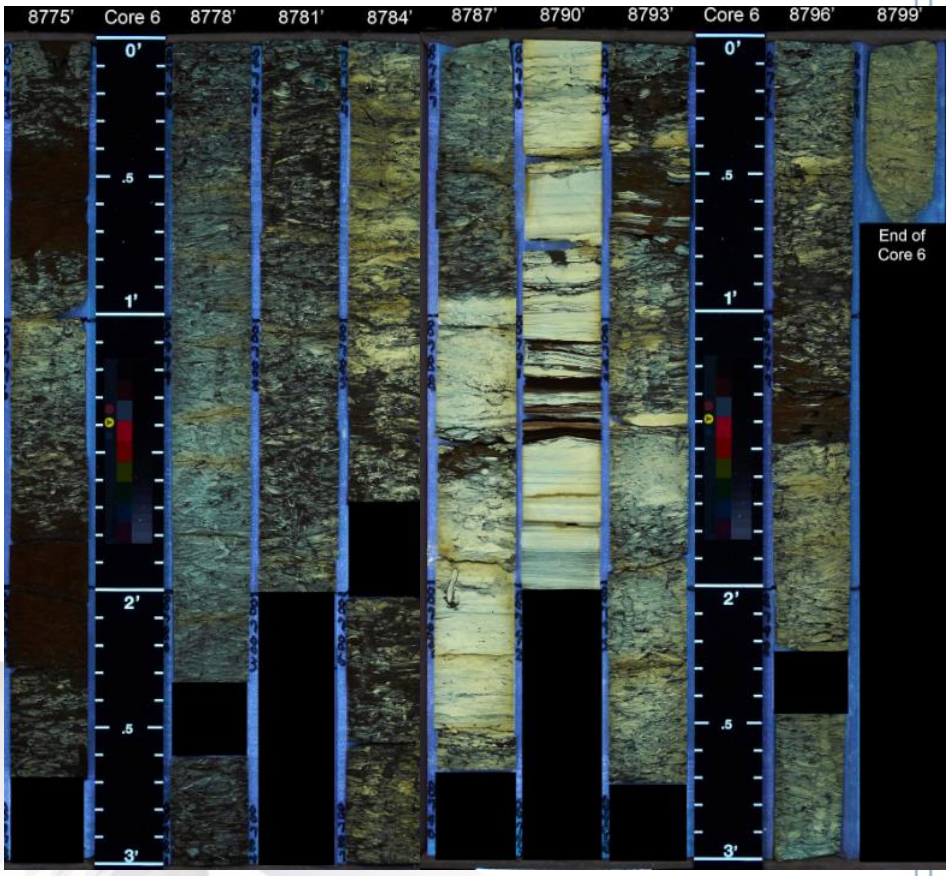


Codell Sandstone, Child VO30-09, DJ Basin

PLAIN LIGHT

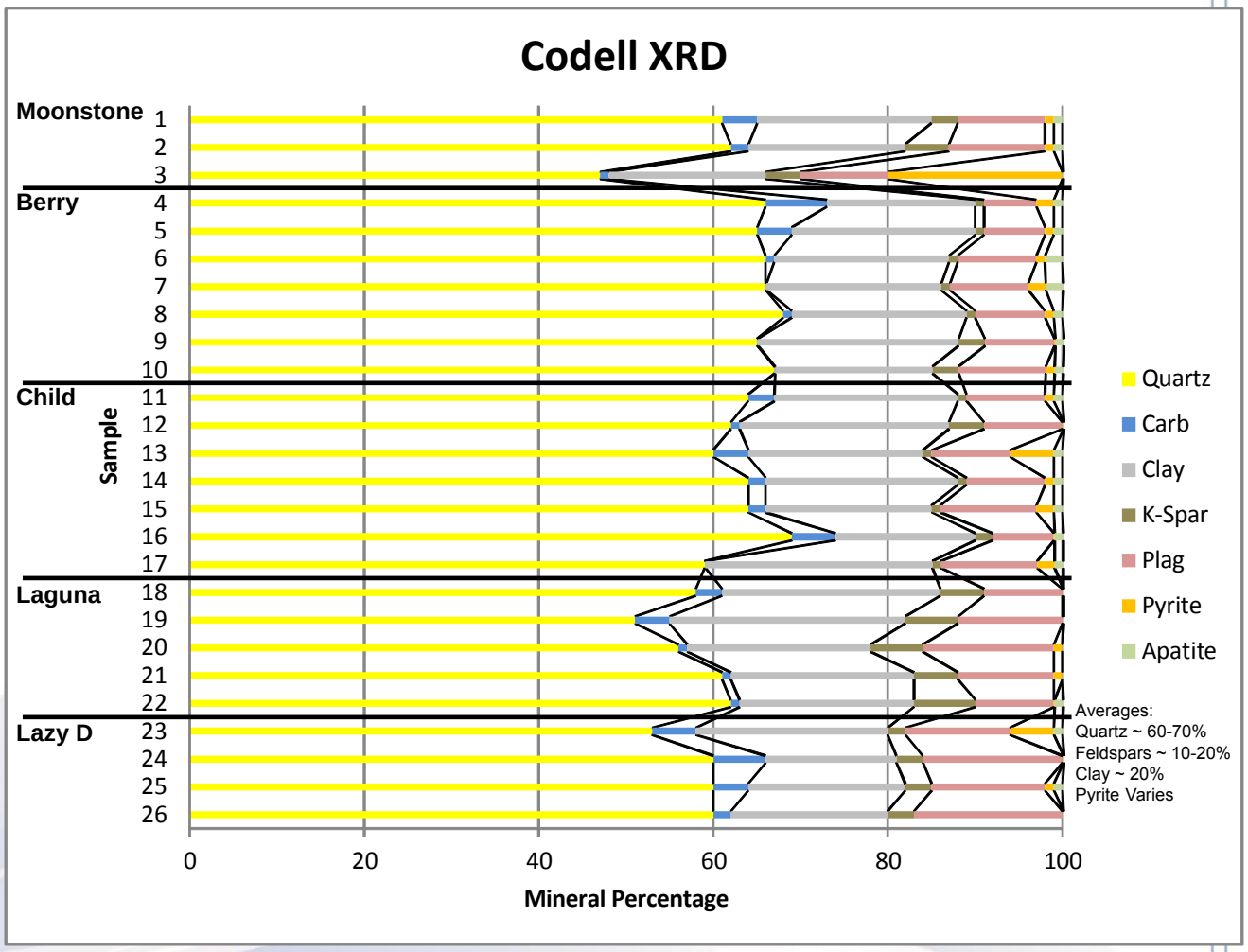


UV LIGHT



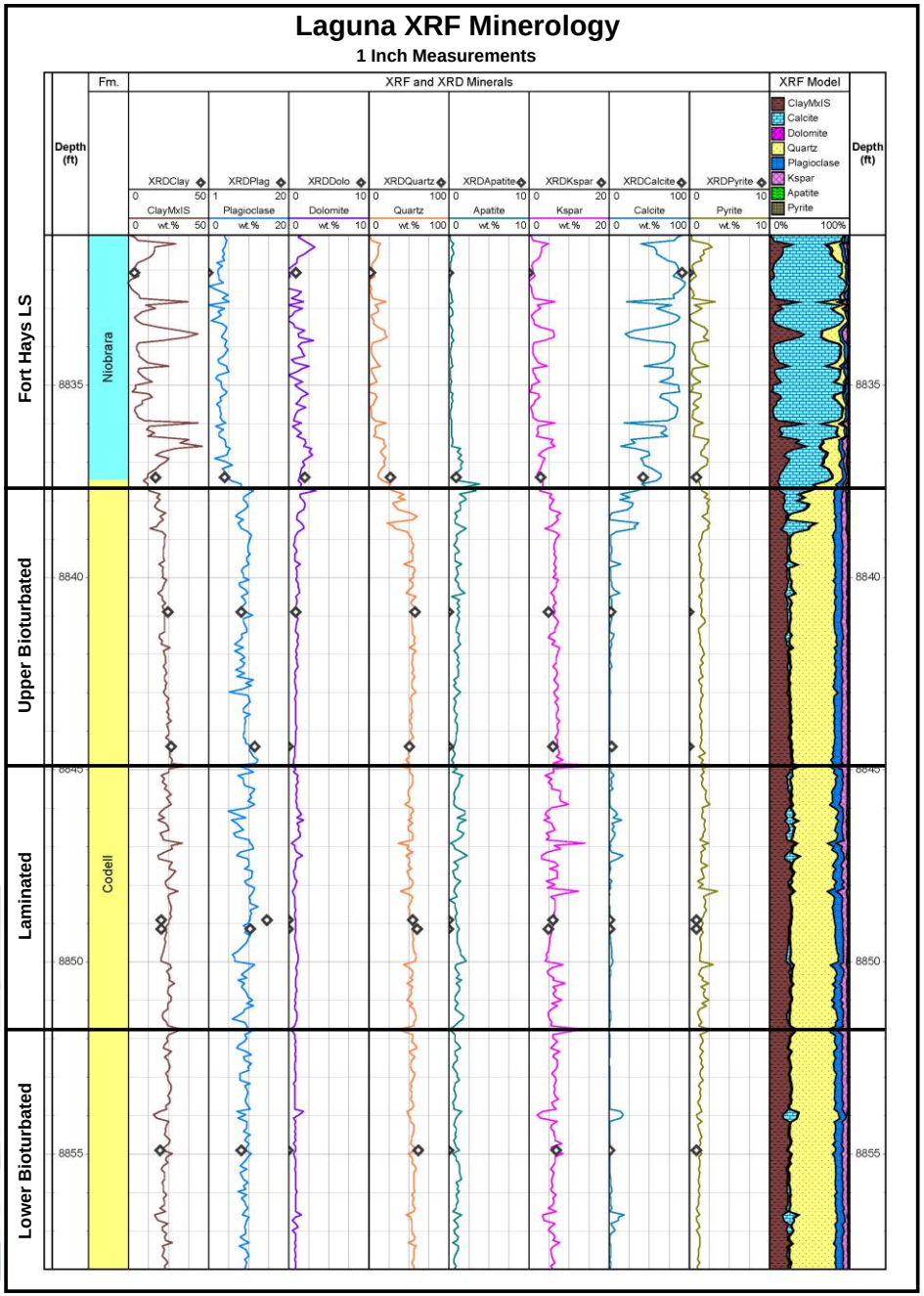
Codell Lithology / X-Ray Diffraction

- Codell sandstone is dominated by quartz with other major minerals being clays and feldspars
- Minor minerals include Calcite, Apatite, Glauconite, and Pyrite
- Mineral assemblages are consistent whether in Bioturbated or Laminated Facies
- Clays are mostly illite with minor mixed layers



Laguna XRF

- 1” measurements
- Very little variation between Laminated and Bioturbated Facies
- Surfaces are hard to pick out even at this resolution



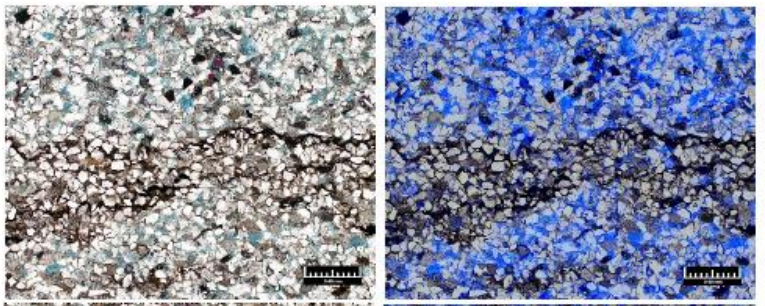
Codell Thin Section Analysis

- Thin Sections show porosity in both plain and epiflourescent light
- Under epiflourescent 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
- Grains are very angular and Feldspars are only partially weathered indicating low transport distance from source

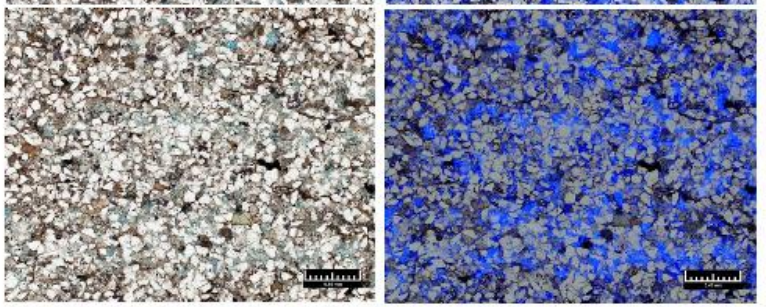
Codell thin section photos show abundant intergranular pores. Epiflourescent light photos show high microporosity accounting for high amounts of bound water in matrix

50x

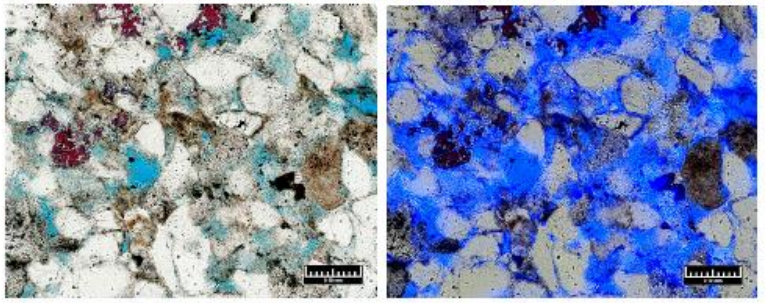
200x



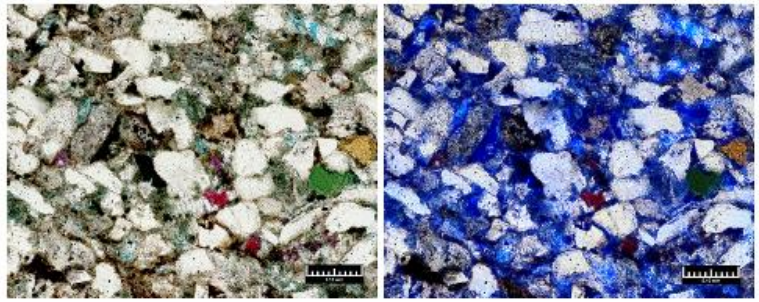
Laminated
Fine grained to very fine grained sand with interspersed clay. Moderatly sorted angular sand grains with intergranular clay



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



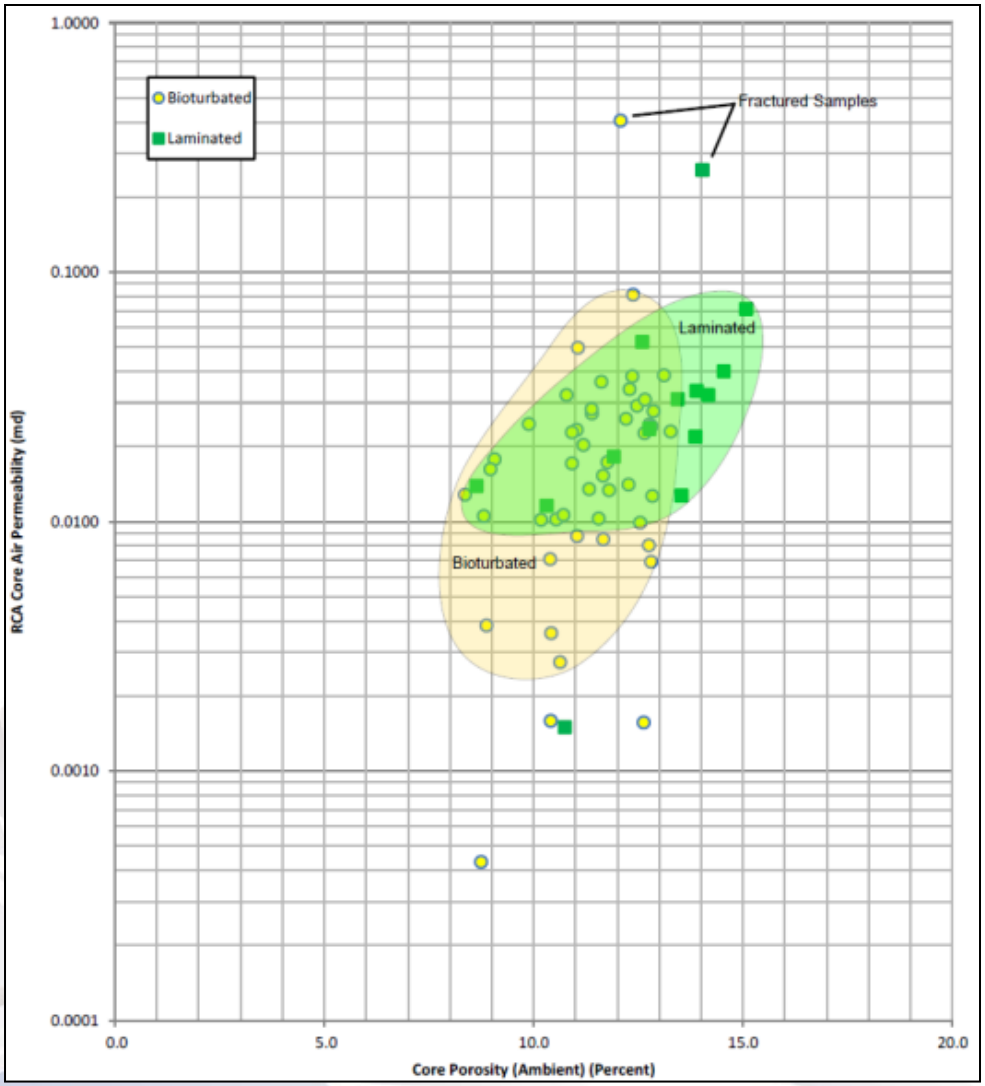
Laminated
Fine grained to very fine grained sand with interspersed clay. Poorly sorted angular sand grains with intergranular clay

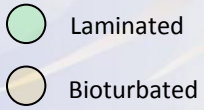


Bioturbated
Fine grained to very fine grained sand with interspersed clay. Poorly sorted angular sand grains with intergranular clay

Codell Porosity and Permeability

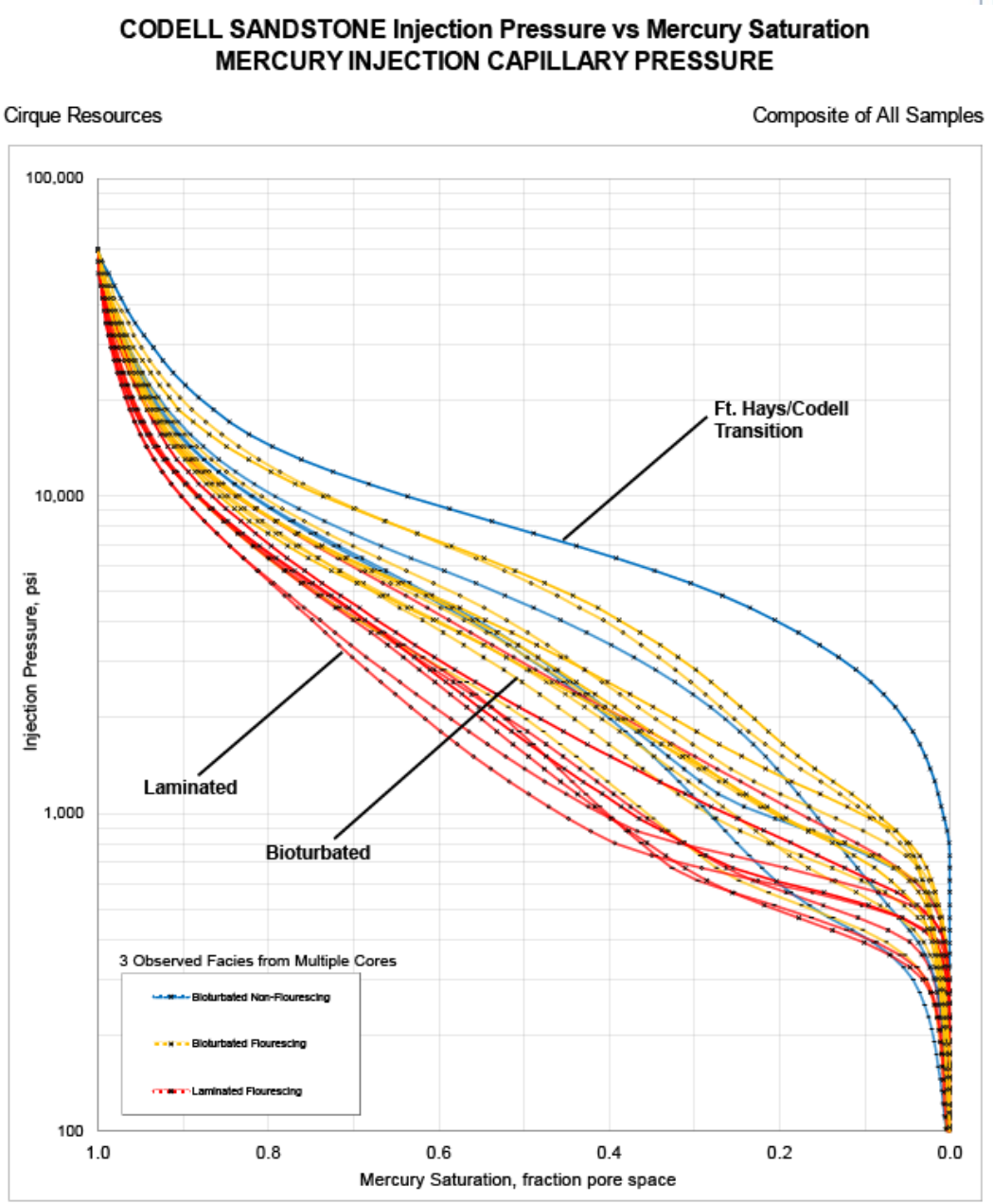
- Laminated zone has better slightly reservoir characteristics than bioturbated zone
- Both Facies contain oil
- 2 reservoir system?





Mercury Injection-Capillary Pressure Pore Throat Size

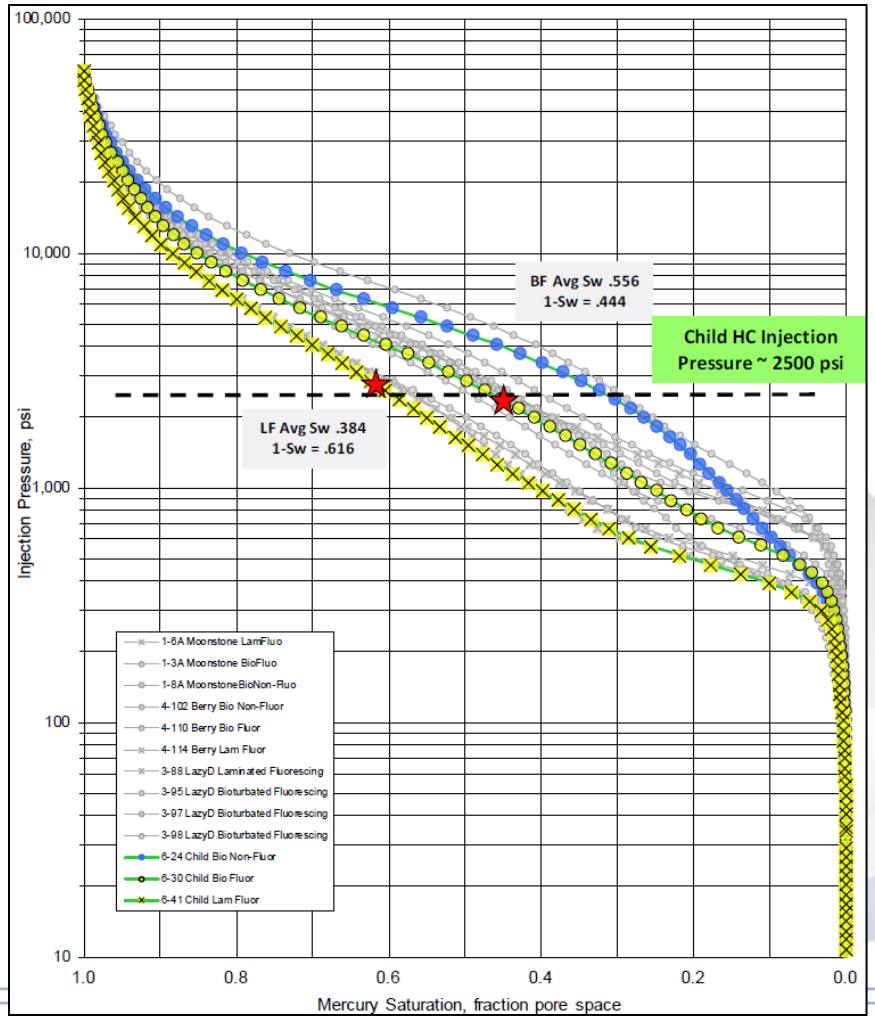
- The laminated zone has larger pore throats and accepts mercury under lower pressures
- This is likely the main pathway for oil migration in the Codell
- Production and core data suggests a mix matrix and fractured reservoir system?
- Ft Hayes contribution?



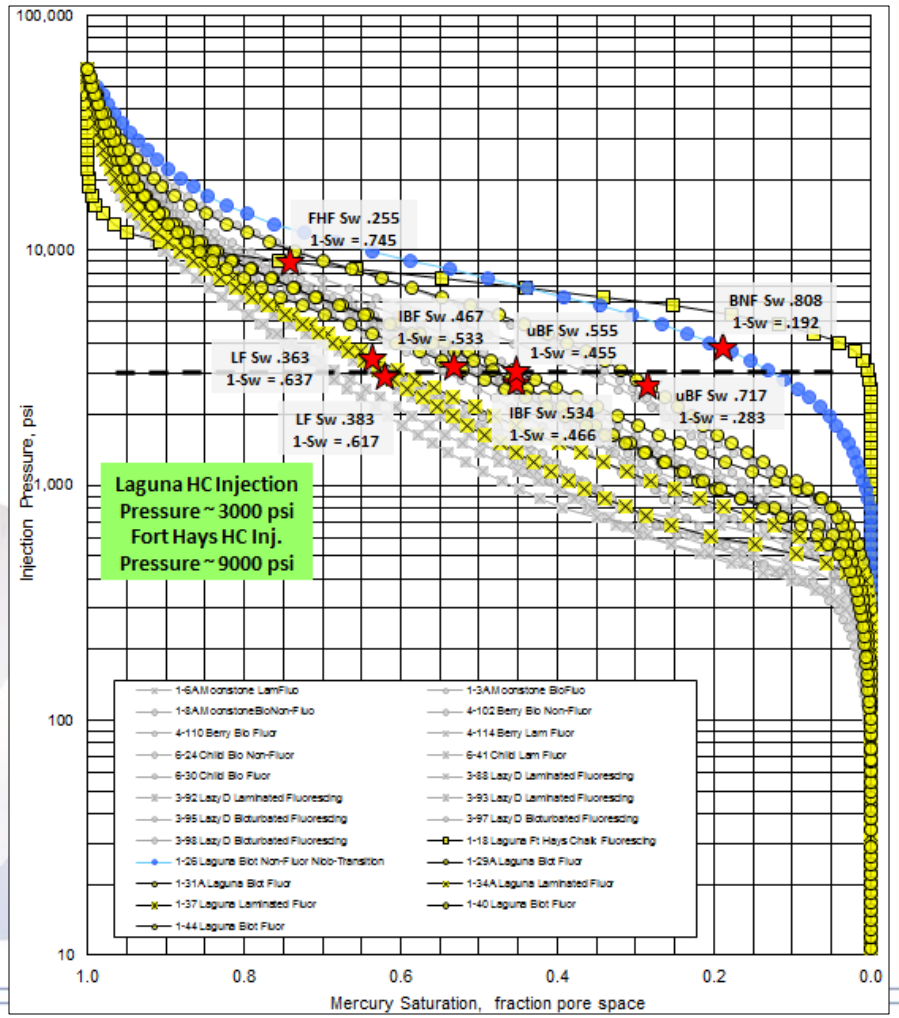
Mercury Injection-Capillary Pressure Injection Pressure

- The Bioturbated zone has a range of pressure that it will accept mercury injection, showing a variety of pore throat sizes
- Injection pressure can be estimated when plotting 1-Sw (x-axis) on the injection pressure line for the same sample as MICP was run
- No cores have the same injection pressure

Noble Energy: Child VO 30-9

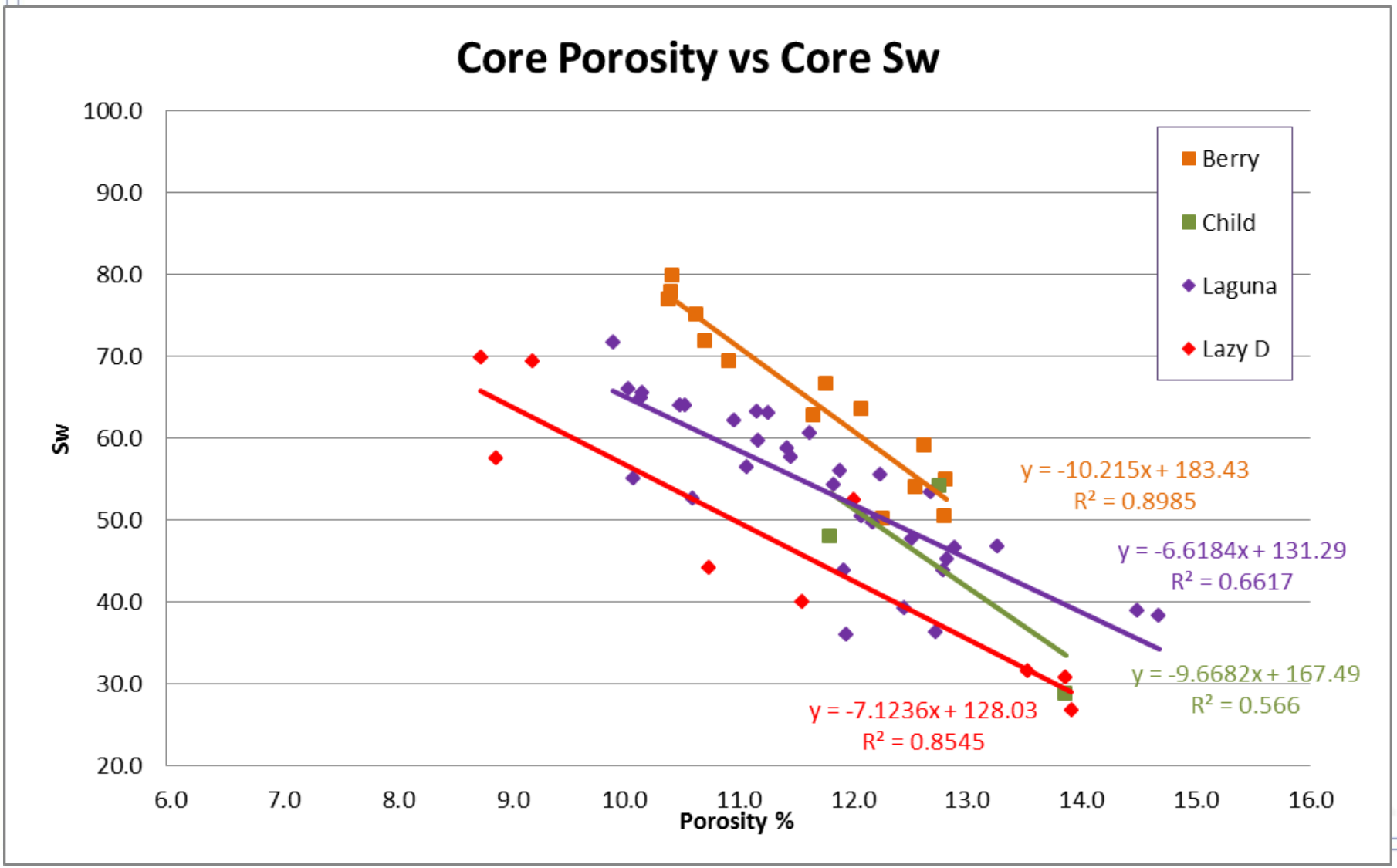


Cirque Resources: Laguna 8-8-2CH



Codell Porosity vs Saturation

- Codell Sw decreases as porosity increases
  - Core data ranges from 9-15% Phi and 25-80% Sw
- No cores have the same regression equation

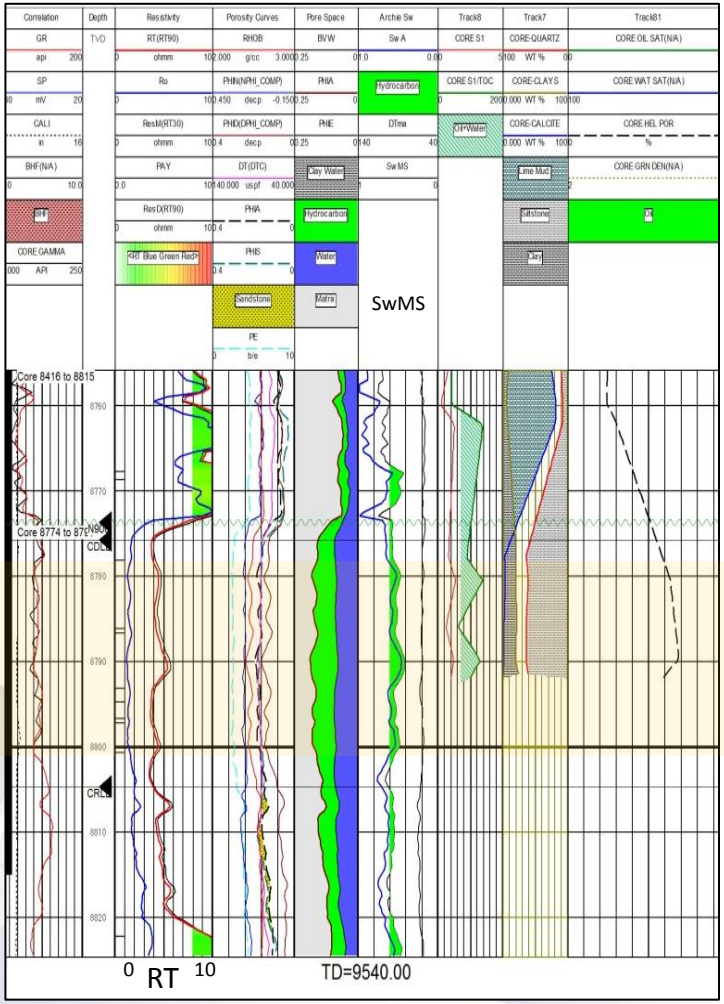


Petrophysics / Log Analysis

Analysis Assumptions

- Used Modified Simandeax due to clay content within sand
- Rw determined from lowest measured produced water salinity
- Porosity calibrated to core measurements
- Low Resistivity Pay can be evaluated only with correlation to core data, then extrapolated to older wells

Noble Energy: Child VO 30-9

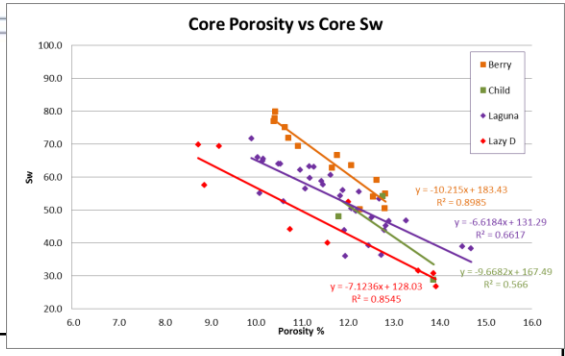


Modified Simandoux Equation

If (Vshl[] < 1)
SwMS[] = (sqrt((Vshl[]/Rshl)^2 + 4*PHIE[]^m/(a*Rw*(1-Vshl[])*RT[])) - Vshl[]/Rshl)/(2*PHIE[]^m/(a*Rw*(1-Vshl[])))
ElseSwMS[] = 1
End If

Rw = 0.055 (48K ppm 200 deg F)
Rsh = 1.2 ohm
Mat Den= 2.68
m= 1.85
n= 1.87

Log Calculated Saturation Vs. Core



Core Calculated Saturation

Log Calculated Saturation

A

49021206420000
NOBLE ENERGY INC
BERRY UN 13-9
2000 FSL 2000 FEL
TWP: 16 N - Range: 66 W - Sec. 13
Datum=6076.00

7.9 miles

49021206390000
NOBLE ENERGY INC
CHILD VO 30-9
2180 FNL 1980 FEL
TWP: 15 N - Range: 65 W - Sec. 30
Datum=5991.00

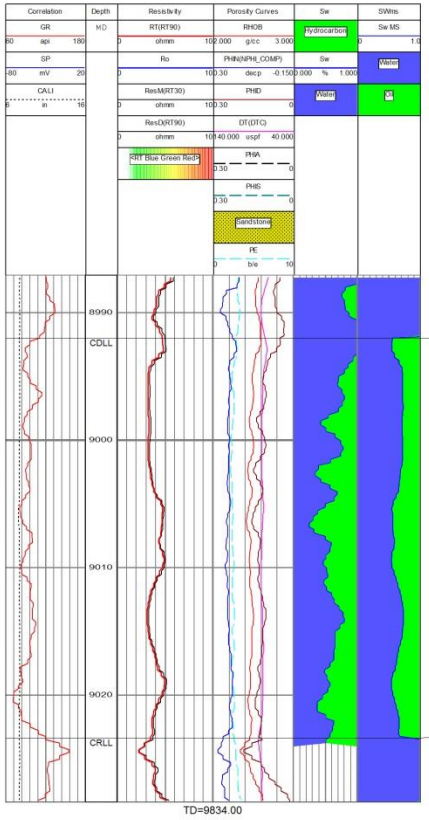
9.5 miles

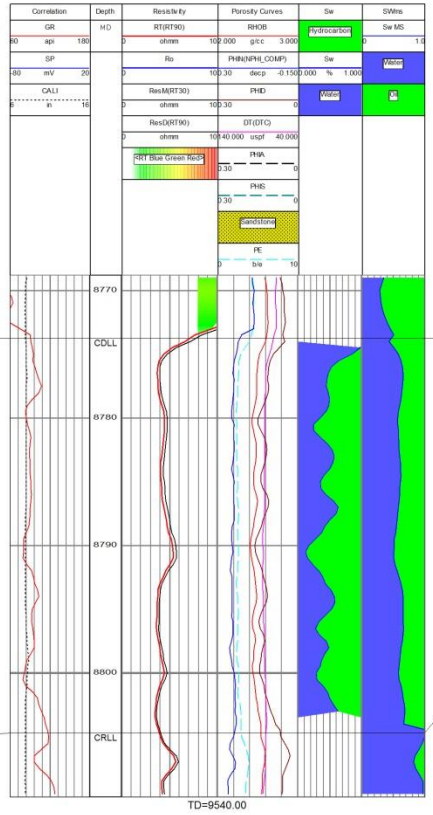
49021206510000
ANADARKO E & P CO LP
SHATTO 13-65-10-7
2360 FNL 2360 FEL
TWP: 13 N - Range: 65 W - Sec. 10
Datum=5866.00

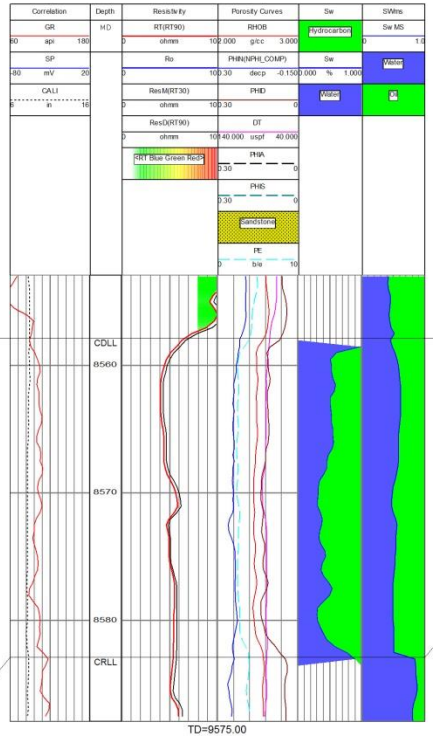
12.5 miles

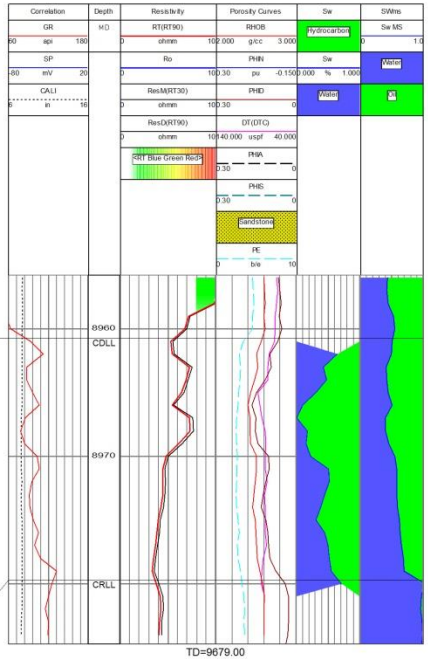
05123318320000
NOBLE ENERGY INC
LAZY D ZN 03-09
2639 FSL 1990 FEL
TWP: 11 N - Range: 66 W - Sec. 3
Datum=5910.00

A'





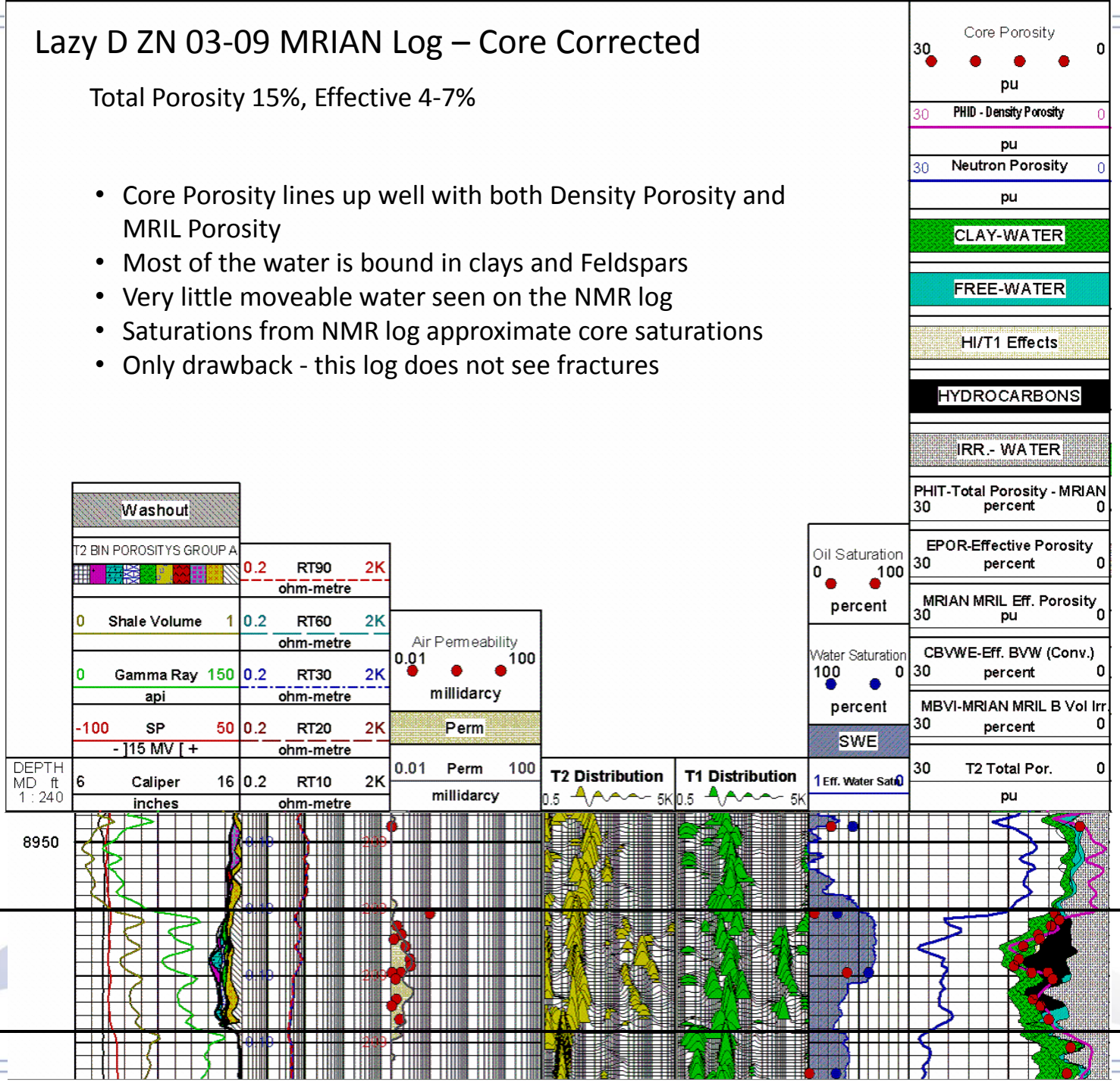




Lazy D ZN 03-09 MRIAN Log – Core Corrected

Total Porosity 15%, Effective 4-7%

- Core Porosity lines up well with both Density Porosity and MRIL Porosity
- Most of the water is bound in clays and Feldspars
- Very little moveable water seen on the NMR log
- Saturations from NMR log approximate core saturations
- Only drawback - this log does not see fractures



Codell

Fluid Analysis

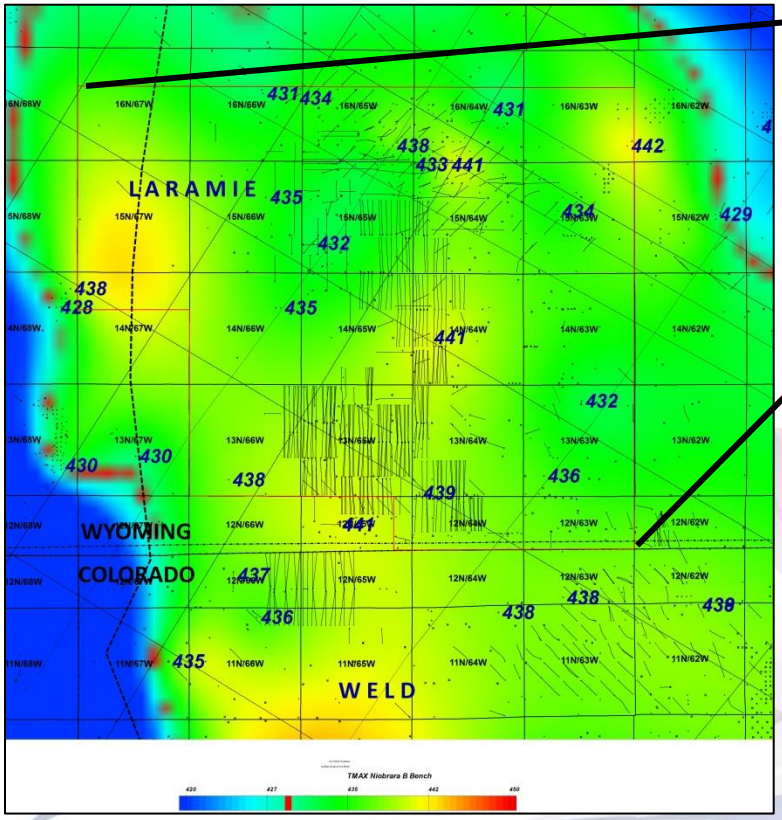
- Oil gravity = 38° API
- GOR = 900 scf/bbl average
- Water cut ranges from a low of 20% to a high of 45%
- Reservoir pressure has not been directly measured but DFIT & DST indicates a range of .51 to .58 psi/ft gradient
- Niobrara sourced oil in Codell

Regional Thermal Maturity

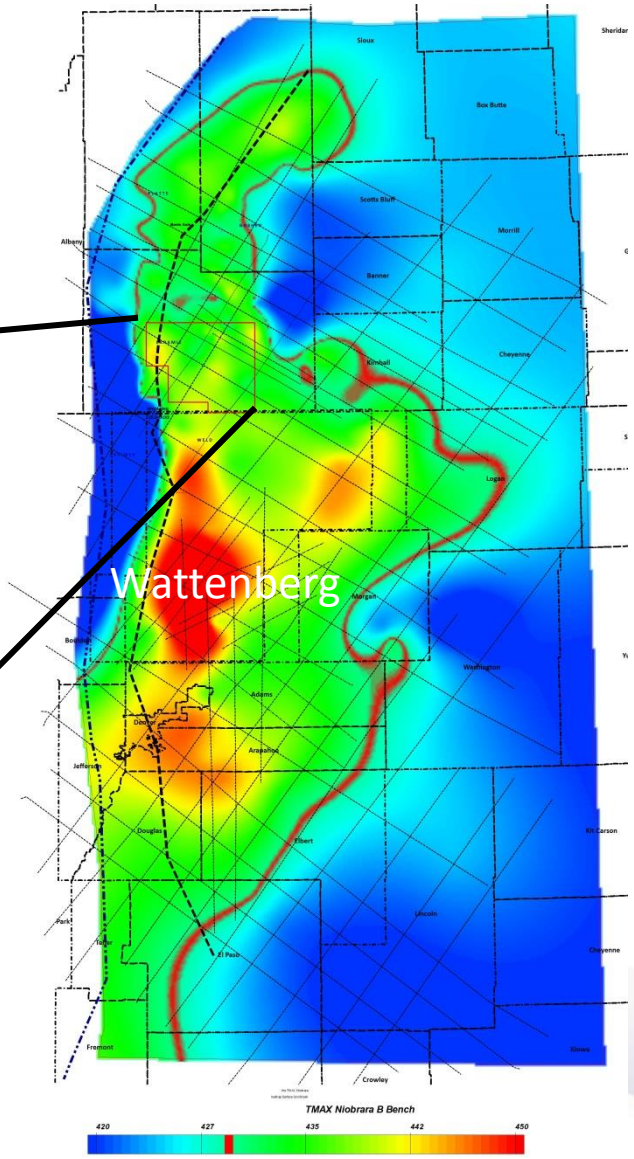
Niobrara T_{max} Contours and Burial Histories

Tmax Contours for the Niobrara

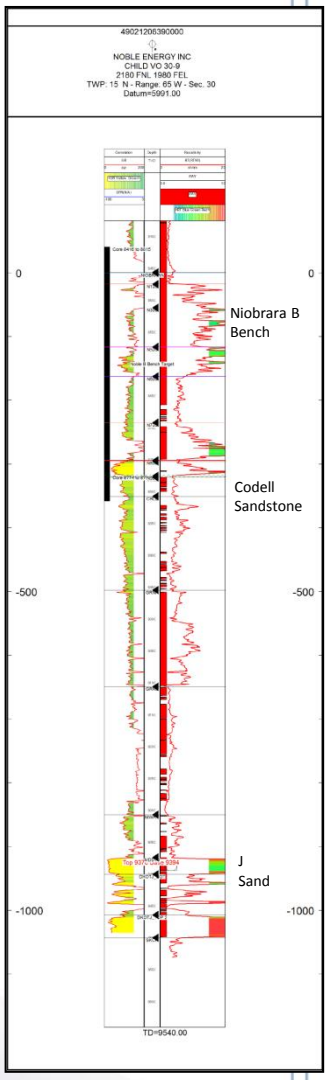
- Brennsee/Fairway area lies within a favorable Thermal Maturity fairway for the cretaceous petroleum system
- T_{Max} values in Niobrara of 435 to 441 show Thermal Maturity for oil in Project Area



Modified from Landon, Longman, Luneau. 2001



Type Log

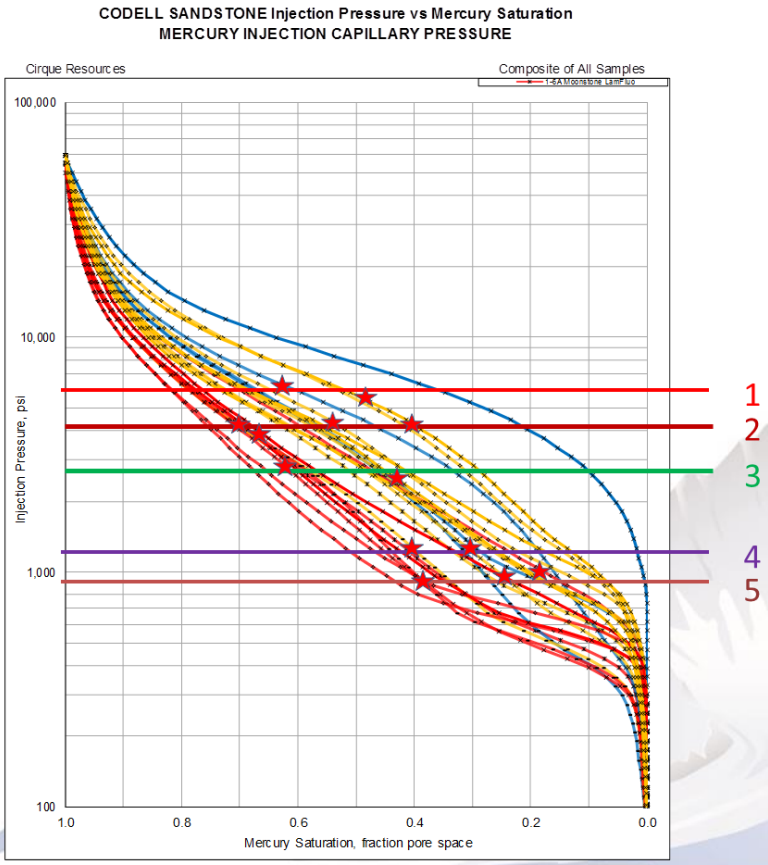


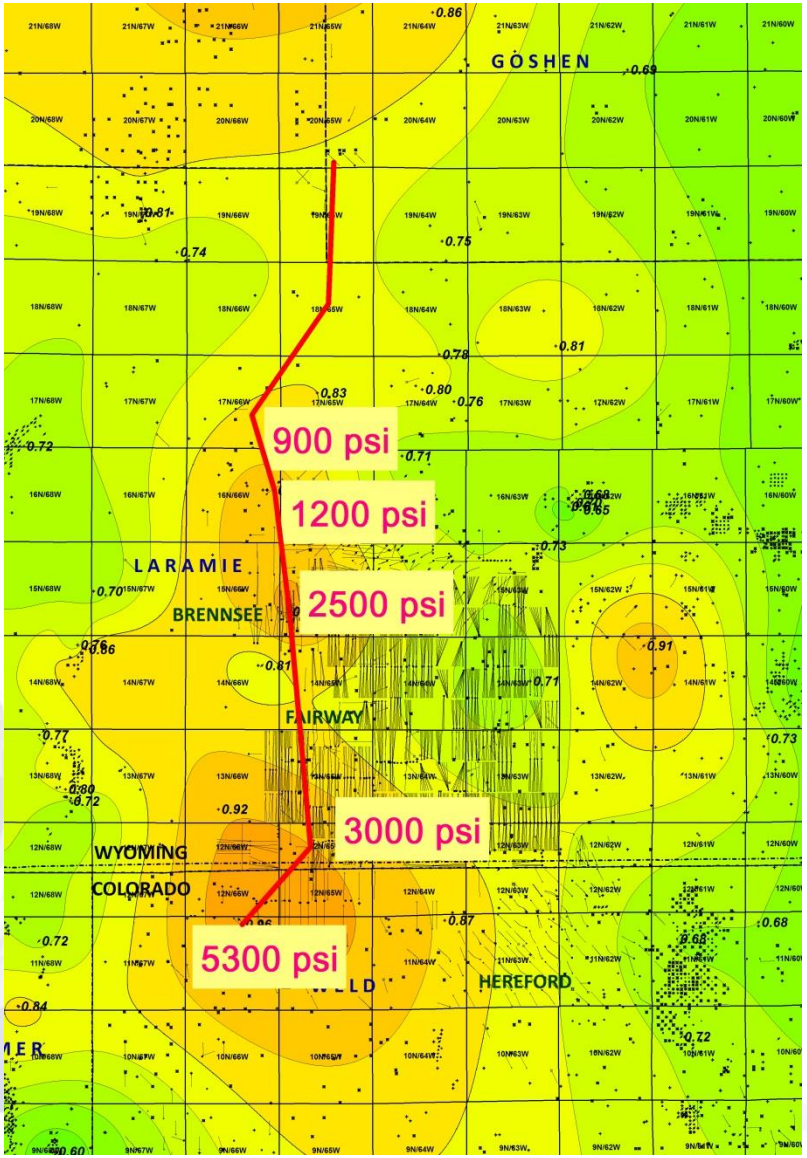
(1)

Regional Thermal Maturity

Vitrinite Reflectance (Ro) for J Sand Interval

- Samples were analyzed using vitrinite reflectance in the J Sand due to problematic vitrinite populations in the Niobrara
- Thermal maturity is responsible for injection pressure and charge





Codell Wells

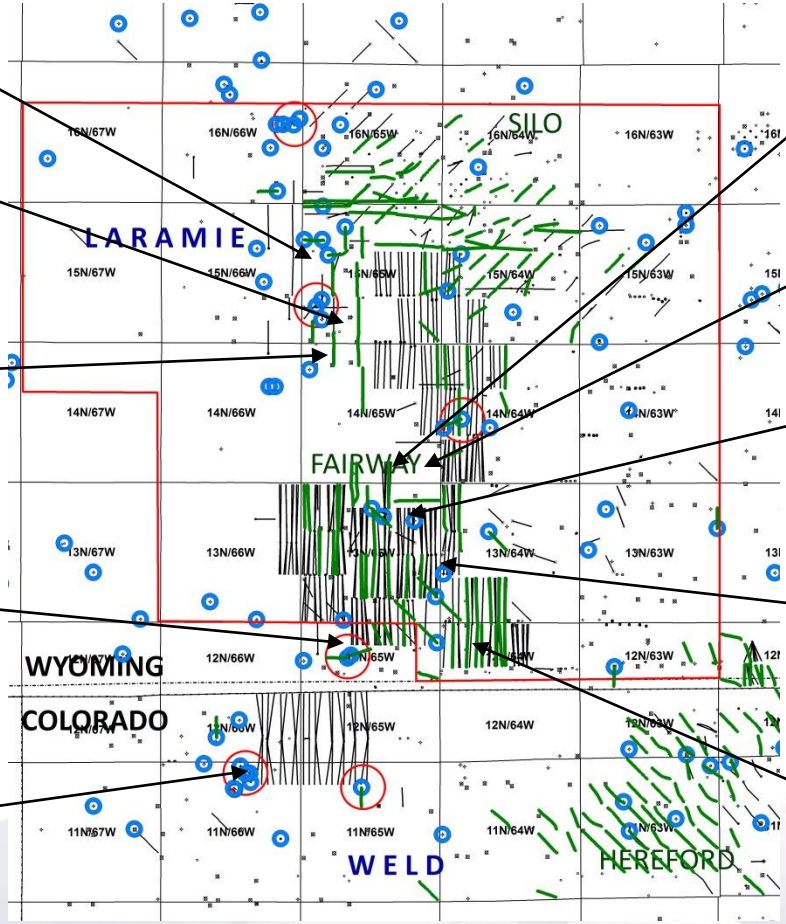
Samson Energy (Cirque)
Brennsee Field
11 Codell Wells Producing

Samson Energy (Cirque)
Rimrock 33-4-6-1CH
First Production: 2/2014
IP30d: 620 boe/d (960)

Samson Energy (Cirque)
Magee 9-16-2-1CH
First Production: 11/2014
IP30d: 1,216 boe/d (1280)

Cirque
Laguna 8-8-2CH
First Production: 06/2014
IP30d: 151 boe/d (640)
Drilled in Fault Zone

Cirque
Railay 28-3-1CH
First Production: 09/2014
IP30d: 110 boe/d (640)
Drilled in Fault zone



EOG
Jubilee 103-0433H
IP30d: 1,366 boe/d (1280)

EOG
Windy 508-1806H
IP30d: 1,192 boe/d (1280)

EOG
Jubilee 553-1034H
IP30d: 1,157 boe/d (1280)

EOG
Jubilee 584-1705H
IP30d: 1,169 boe/d (1280)

EOG
2 Bull Canyon Wells
IP30d: 1,142 boe/d (1280)

Source: HPDI.

Summary

- Codell has historically been a major contributor in the DJ Basin. The "First Burrowed SS Play"!
- Codell SS is primary driver of Wattenberg being extended to the North into Laramie County, WY.
- We believe the Codell is eastern sourced but do not have a good handle on depositional environment.
- Unconformity at the Base of Ft. Hayes LS is primarily responsible for Codell thinning.
- Core Data is essential to understanding the Codell Play due to poor log response. NMR Logs are the next best thing.
- Clays are not the only minerals that bounds water in the Codell.
- Log density porosity is a good match to core porosity.
- MICP is essential to understanding pore throat distribution and injection pressures.
- Don't forget about thermal maturity and charge!
- Oil has been typed back to Niobrara source.