Characterization and Assessment of the Controls on Performance of Niobrara and Codell Reservoirs, Northern DJ Basin, Colorado

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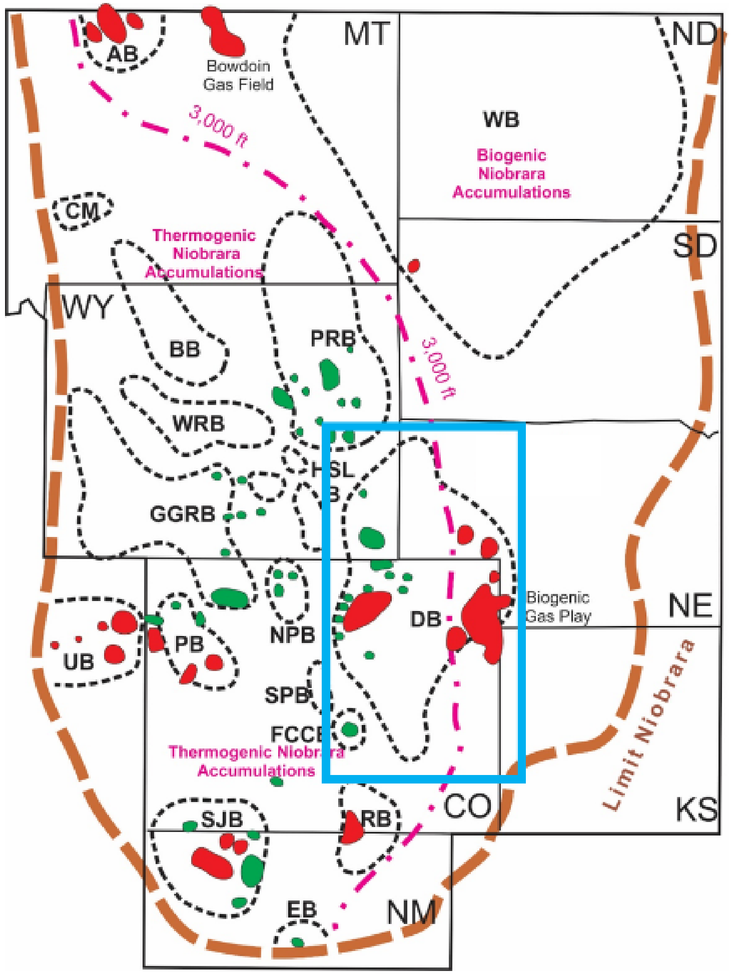
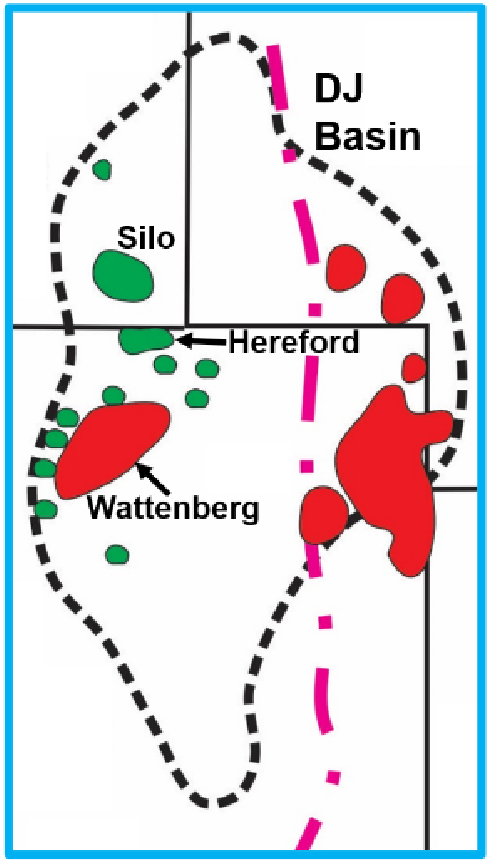
Chalk Bluff Development Optimization Project

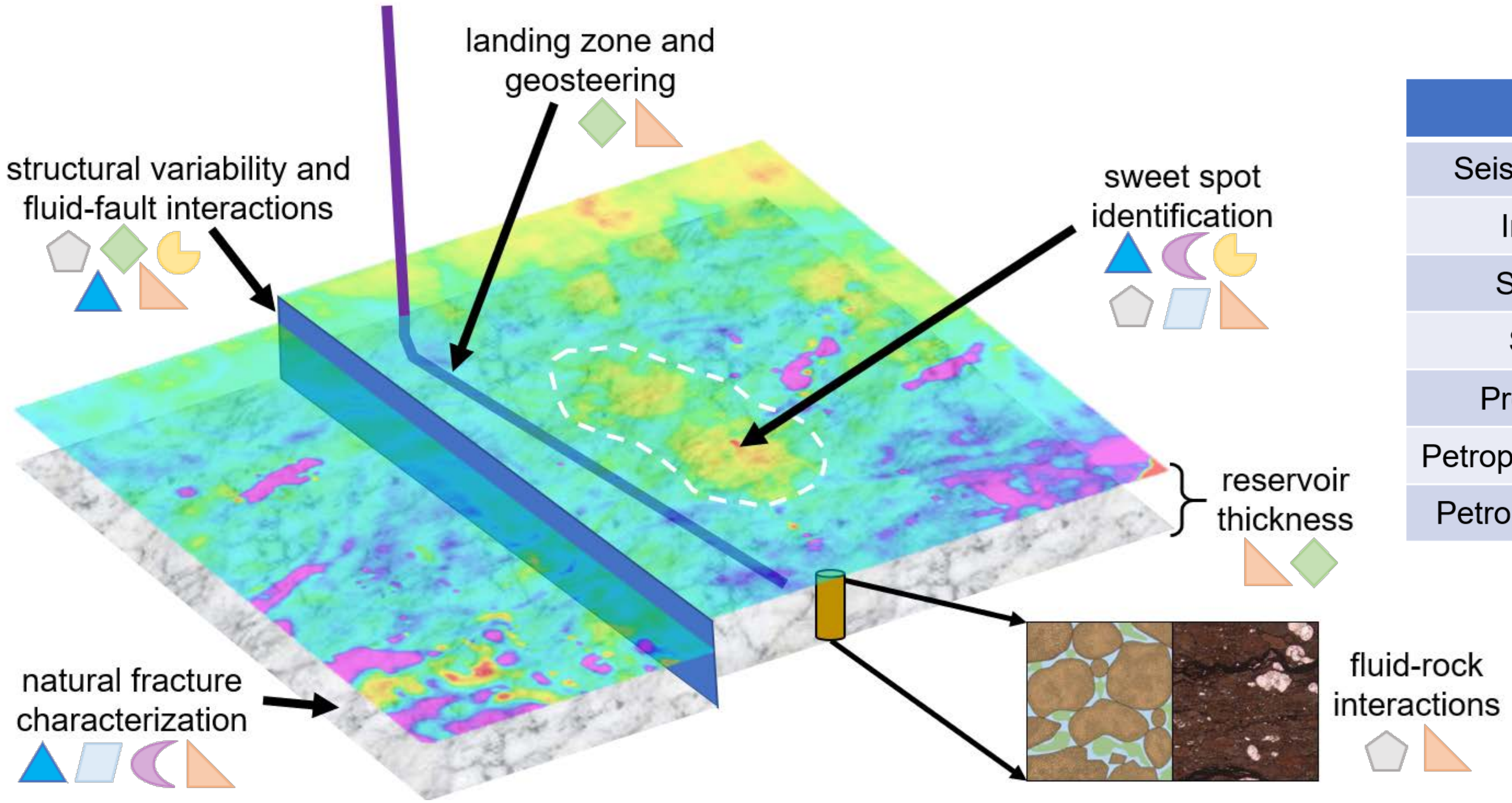


Modified from Sonnenberg and Underwood, 2012



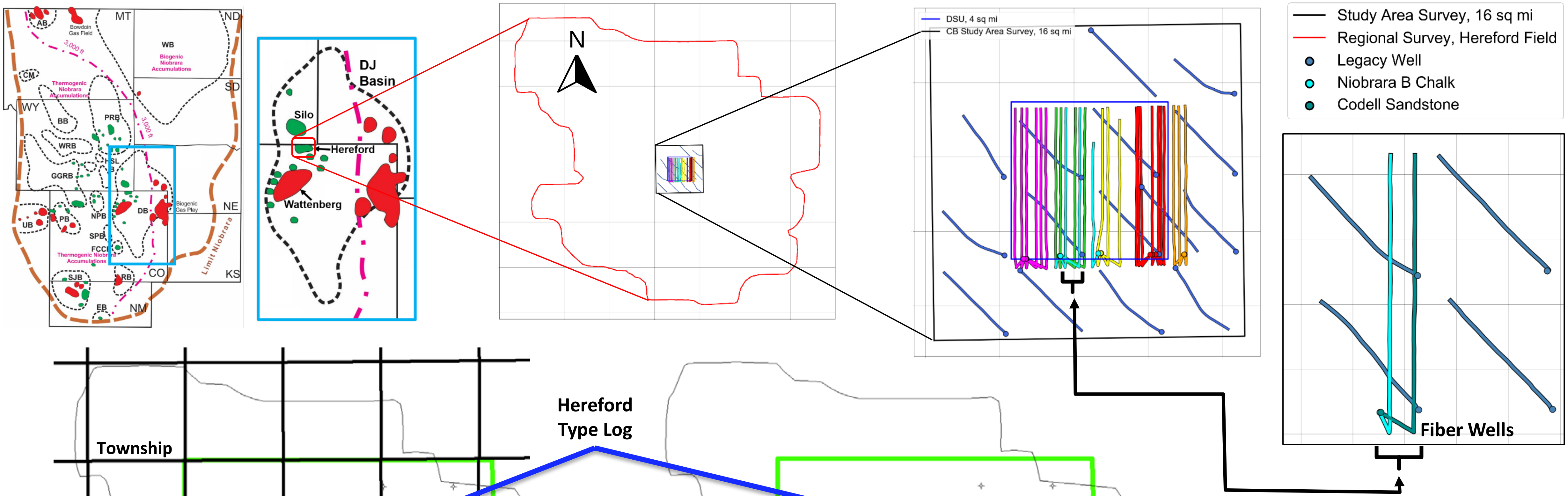
- Redevelopment of the Hereford Field in the northern Denver-Julesburg Basin
  - Features legacy wells and newly drilled wells
- Two targets
  - Codell Sandstone
  - Niobrara Chalk
- Goals
  - Accelerate learnings in Chalk Bluff to optimize additional D&C in the area
  - Generalize learnings to be applied to other unconventional reservoirs (e.g., Permian, Eagle Ford, Austin Chalk)

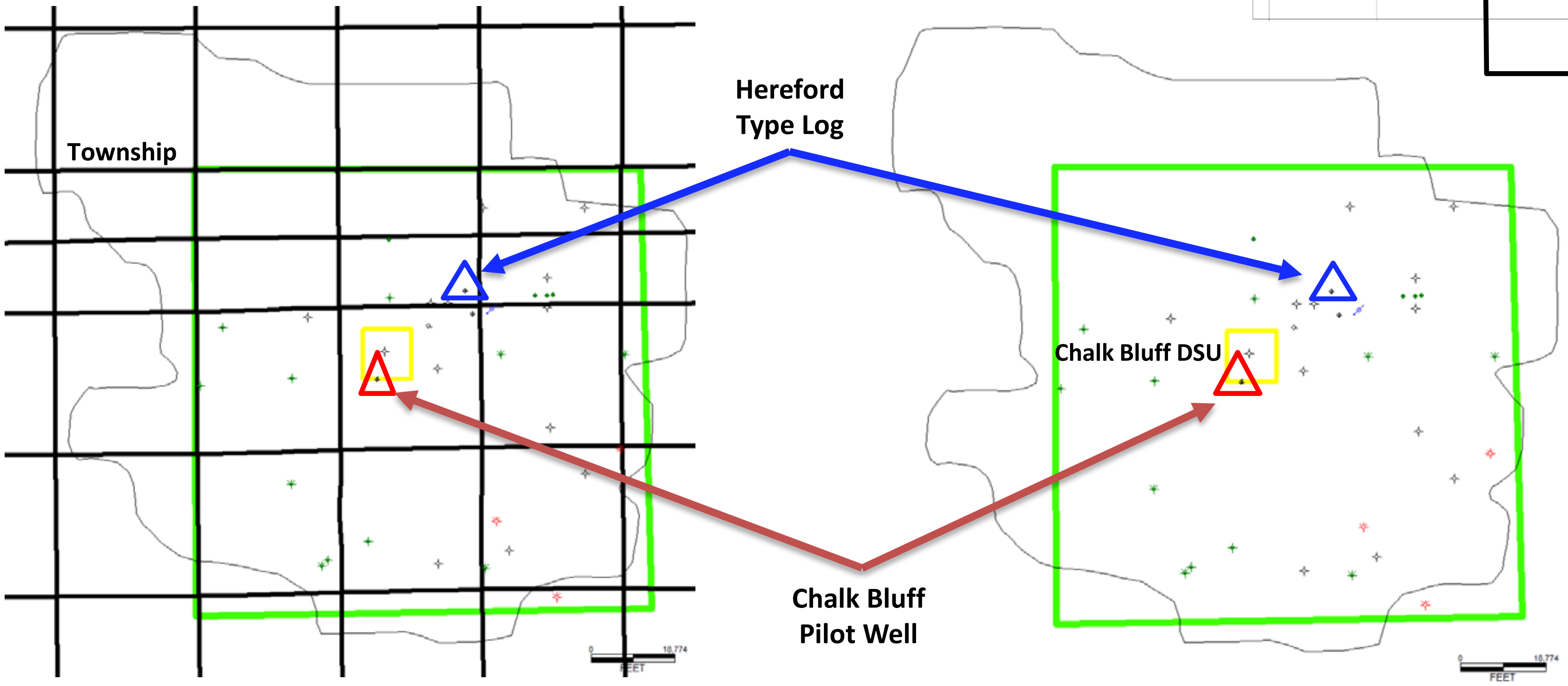
Characterizing Geologic Heterogeneity



Method	Symbol
Seismic attribute analysis	blue triangle
Image log analysis	light blue parallelogram
Structural modeling	green diamond
Seismic inversion	purple crescent
Production evaluation	yellow pie shape
Petrophysical characterization	orange right triangle
Petroleum systems analysis	grey pentagon

Data Overview



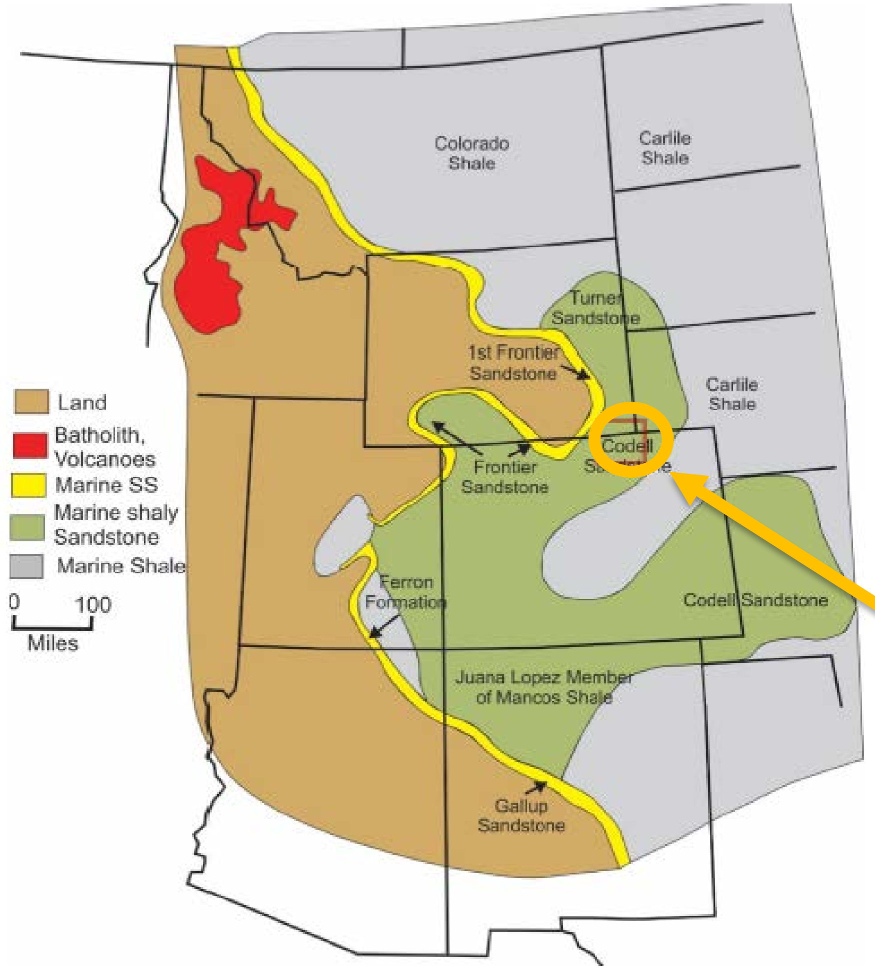


Hereford / Chalk Bluff Study Vertical Well Data Distribution

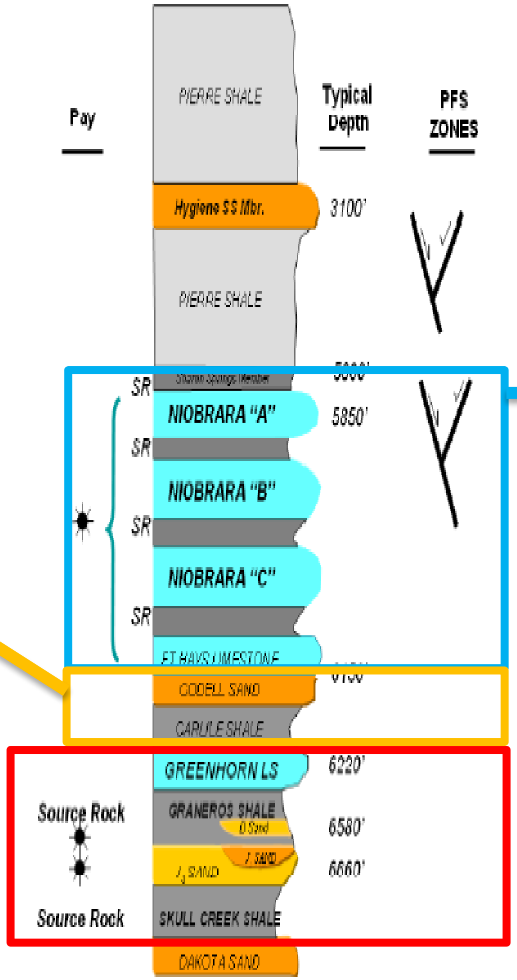
Assessing geologic heterogeneity

REGIONAL GEOLOGY AND DJ BASIN OVERVIEW

Depositional Context

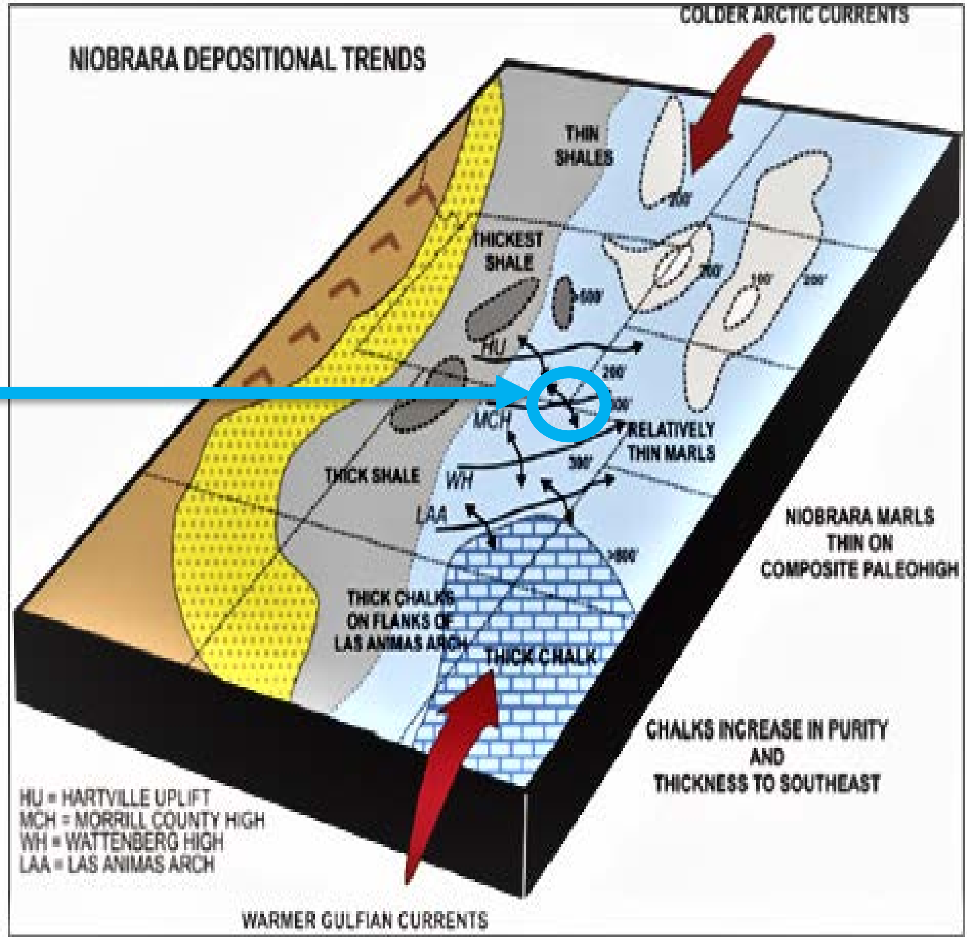


Modified from Haun et al., 1972



Modified from Sonnenberg, after Underwood, 2013

Figure 2.1. Stratigraphic column of Cretaceous interval for the 3D seismic area. A separate "D" bench may be found in some areas. Two tiers of polygonal type faults are recognized. Approximate drilling depths are indicated.



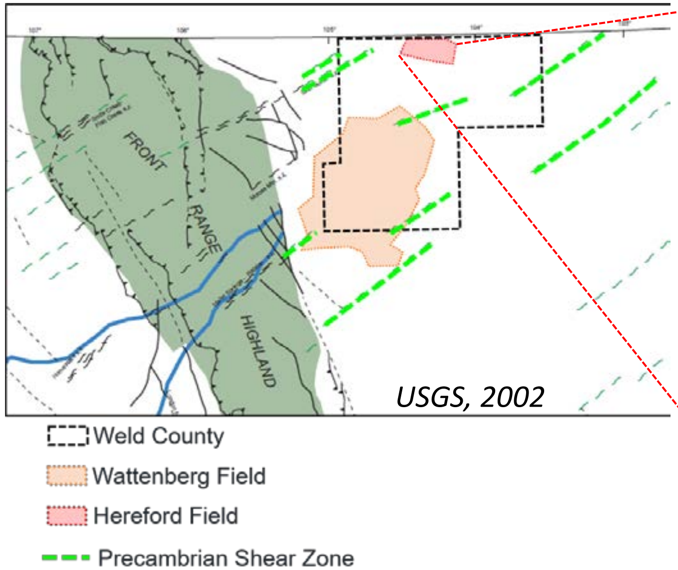
(modified from Longman et al., 1998

Codell Sandstone (Turonian Age)

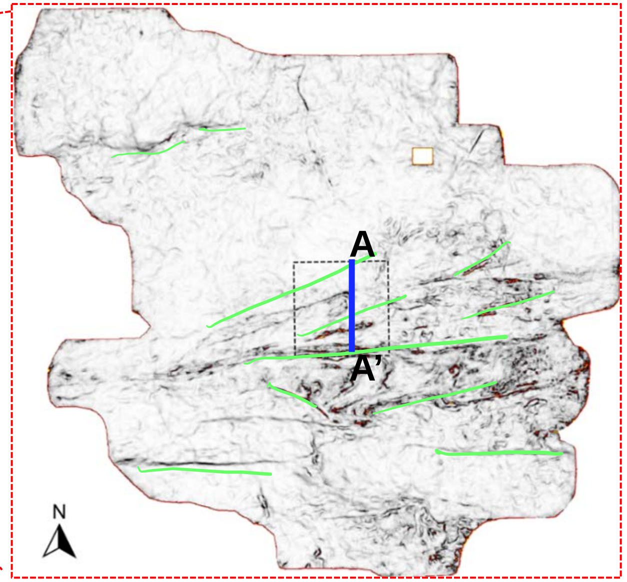
Niobrara Formation (Santonian - Turonian Age)

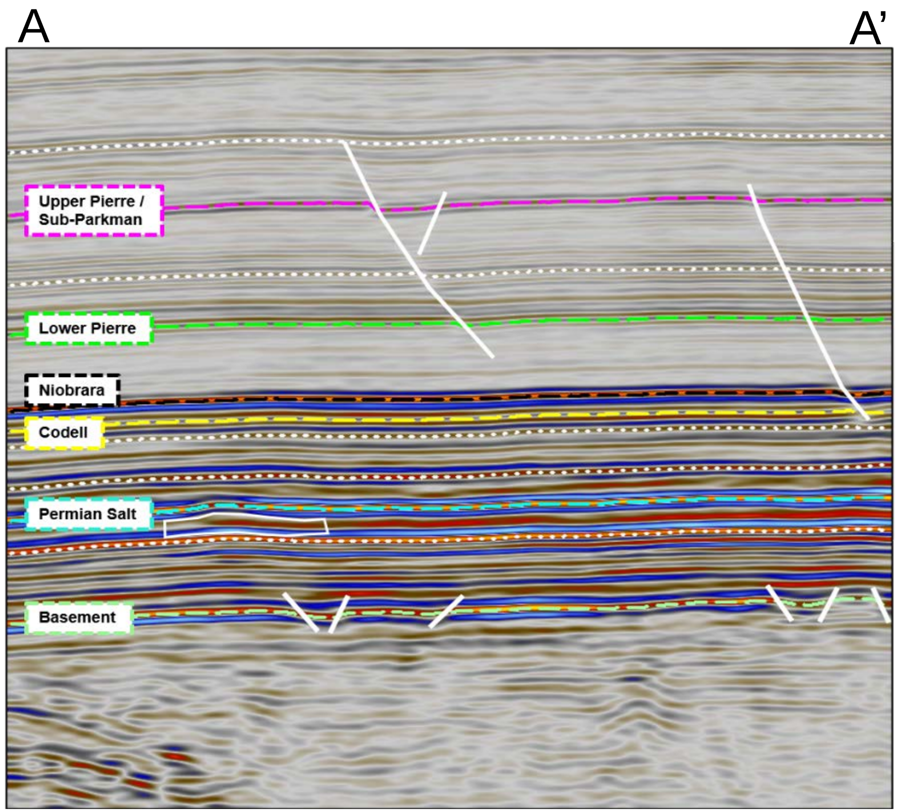
Structural Context

Precambrian



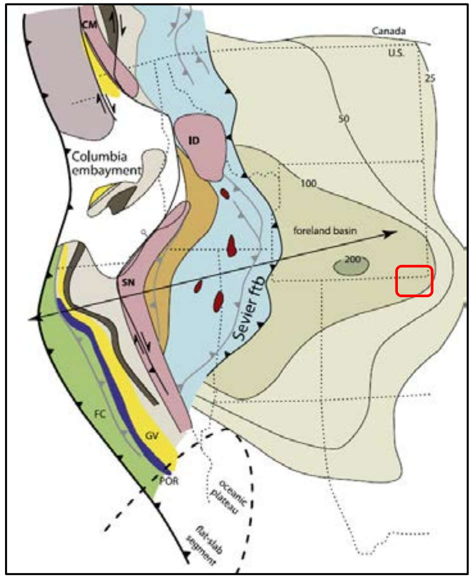
USGS, 2002



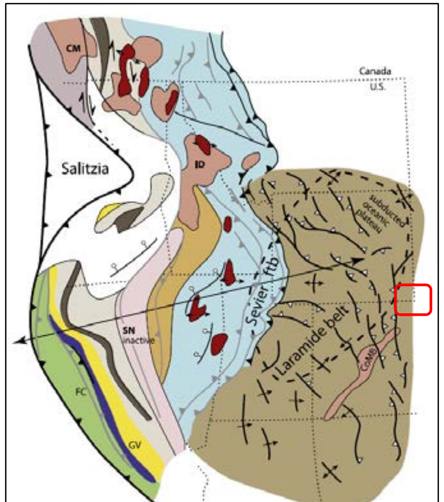


Identification of two-tiered polygonal fault system (Sonnenberg and Underwood, 2013)

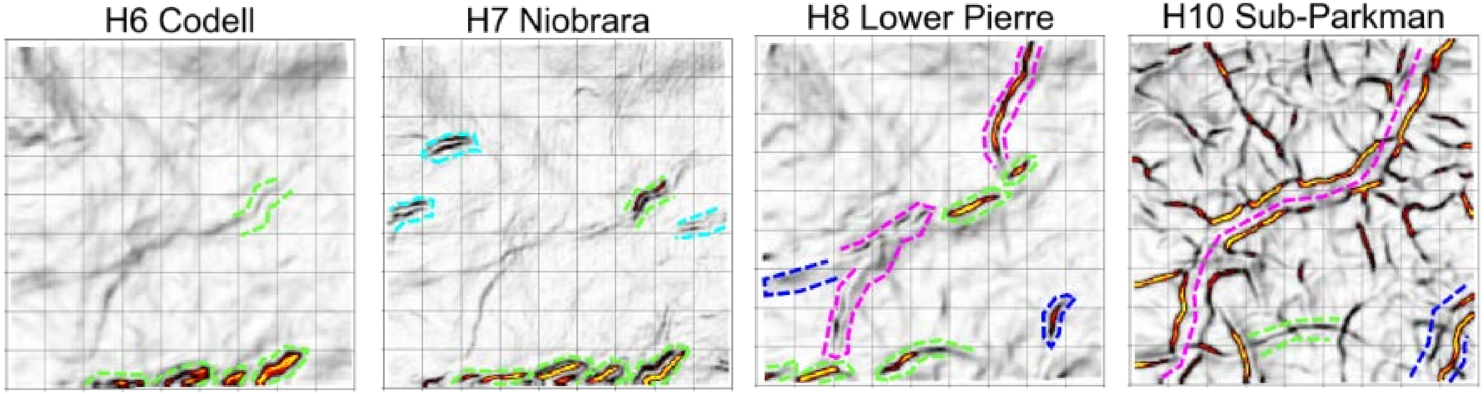
Late Cretaceous, 80 Ma



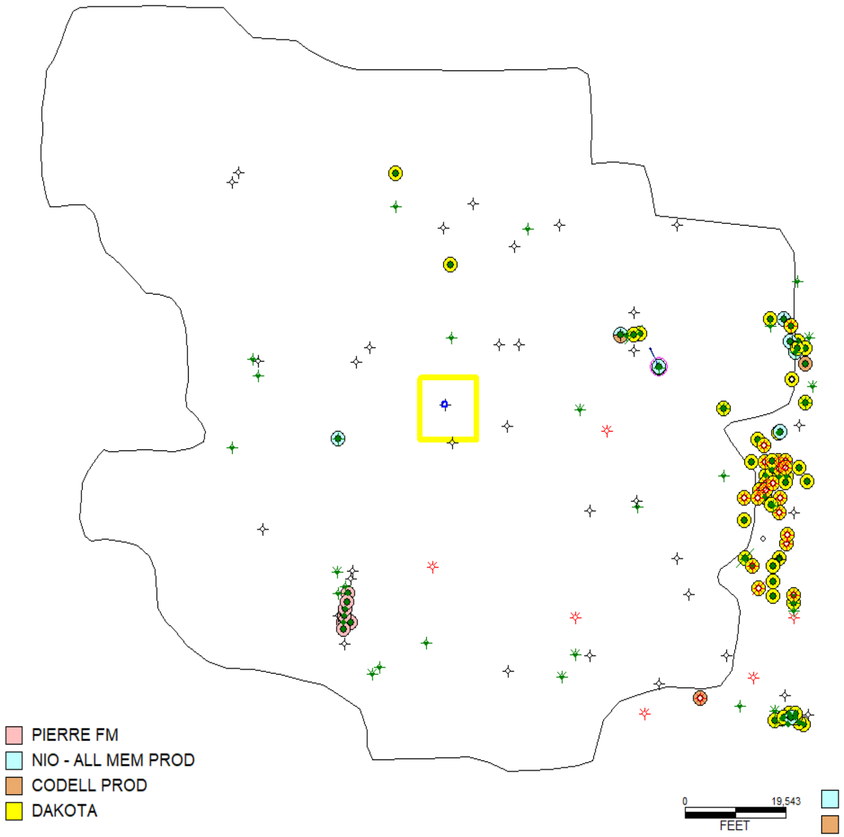
Paleogene, 50 Ma

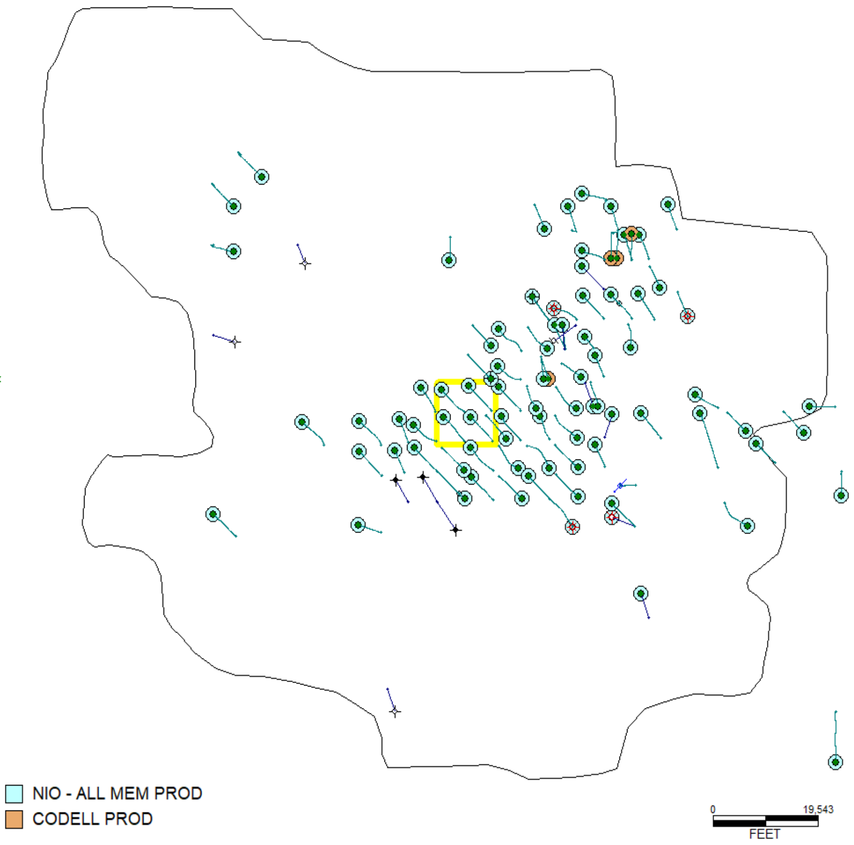


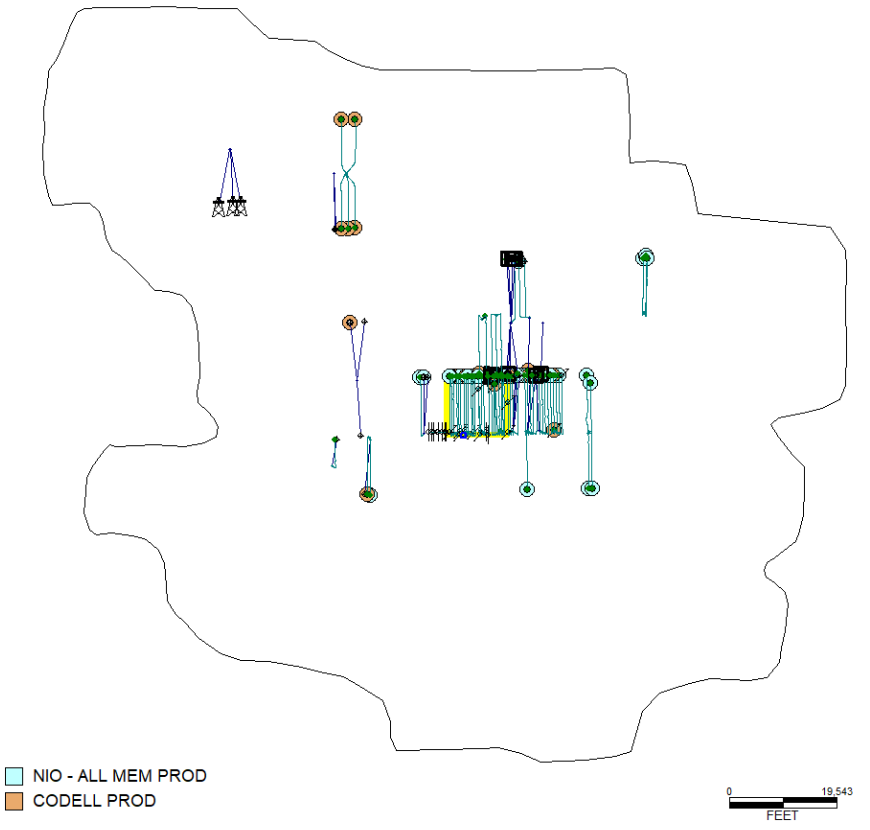
Yonkee and Weil, 2015



Hereford Field Production Evolution





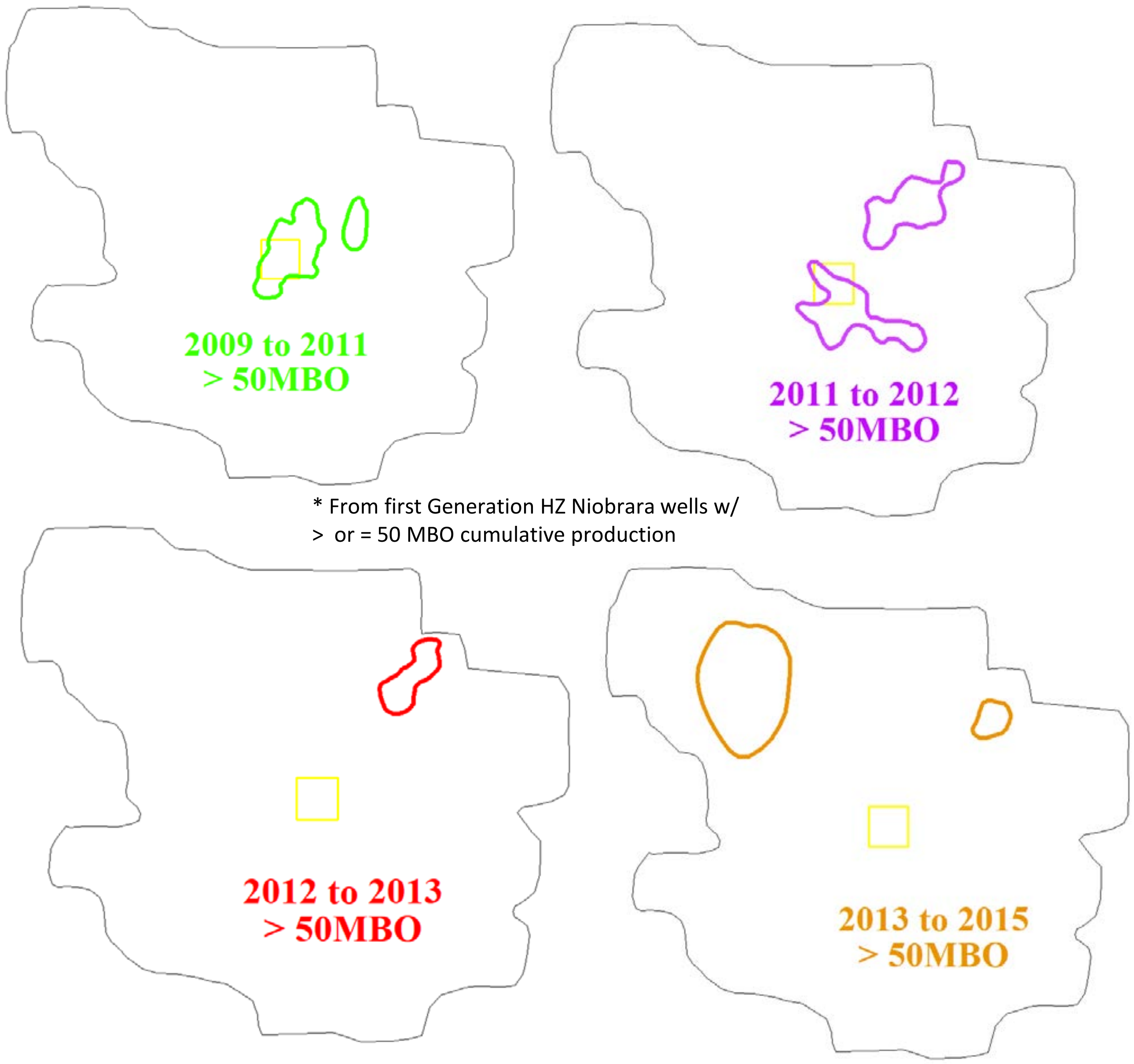


1st Generation Conventional Wells
(Pre 2009)

1st Generation Unconventional Wells, EOG
Uncemented Liner – Sliding Sleeve Completions (SRL)
(2009 - 2015)

2nd & 3rd Generation Unconventional Wells Fifth Creek & HighPoint Resources
Cemented with Plug and Perf Completion (SRL & XRL)
(2015 - 2021)

Legacy Field Progression - Cumulative Production



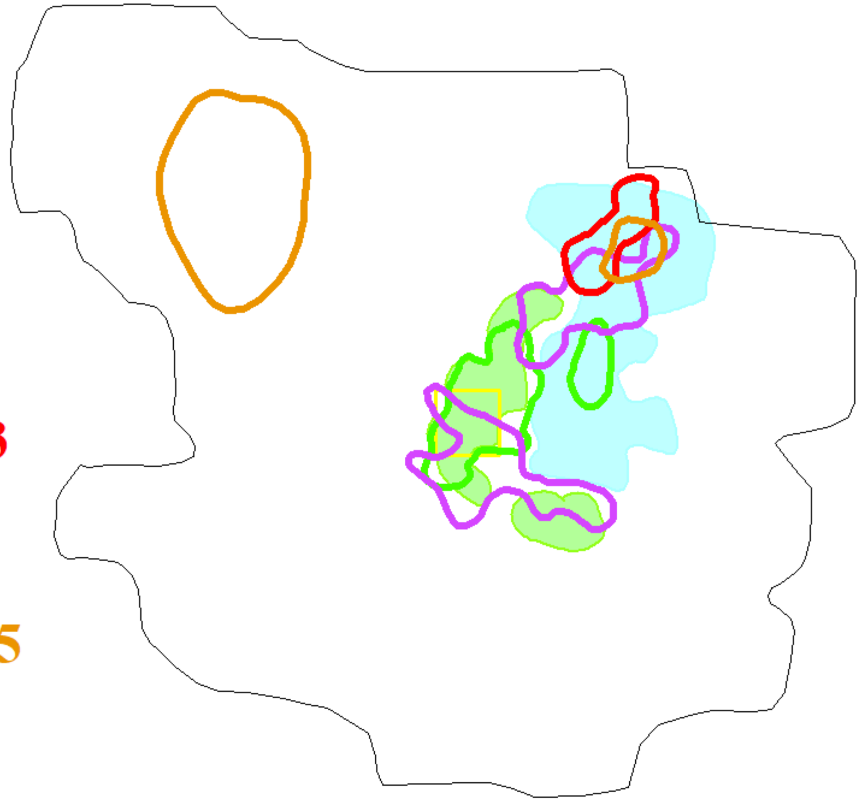
* From first Generation HZ Niobrara wells w/
> or = 50 MBO cumulative production

2009 to 2011
> 50MBO

2011 to 2012
> 50MBO

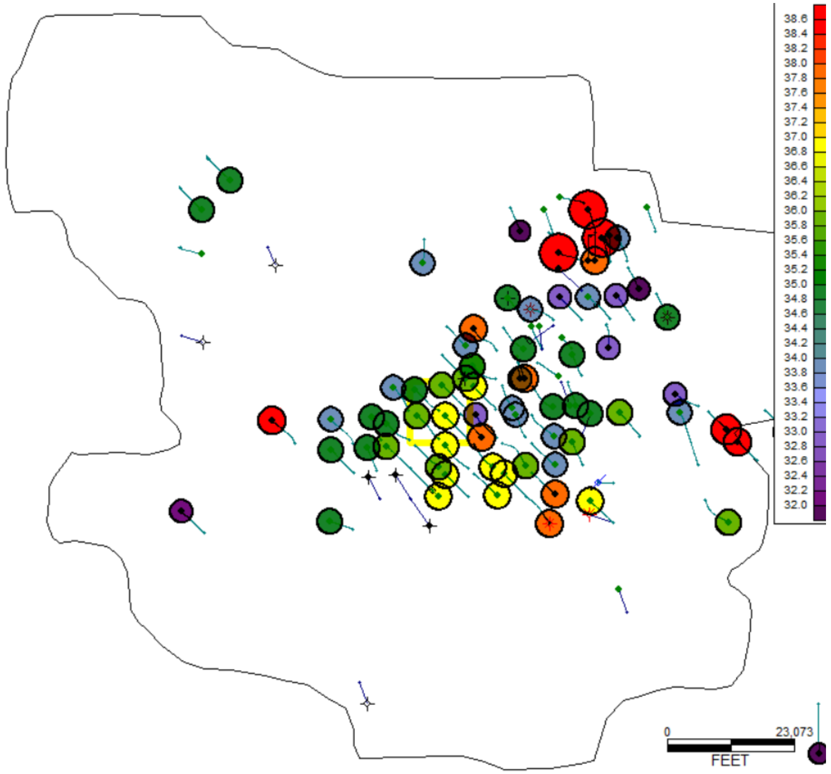
2012 to 2013
> 50MBO

2013 to 2015
> 50MBO

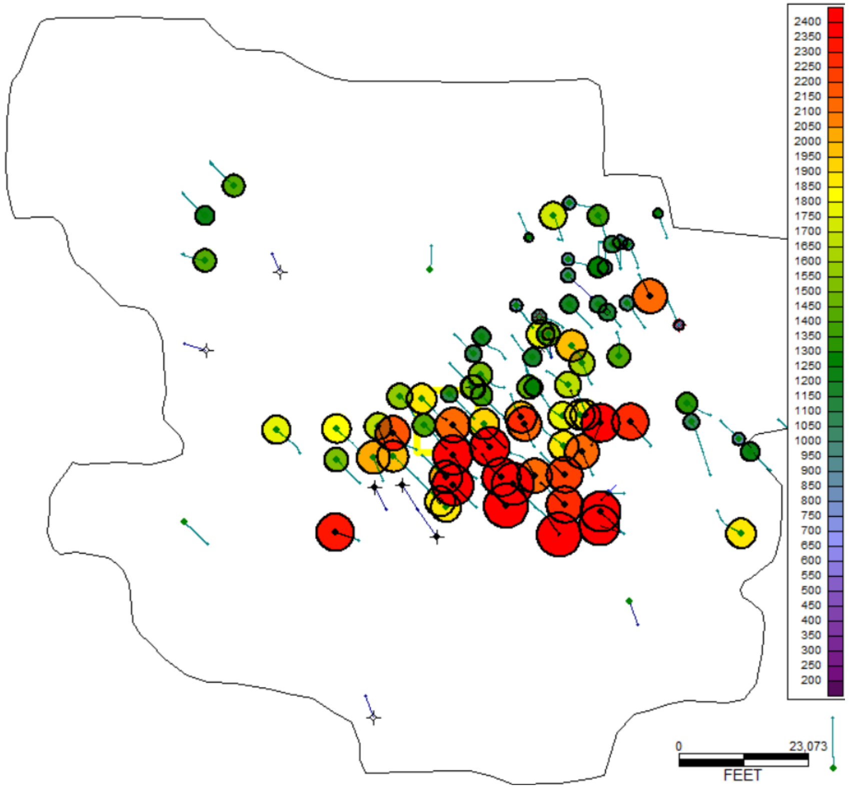


Green Shade = >50% Cum Oil Cut
Blue Shade = < 50% Oil Cut

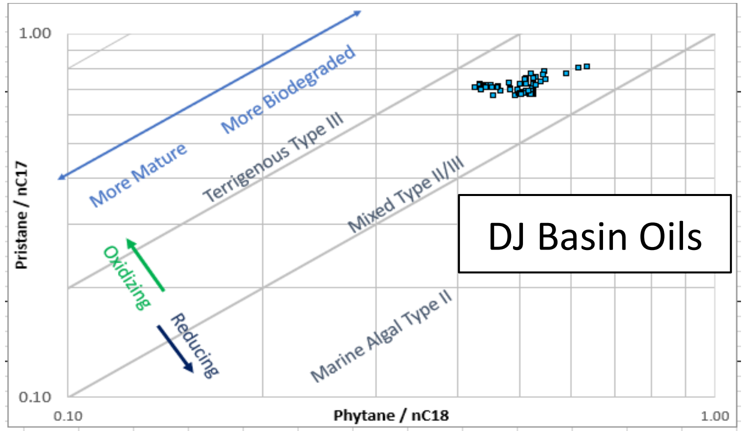
Produced Fluid Heterogeneity

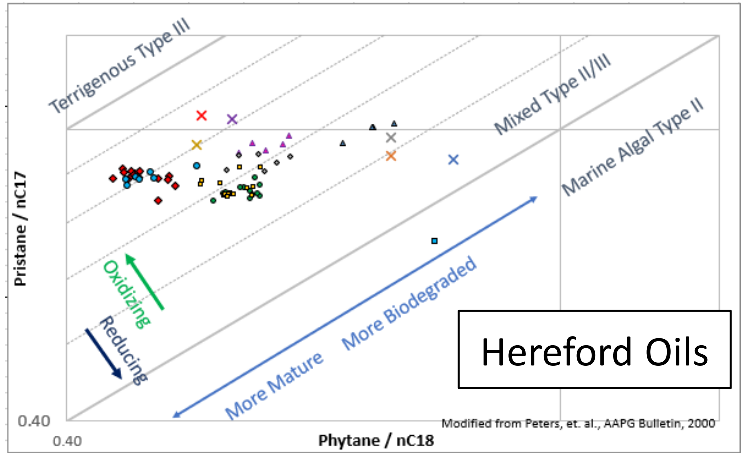


Hereford – (1st Generation)
IP Oil Gravity Bubble Map
(32 to 38 deg)



Hereford – (1st Generation)
CUM GOR Bubble Map
2400 to 200 (scf / BO deg)

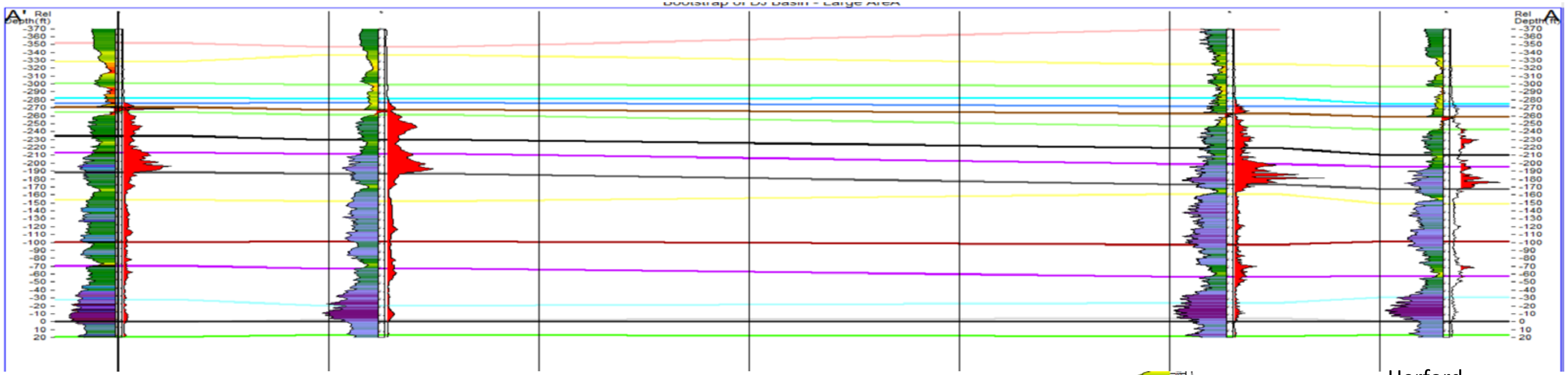




Stratigraphy, structure, and temperature

DETAILED REGIONAL STUDY OF HEREFORD FIELD

Hereford Geology



Chalk Bluff Pilot

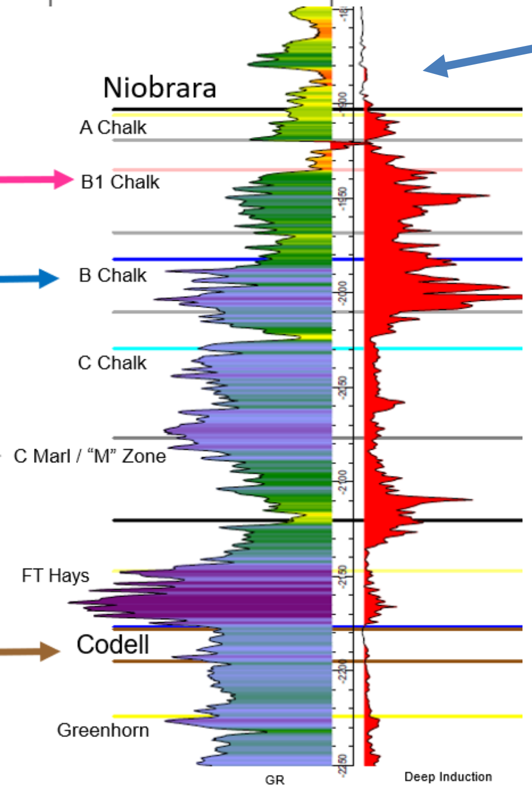
Herford Study Area – Reservoir Log Stats

- **B1 Chalk**
- Avg Thickness: 29’
- Range (8 to 52’)
- > / = 20 ohm/m (DIL): 0 - 34’ (14’ Ave)

- **B Chalk**
- Avg Thickness: 36’
- Range (20 to 56’)
- > / = 20 ohm/m (DIL): 0 to 43’ (25’ Ave)

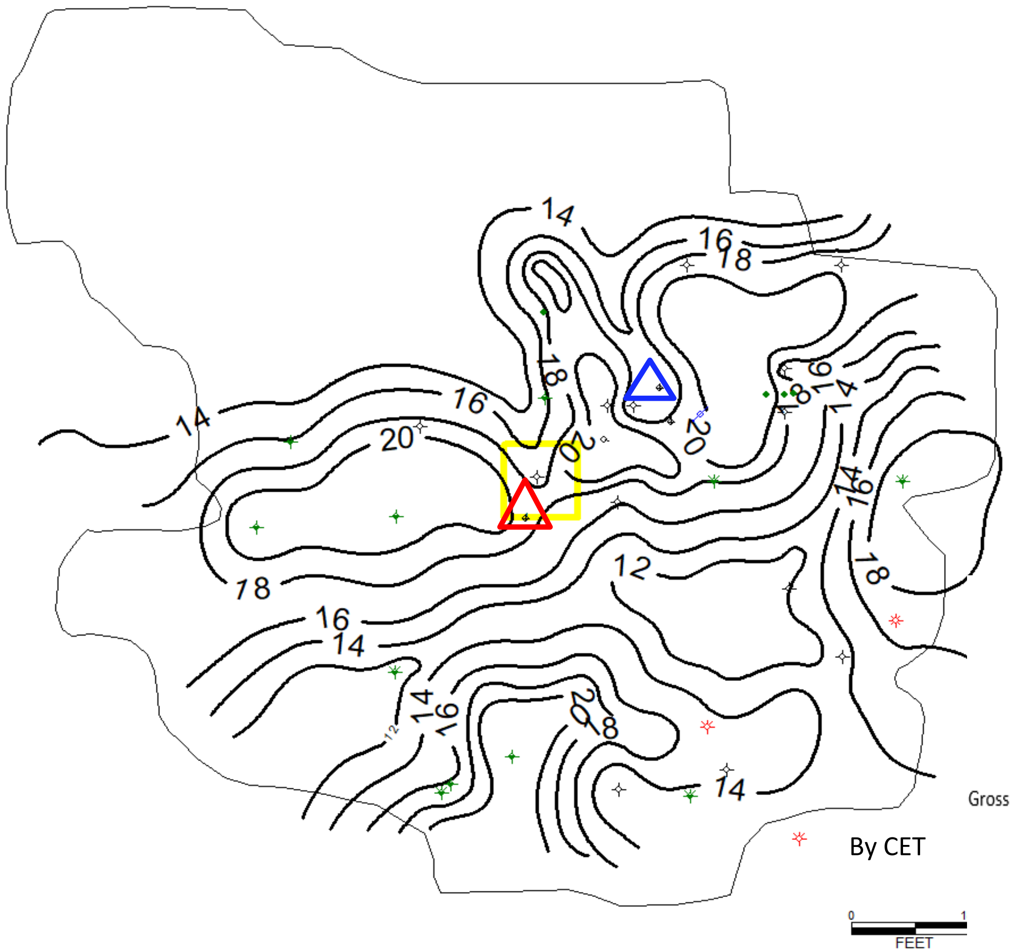
- **C Marl**
- Avg Thickness: 45’
- Range (10 to 72’)
- > / = 20 ohm/m (DIL): 0 to 26’ (5’ Ave)

- **Codell**
- Avg Thickness: 16.5’
- Range (<1 to 25”)
- > / = 4 ohm/m (DIL): 1.8 to 19+ (7.4’ Ave)

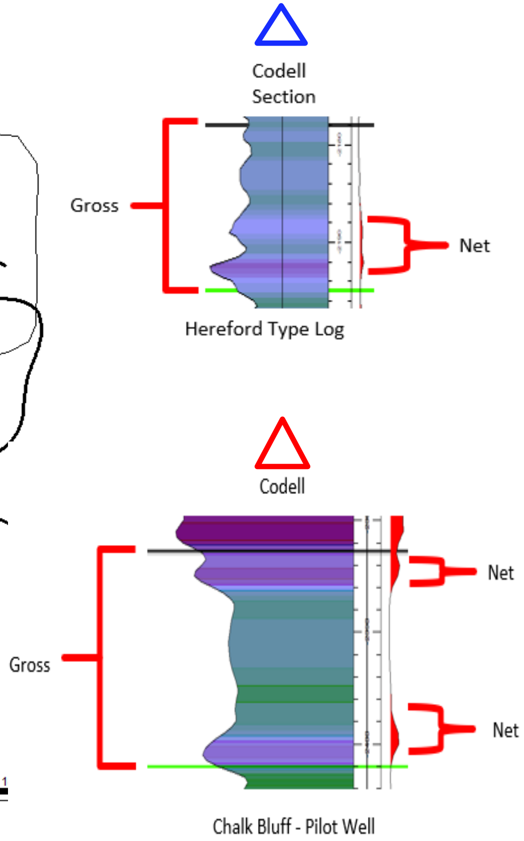


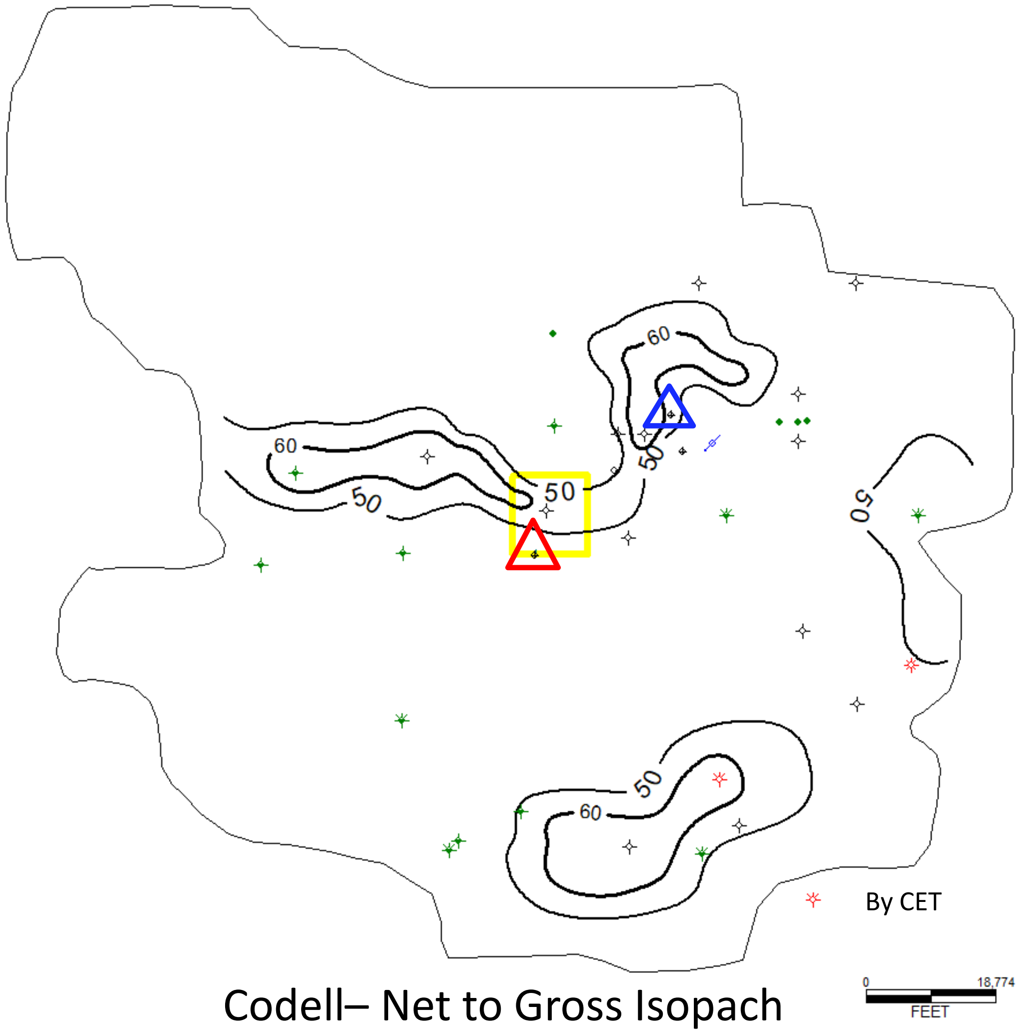
Herford Type Log

Codell



Codell–Gross Isopach
C.I. = 2 Ft

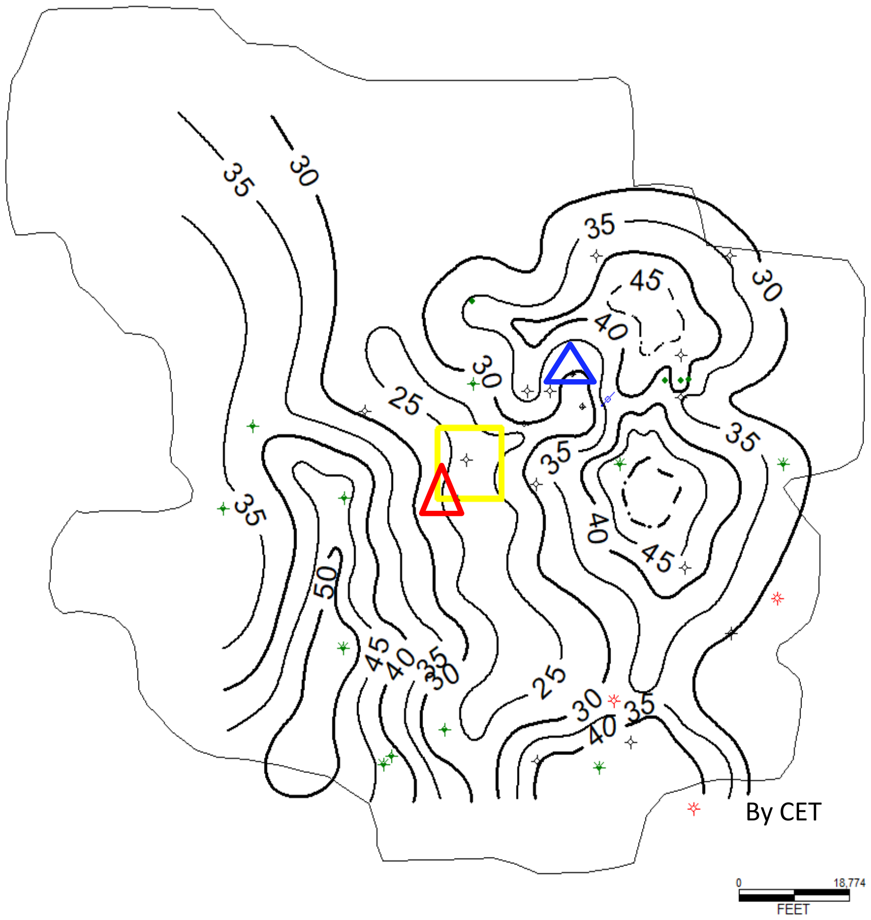




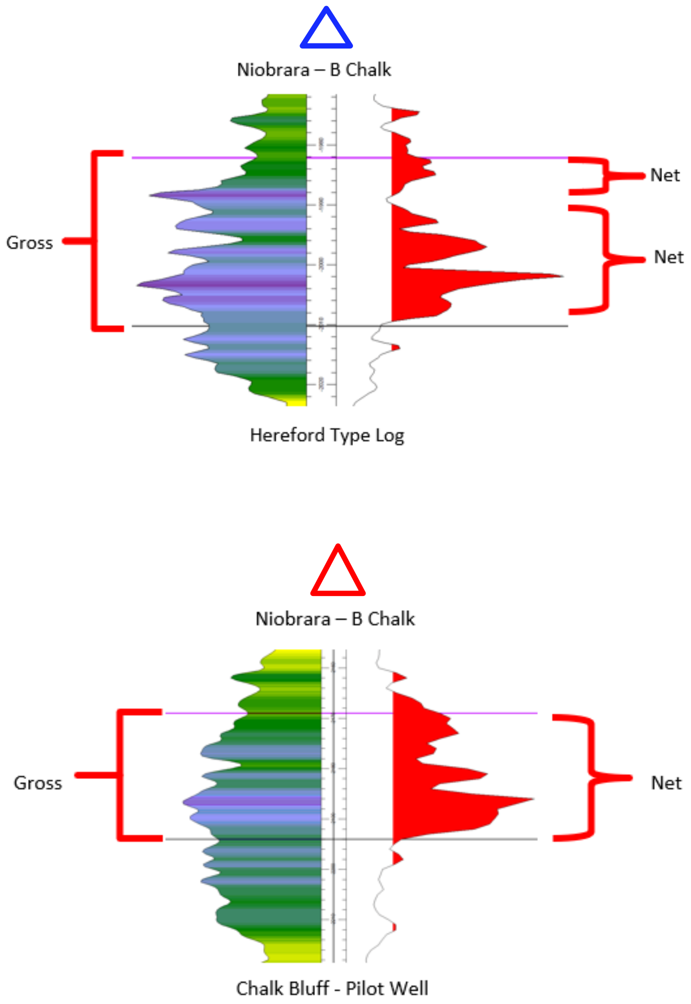
Codell– Net to Gross Isopach
C.I. = 10% Net to Gross

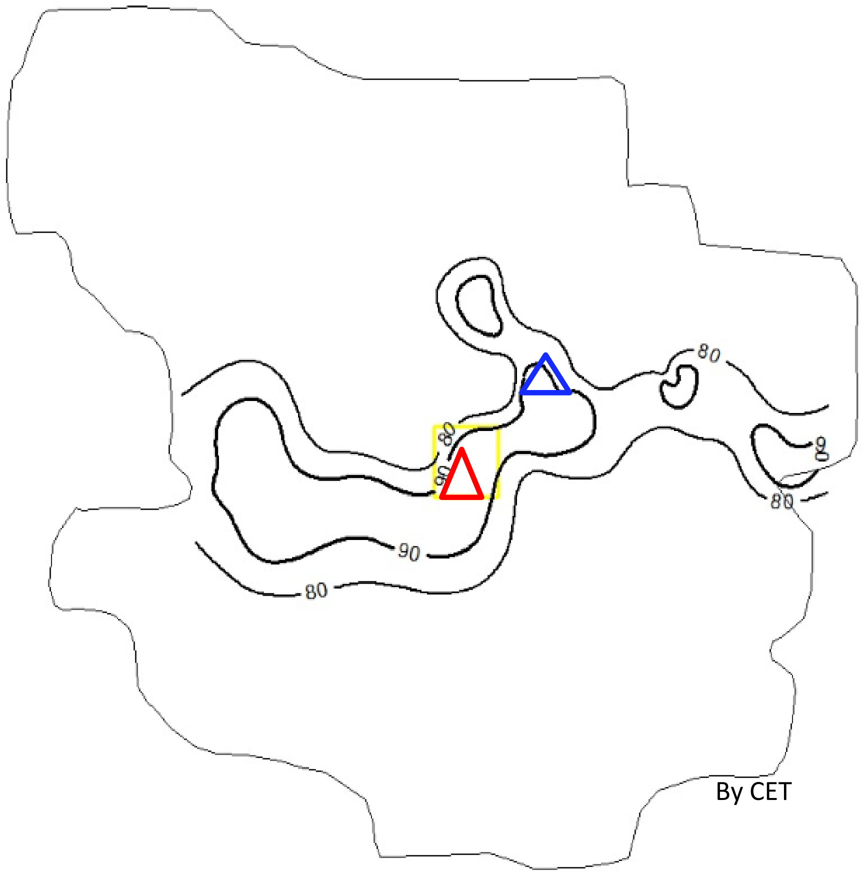
Net = (>/=) 4 ohm/m deep resistivity

Niobrara



Niobrara B Chalk –Gross Isopach
C.I. = 5’

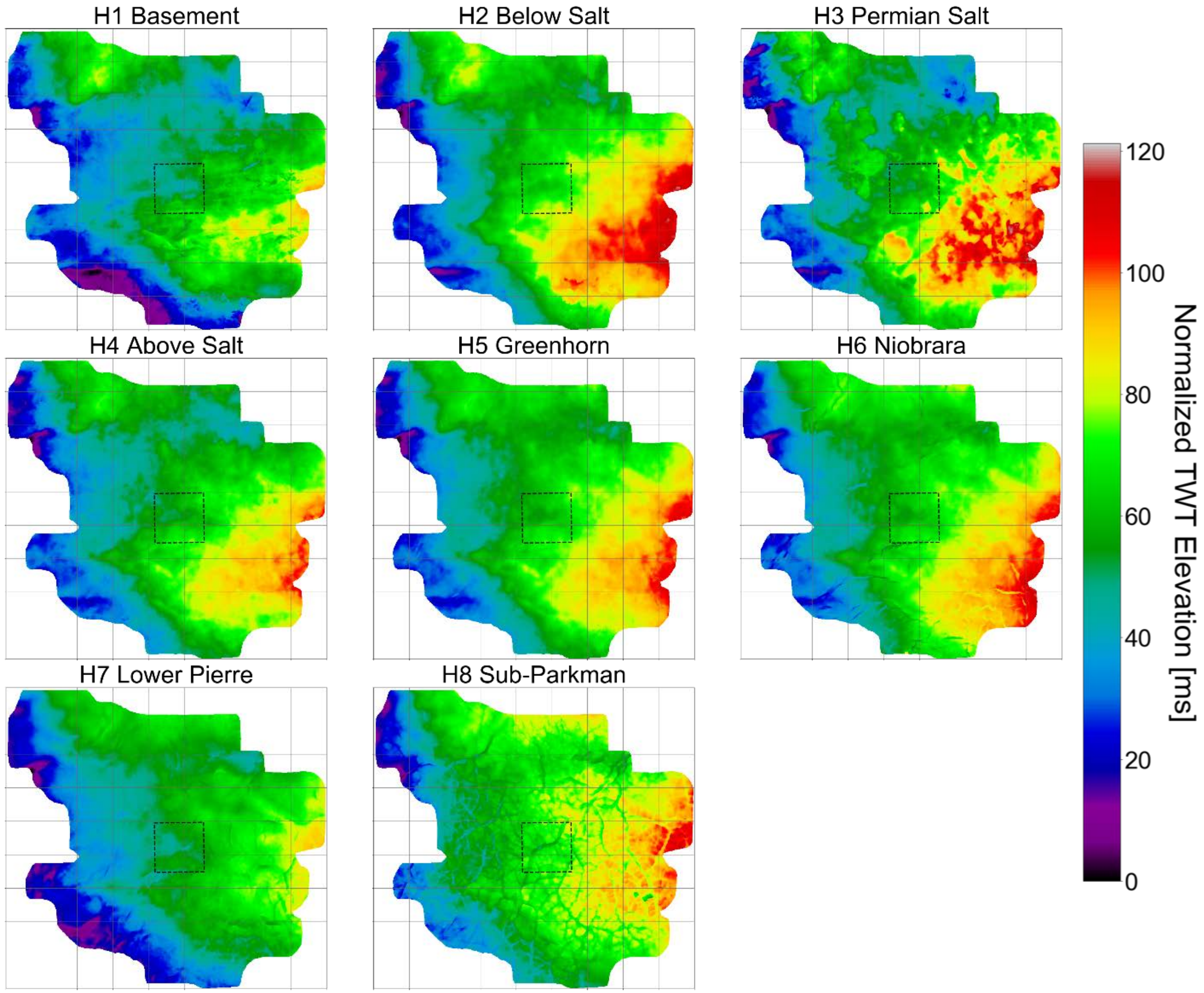


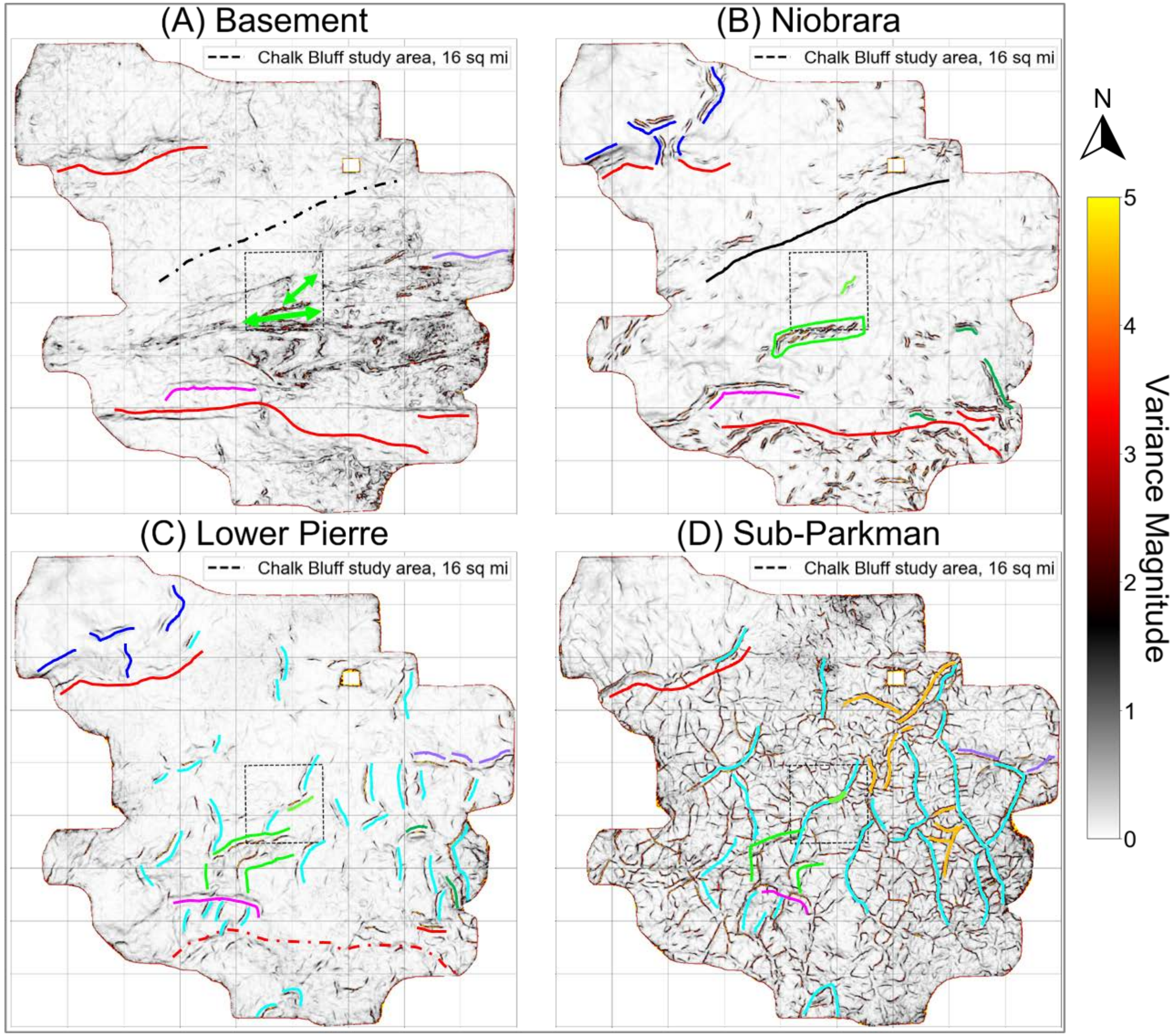


Niobrara B Chalk – Net to Gross Isopach
C.I. = 10% Net to Gross

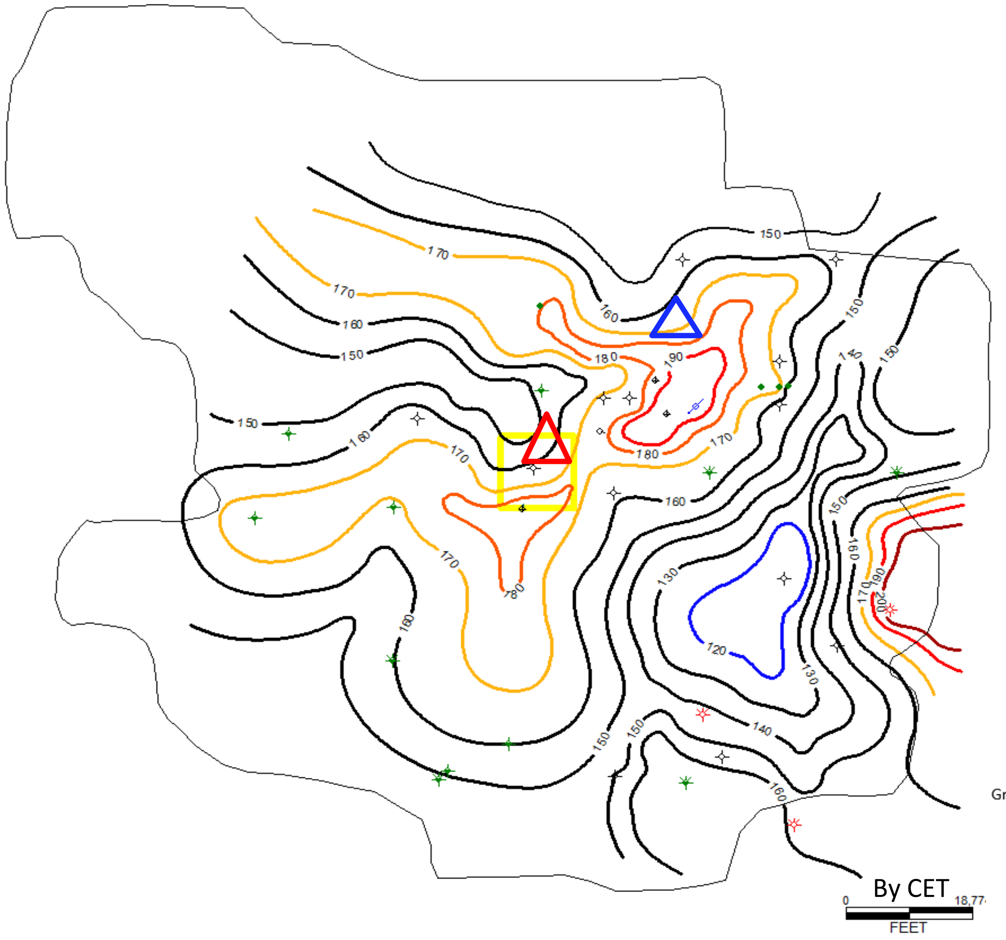
Net = (>/=) 20 ohm/m deep resistivity

Present-Day Expression of Structure

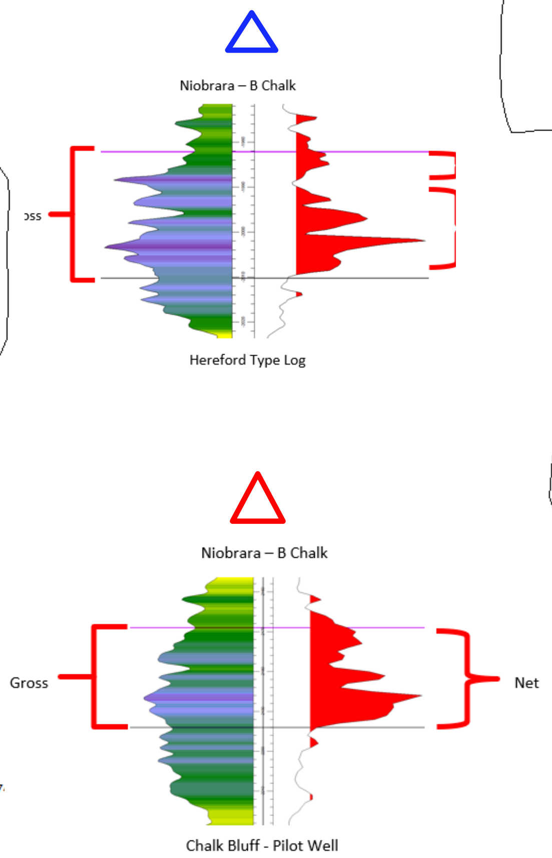


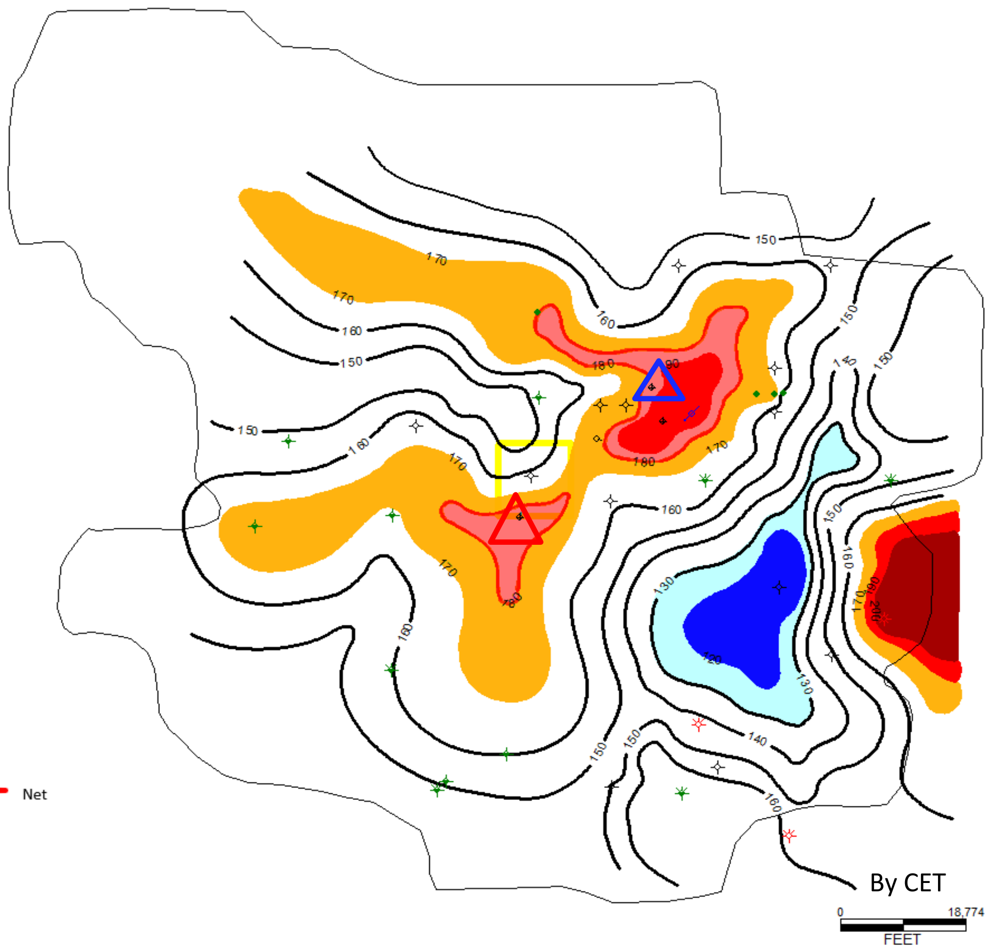


B Chalk Formation Temp



Niobrara B Chalk – Formation Temp
C.I. = 10 Deg (f)





Niobrara B Chalk – Formation Temp w/ Shading
C.I. = 10 Deg (f)
Shade Interval 170 deg (F) to 200 deg (F)

Compaction

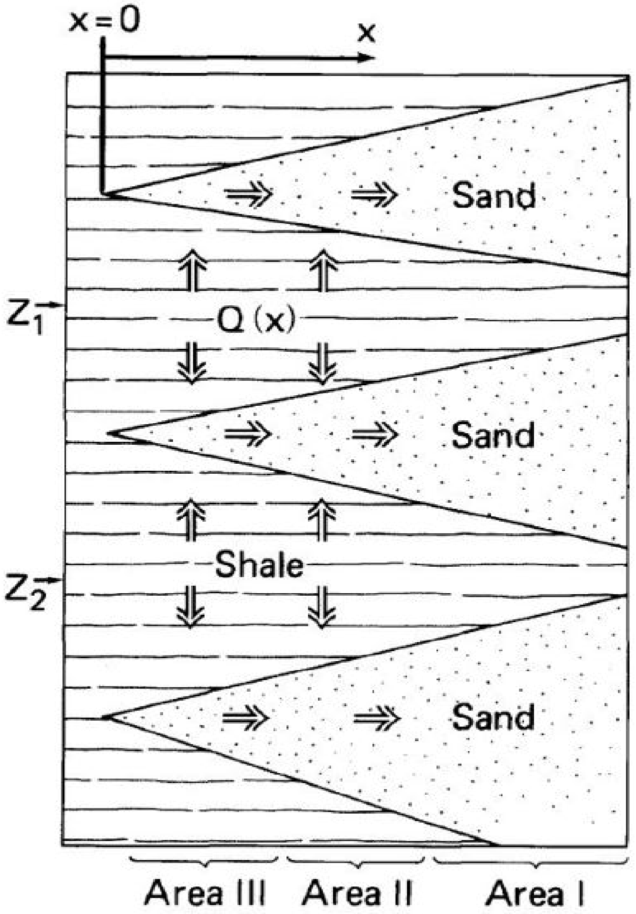
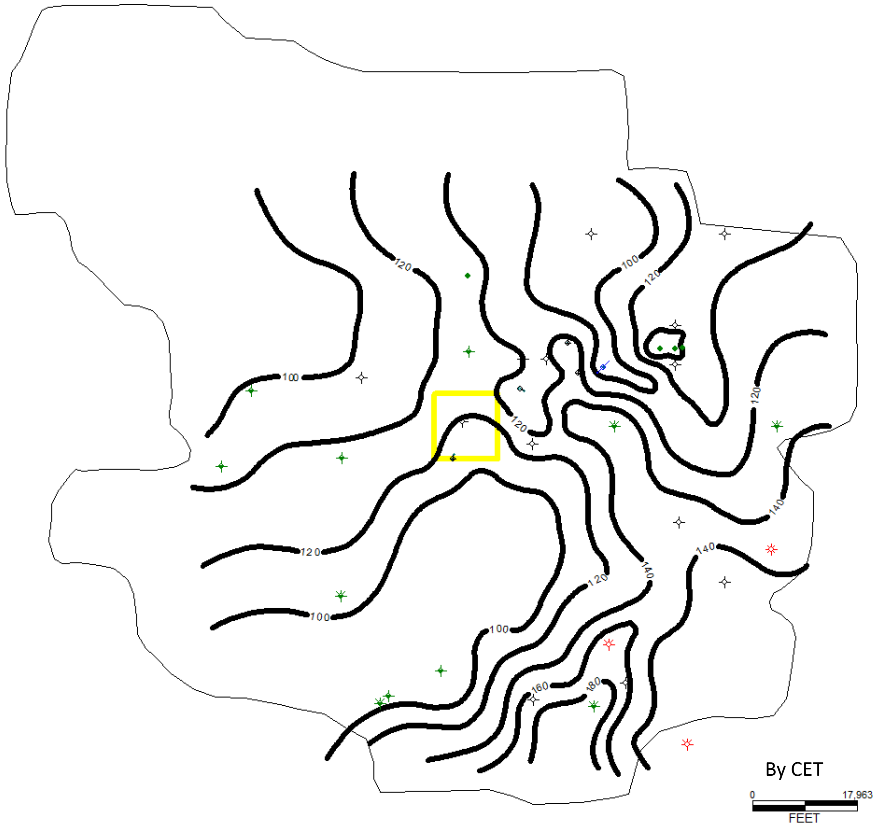


Figure 10—Cross section of idealized sand-shale sequence analyzed in this study.

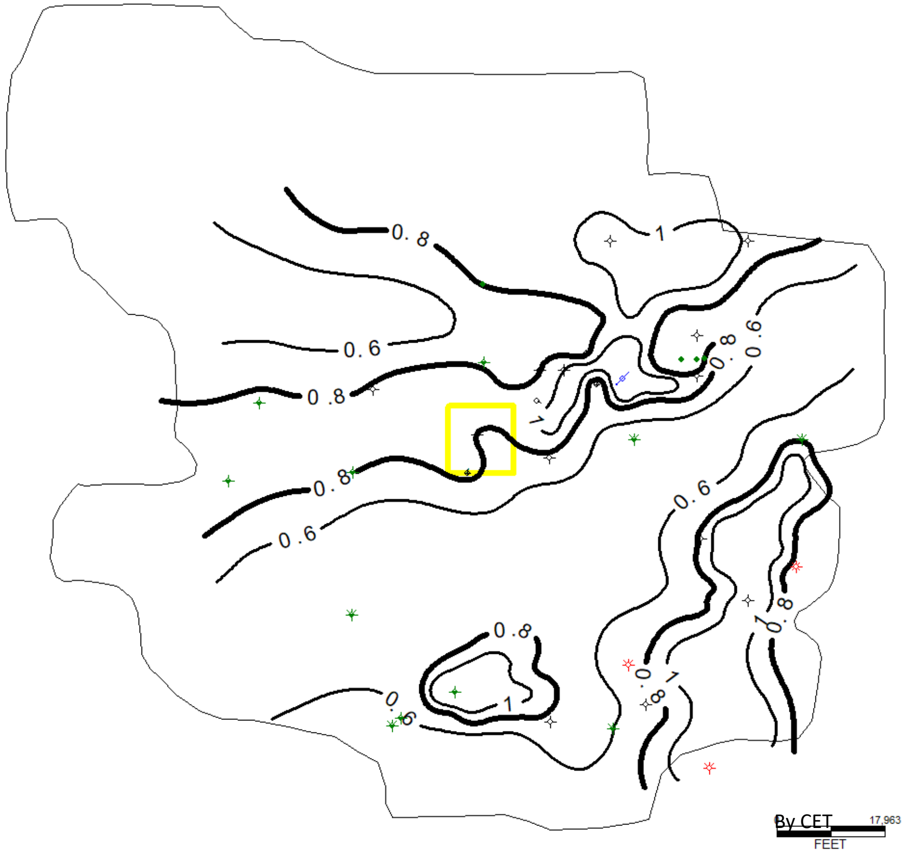
From Bredehoeft Et al 1988

Shale (ductile) compact differentially in relation to the Sand (brittle)



Niobrara Total Chalk – Isopach
C.I. = 20'

Total Chalk = Nio Chalk (A+B1+B+C)



Niobrara Total Marl to Total Chalk – Isopach
C.I. = 10% Marl to Chalk

Marl to Chalk = (Nio Marl A+B1+B+C) / (Nio Chalk A+B1+B+C)

Marl (ductile) compacts differentially in relation to the Chalk(brittle)

Compaction – Fluid Compartmentalization

Petroleum System Charge Analog - (Niobrara Chalk Reservoir Fracture)

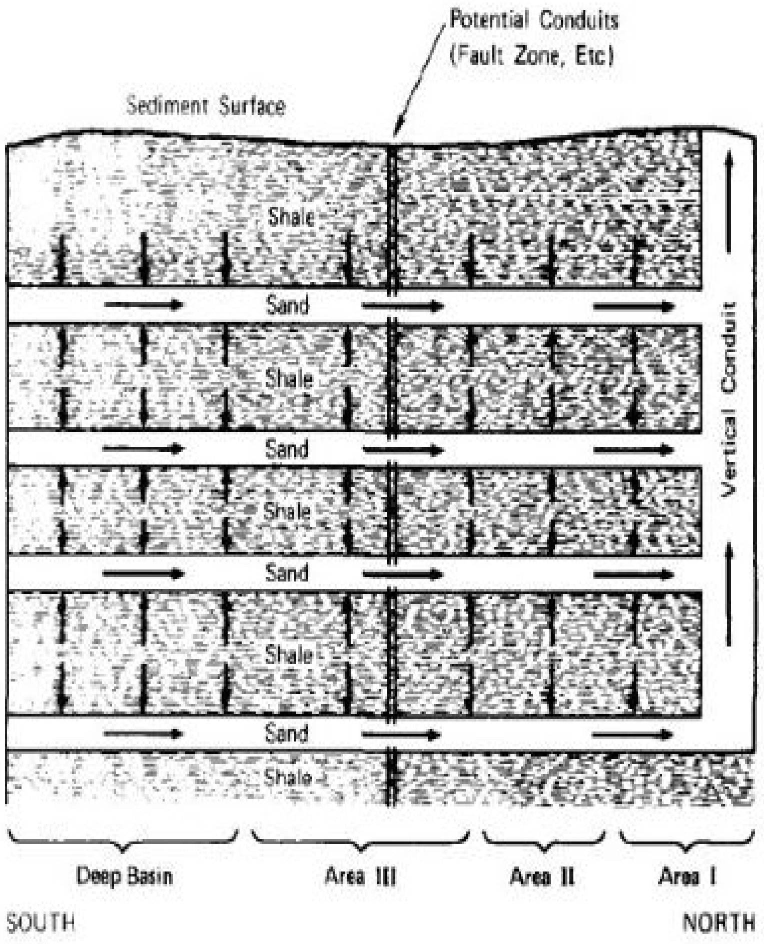
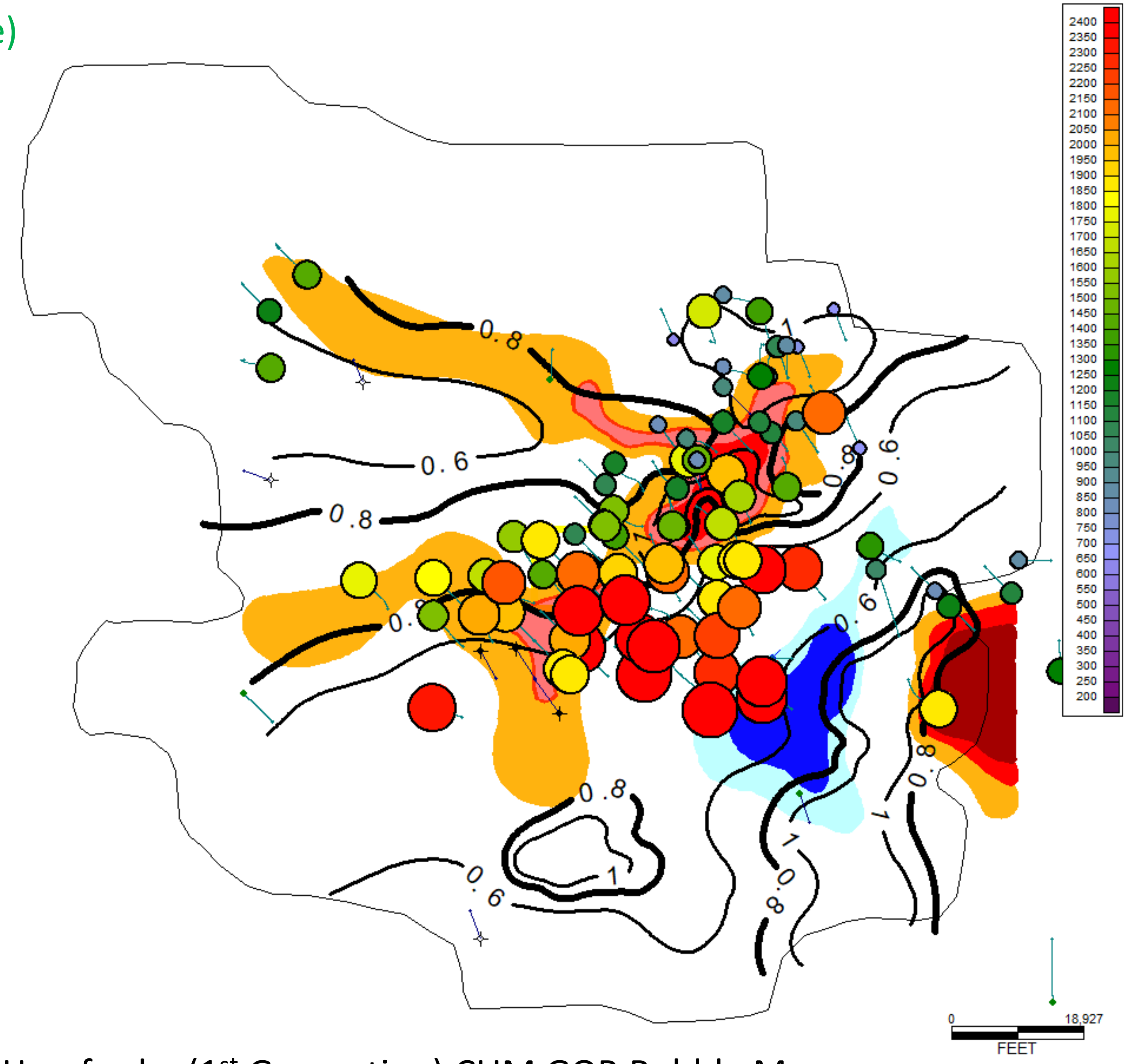


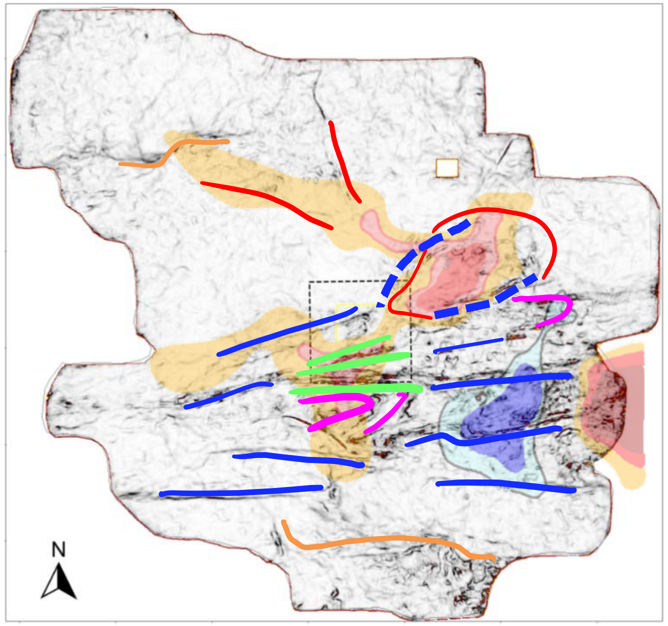
Figure 12—Diagrammatic cross section of a compartmentalized flow system.

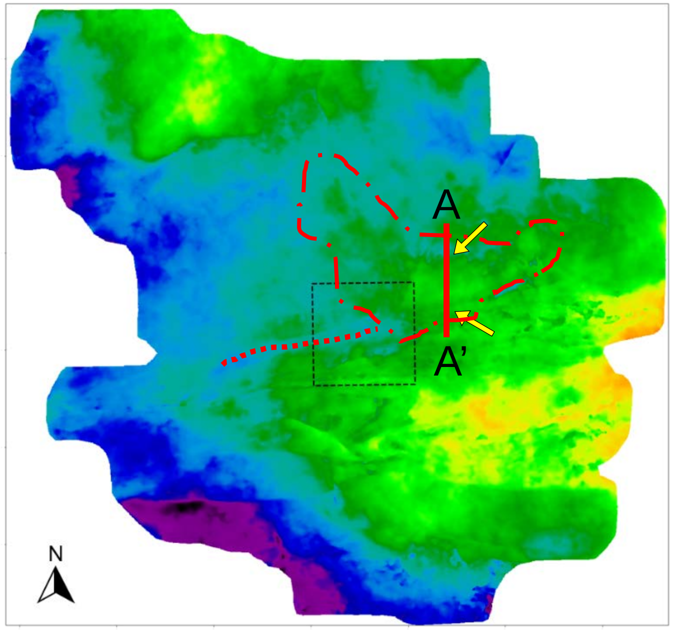
From Bredehoeft Et al 1988

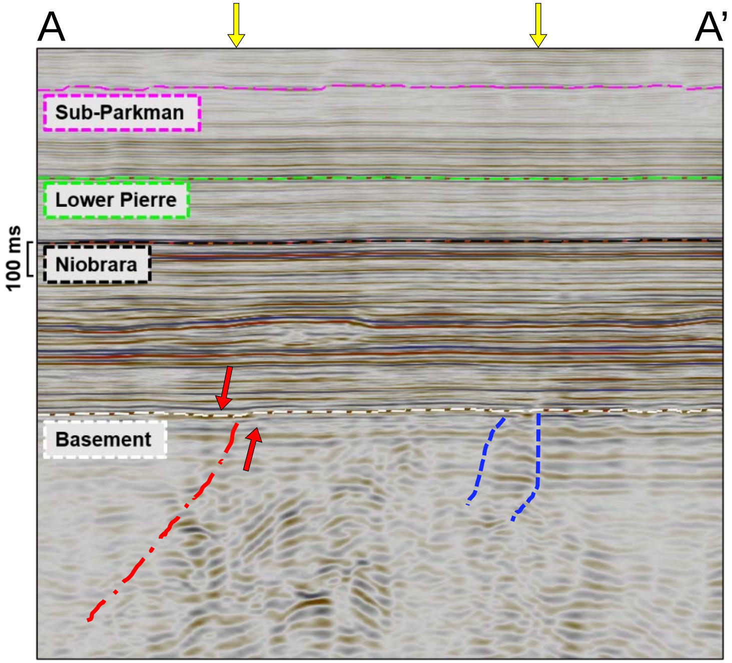


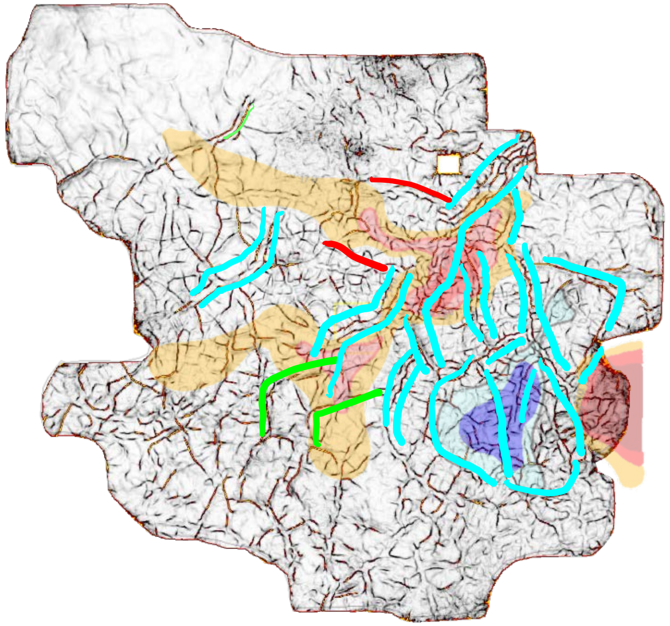
Hereford – (1st Generation) CUM GOR Bubble Map
W/ B Chalk Formation Temp Shade & Marl to Chalk Ratio Isopach

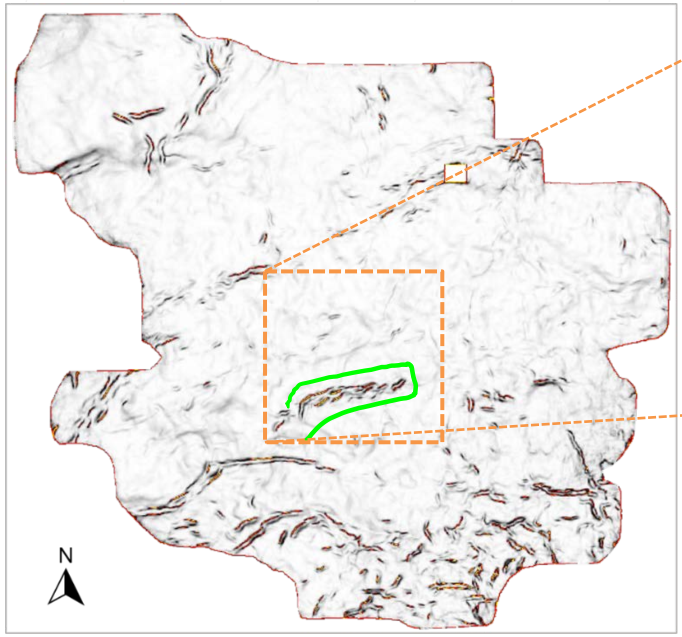
Basement Control on Temperature and Expulsion

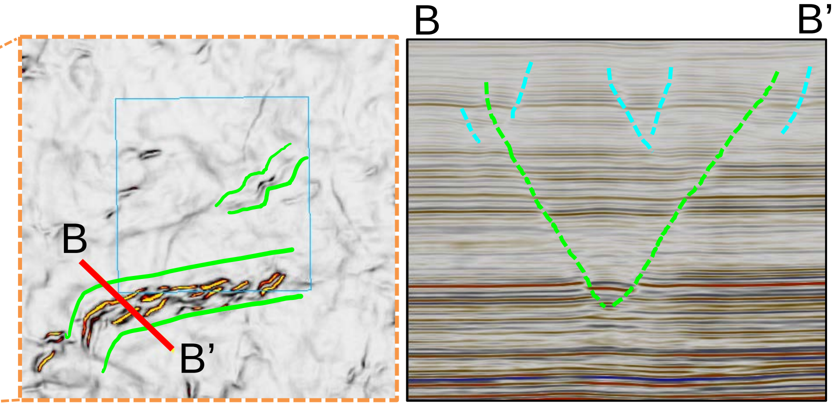




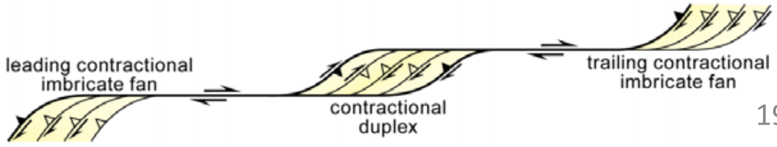






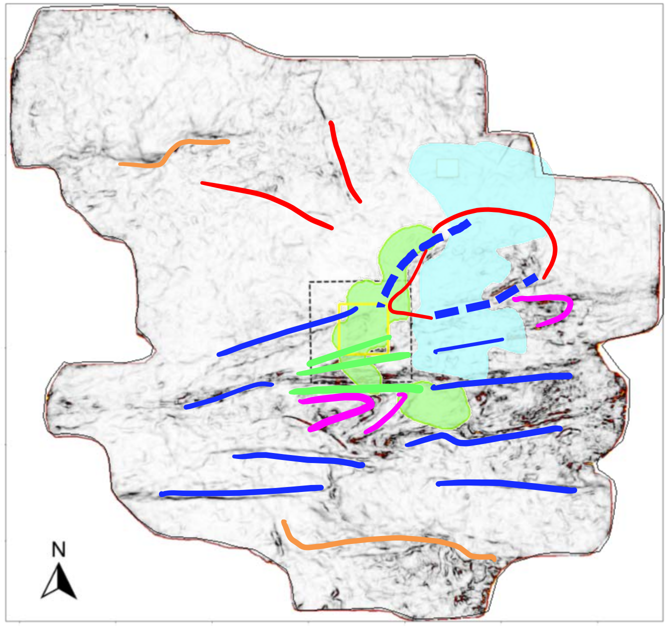


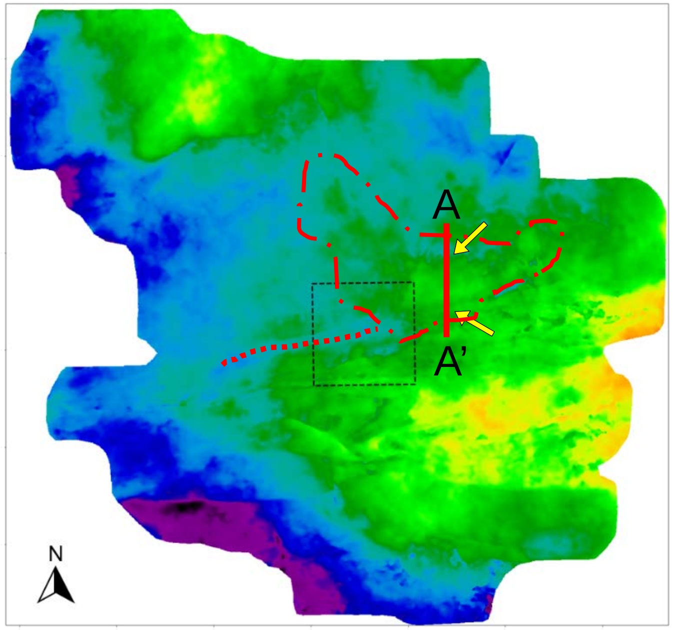
Map view of an idealized dextral strike-slip system

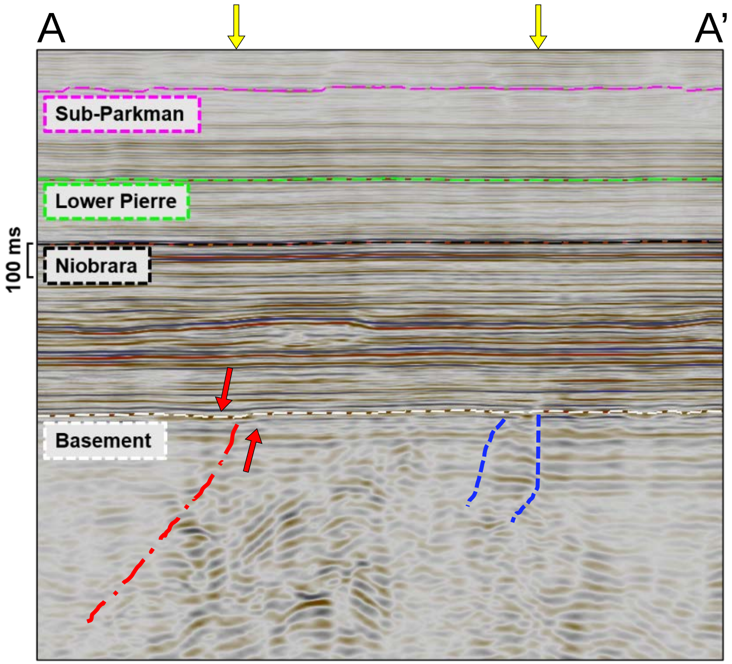


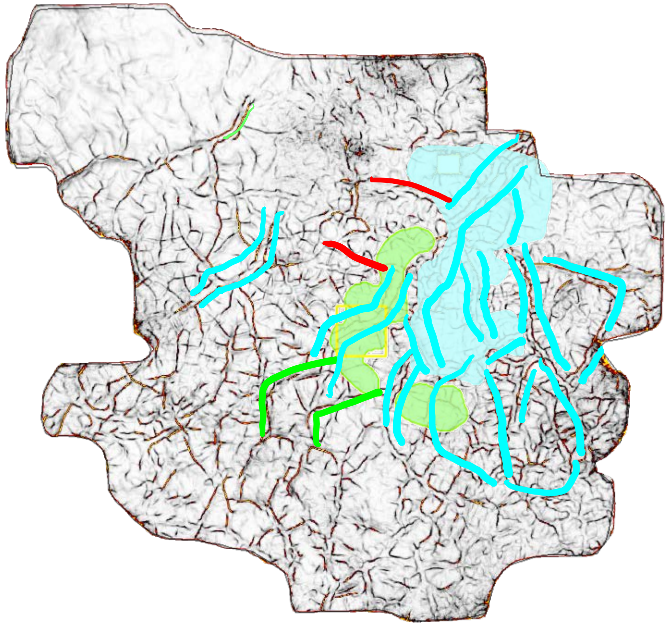
after Woodcock & Fischer (1986) *J. Struct. Geol.* **8(7)** 725-735

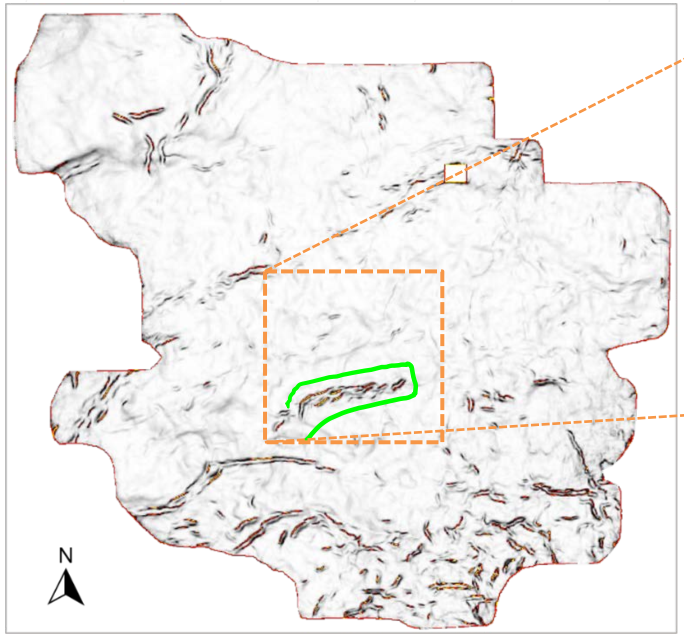
Basement Control on Temperature and Expulsion

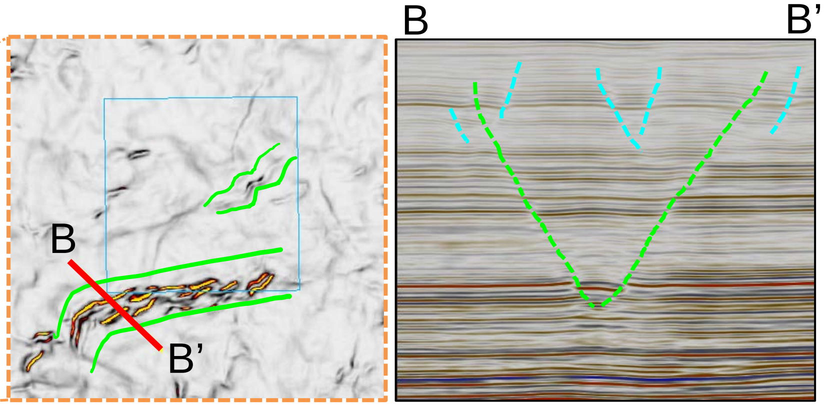




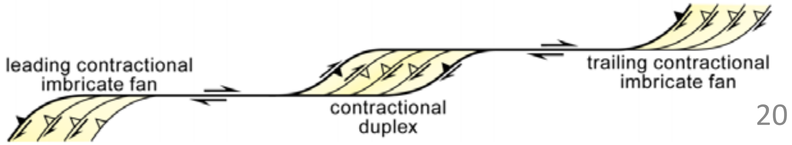






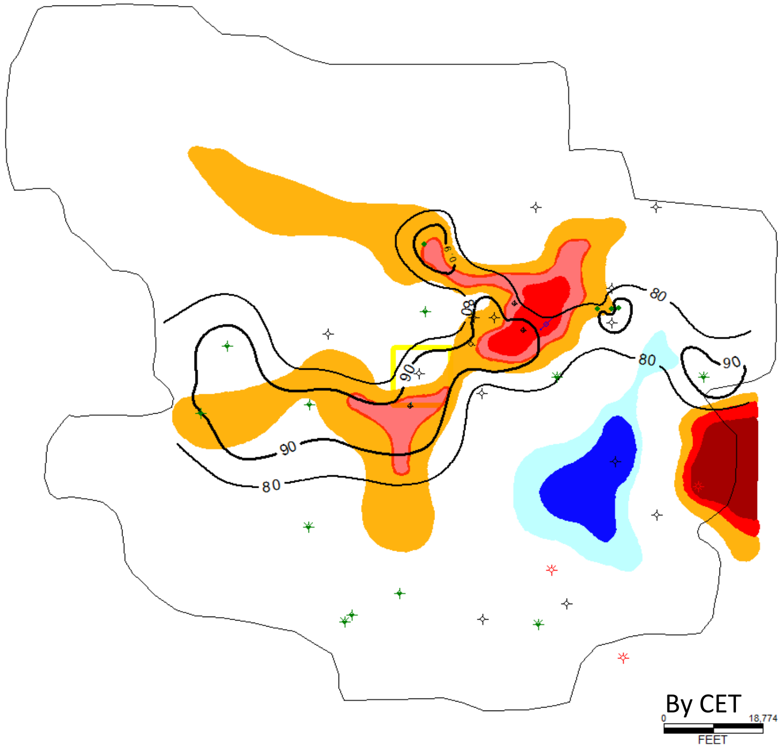


Map view of an idealized dextral strike-slip system



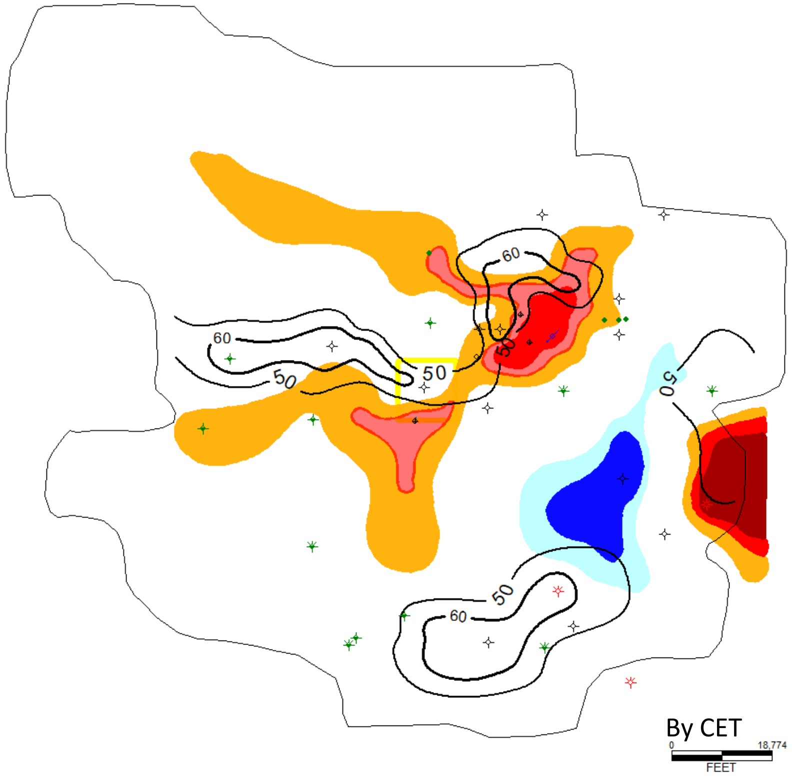
after Woodcock & Fischer (1986) *J. Struct. Geol.* **8(7)** 725-735

Compaction – Impacts on Reservoir Quality



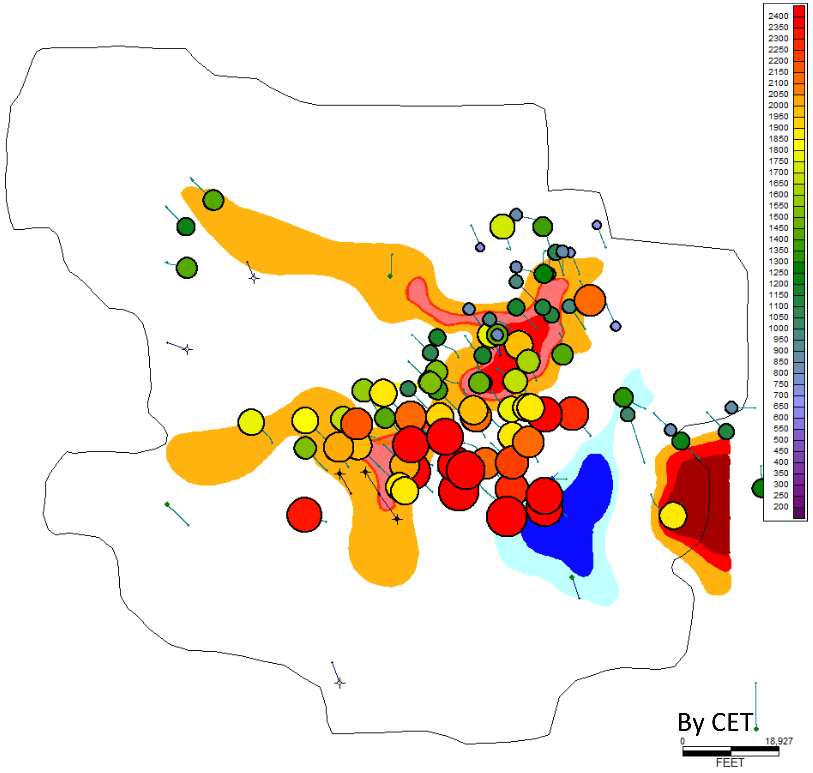
Niobrara B Chalk – Net to Gross Isopach
C.I. = 10% Net to Gross

W/ B Chalk Formation Temperature Shade



Codell– Net to Gross Isopach
C.I. = 10% Net to Gross

W/ B Chalk Formation Temperature Shade

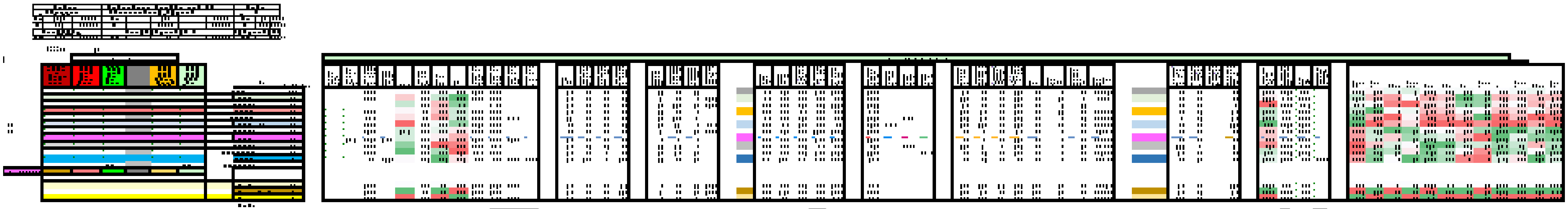


Hereford – (1st Generation) CUM GOR Bubble Map - With B Chalk Formation Temp Shade
2400 to 200 (scf / BO deg)

Vertical log assessment

HIGH-RESOLUTION PETROPHYSICAL ANALYSIS AND RESERVOIR CHARACTERIZATION

Geological Data Integration - Petrophysical Model



	Formation	Mem Thickness
NIO Gen	7321	274
A Ch	7324	13
A MARL	7337	16
B1 CH	7353	33
B1 MARL	7386	14
B CH	7400	28
B MARL	7428	19
C CH	7447	48
C MARL	7495	43
C MARL BASE	7538	27
Ft HYS	7565	30
Ft HYS BASE	7595	
Codell	7596	17
Upper Codell		8
Lower Codell	7604	9
Codell BASE	7613	

Log Curves and Clay Calcs

Cal Formation Psi = (psi/ft)*depth	Cal Formation temp (deg(f) y = mx+c	GAPI (ECGR): Environmentally Corrected Gamma-Ray	LOG HIRES Gamma -NMR (API)	SP (mV)	LOG Density from Combo - (G/C3)	Density from Core - (G/C3)	PE (Barns)	Clay Volume Steiber: (V Clay) % Calculated Vcl = IGR/[3.0 - (2.0*IGR]	Clay Volume Clavier: (V Clay) % Calculated Vcl = 1.7*[3.38*(IGR+0.7)^2]^0.5	(NMR) Clay Volume Steiber: (V Clay) % Calculated Vcl = IGR/[3.0 - (2.0*IGR]	Volume Clavier: (V Clay)Dece Calculated Vcl = 1.7*[3.38*(IGR+0.7)^2]^0.5
3,206.94	189.86	48.84	135.18	-122.32	2.53	2.66	4.58	4.19%	5.24%	14.75%	18.16%
3,152.12	187.50	84.88	183.15	-128.18	2.52	2.68	5.24	7.68%	9.58%	21.65%	26.77%
3,158.35	187.77	158.34	261.95	-119.42	2.53	2.64	5.07	16.17%	20.03%	42.47%	48.71%
3,168.89	188.22	63.23	155.33	-123.05	2.50	2.64	4.77	5.23%	6.57%	16.89%	21.06%
3,178.99	188.65	75.07	175.27	-125.60	2.50	2.63	4.76	6.32%	7.95%	20.20%	25.07%
3,188.02	189.04	32.99	113.10	-140.68	2.48	2.66	5.02	2.61%	3.26%	10.68%	13.41%
3,198.13	189.48	51.76	140.15	-120.10	2.56	2.67	4.53	4.25%	5.34%	14.82%	18.47%
3,212.53	190.10	27.19	102.60	-120.13	2.56	2.66	4.38	2.13%	2.66%	9.17%	11.55%
3,232.10	190.88	45.26	142.67	-116.59	2.51	2.61	4.24	3.67%	4.60%	15.17%	18.91%
3,247.15		32.58	131.48	-114.14	2.54	2.69	4.16	2.60%	3.24%	13.34%	16.71%
3,259.40	191.58	9.50	61.18	-122.69	2.61	2.71	4.51	0.74%	0.92%	4.33%	5.43%
3,269.94	192.56	19.74	106.46	-124.01	2.48	2.70	2.52	1.53%	1.91%	9.62%	12.12%
3,268.00	192.48	17.28	112.80	-123.27	2.50	2.70	2.48	1.34%	1.67%	10.43%	13.14%
3,271.66	192.64	21.53	101.36	-124.63	2.47	2.70	2.54	1.67%	2.08%	8.97%	11.30%

NMR

NMR Total Porosity TCMR .CFCF	NMR CFCF (BFV): Bound Fluid Volume	NMR CFCF (CMFF): CMR Free Fluid	NMR T2 Logarithmic Mean T2LM (ms)
0.011	0.0098	0.0011	107.43
0.010	0.0093	0.0009	31.51
0.013	0.0119	0.0014	61.42
0.011	0.0099	0.0006	171.91
0.015	0.0135	0.0020	180.28
0.012	0.0110	0.0008	45.08
0.010	0.0078	0.0019	58.46
0.009	0.0080	0.0009	133.16
0.011	0.0101	0.0009	122.66
0.012	0.0106	0.0013	121.11
0.011	0.0094	0.0015	107.34
0.008	0.0072	0.0011	14.17
0.010	0.0084	0.0012	12.36
0.007	0.0062	0.0010	15.50

Sample Organics

Diff - Sample Fm Ave vs Smoker Ave	TOC (Schmoker) TOC Wt% = 0.01*(154.497/Dens)-58.271	Sample TOC (wt%)	Sample (S1) Fee Oil Yield BO/Ac-Ft
1.235	3.715	2.480	94.053
1.117	4.064	2.947	106.877
-0.048	3.853	3.901	138.960
1.836	4.490	2.654	129.614
1.748	4.420	2.673	117.529
2.730	4.919	2.188	139.510
0.823	3.065	2.242	44.332
0.788	3.075	2.287	58.190
0.318	4.345	4.028	153.523
1.780	3.541	1.761	74.330
1.487	1.873	0.387	7.584
-4.212	4.990	0.778	42.231
-3.687	4.555	0.868	29.693
-4.676	5.364	0.688	54.770

Petrophysical Model – Reservoir Deliverability

	NMR		
NMR Total Porosity TCMR.CFCF	NMR CFCF (BFV): Bound Fluid Volume	NMR CFCF (CMFF): CMR Free Fluid	NMR T2 Logarithmic Mean T2LM (ms)
0.011	0.0098	0.0011	107.43
0.010	0.0093	0.0009	31.51
0.013	0.0119	0.0014	61.42
0.011	0.0099	0.0006	171.91
0.015	0.0135	0.0020	180.28
0.012	0.0110	0.0008	45.08
0.010	0.0078	0.0019	58.46
0.009	0.0080	0.0009	133.16
0.011	0.0101	0.0009	122.66
0.012	0.0106	0.0013	121.11
0.011	0.0094	0.0015	107.34
0.008	0.0072	0.0011	14.17
0.010	0.0084	0.0012	12.36
0.007	0.0062	0.0010	15.50

NMR – Mobile and Clay Bound Fluid Volumes

Calculated Organic Properties			
Matrix (Ambrose corrected ϕeff INDO CAL with Clay) = (ϕeff - ϕOrgano Matrix OM)	ASQ Organinc ϕom = Vke* OM (K from Smoker)	ASQ Organinc ϕom = Vke* OM (K Sample TOC Stage level))	Volume of Kerogen vke = (SMOKER TOC*KVR 8 pb)/ pKerogen)/100
0.092	0.026		0.086
0.089	0.028		0.094
0.099	0.027		0.090
0.092	0.031		0.104
0.090	0.031		0.102
0.085	0.034		0.113
0.084	0.022		0.072
0.092	0.022		0.073
0.111	0.030		0.100
0.108	0.025		0.082
0.062	0.013		0.045
0.107	0.034		0.114
0.102	0.031		0.105
0.112	0.037		0.122

Organic Matrix

	Porosity and Perm						
Log Density Porosity (Not Corrected) =	TOTAL POROSITY (Log Uncor) = ((2.71-pb)/(2.71-pFluid))	ϕEff Log Corr - SIM INDO (CAL) = ϕCDP(1-Clavier SH Cal)	ASQ Sand Shale - ϕe = ((ϕDclay^2 + ϕNclay^2)/2)^1/2	Core Ave. (ϕ)	Core Ave. (HZ K mD)	Core Ave. R35 (Micron) (Winland CALC)	Core Ave. Cap Psi CAL)
0.104	0.085	0.069	0.118	0.078	0.006	0.032	5,648.13
0.113	0.094	0.069	0.117	0.098	0.019	0.060	3,759.00
0.108	0.089	0.047	0.126	0.078	0.001	0.011	12,192.21
0.122	0.104	0.082	0.123	0.086	0.011	0.037	5,882.29
0.121	0.102	0.077	0.121	0.076	0.002	0.021	6,745.44
0.132	0.113	0.098	0.119	0.098	0.026	0.074	2,547.46
0.088	0.070	0.058	0.106	0.067	0.002	0.024	5,187.07
0.089	0.070	0.062	0.114	0.069	0.003	0.028	4,878.56
0.119	0.100	0.080	0.141	0.074	0.002	0.019	8,207.95
0.099	0.081	0.066	0.133	0.079	0.002	0.023	5,313.25
0.058	0.041	0.038	0.075	0.074	0.004	0.033	3,830.83
0.134	0.115	0.101	0.141	0.124	0.015	0.043	3,461.08
0.124	0.105	0.092	0.134	0.125	0.013	0.045	2,869.34
0.143	0.124	0.110	0.148	0.124	0.017	0.040	4,171.17

	Calculated SW & Swe			
Ratio SW = (Ro/Rt)^.5	SIMNDUX - INDO Form	ASQ Swe (Shaly Sand) 1/ϕ Corr Den(Square Root (Rw/Rt + (0.35Vclay/2)^2 - 0.35Vclay/2)	ASQ Shale Method - Correced ϕ - Log Swe (Ro/Rsh)^0.5	SW (Mineral Matrix MM) = (Ro/RT)^0.5
0.806	0.812	0.645	1.027	1.324
0.602	0.627	0.364	0.824	0.957
0.697	0.647	0.312	0.881	1.114
0.368	0.399	0.203	0.752	0.583
0.409	0.436	0.213	0.764	0.649
0.278	0.309	0.178	0.694	0.440
0.887	0.819	0.629	1.133	1.441
0.896	0.929	0.766	1.085	1.445
0.579	0.624	0.431	0.803	0.923
0.993	0.998	0.831	1.057	1.613
2.070	1.990	2.040	2.067	3.599
0.799	0.886	0.731	0.694	1.265
0.926	1.017	0.845	0.747	1.468
0.687	0.770	0.628	0.648	1.085

Ave and Max / Min - Member Stats

	Core Saturations		
Gas Filled Porosity % of BV (Core or Crush)	WTR Sat % PV (Core or Crush)	Gas Sat % PV (Core or Crush)	Oil Sat % PV (Core or Crush)
1.595	36.757	19.527	43.717
2.928	24.349	29.608	46.043
1.311	30.384	16.471	53.144
2.085	22.149	23.122	54.729
1.614	22.660	20.370	56.970
3.127	20.203	31.505	48.292
1.277	44.751	18.786	36.464
1.174	40.937	16.839	42.224
0.612	29.118	8.229	62.653
1.145	51.065	14.931	34.004
1.704	63.857	23.839	12.304
3.505	57.863	27.682	14.455
3.253	60.115	25.648	14.237
3.807	55.160	30.122	14.718

Core & Sample Saturations

	BVW and IND Ratios		
RT 60/85 Ratio	ARCH Bulk Volume Water - Log (BVW) = (Sw x Phi)	ASQ Shale Meathod - Log Porosity Bulk Volume Water - Log (BVW) = (Sw x Phi)	ASQ Shale Sand Meathod - Effective Porosity an SWE - Log (BVW) = (Sw x Phi)
1.05	0.068	0.057	0.065
1.07	0.053	0.057	0.041
1.08	0.067	0.046	0.037
1.05	0.034	0.066	0.025
1.10	0.037	0.066	0.026
0.95	0.024	0.074	0.021
0.99	0.075	0.055	0.066
1.06	0.082	0.056	0.086
1.08	0.061	0.061	0.056
1.07	0.098	0.050	0.096
1.09	0.125	0.040	0.146
1.06	0.084	0.065	0.101
1.05	0.094	0.063	0.112
1.06	0.075	0.067	0.091

BVW Scenarios (Grain Size & Wettability)

Calibrated Organic and Effective Porosity → Effective Reservoir Saturation

Reservoir Quality Summary

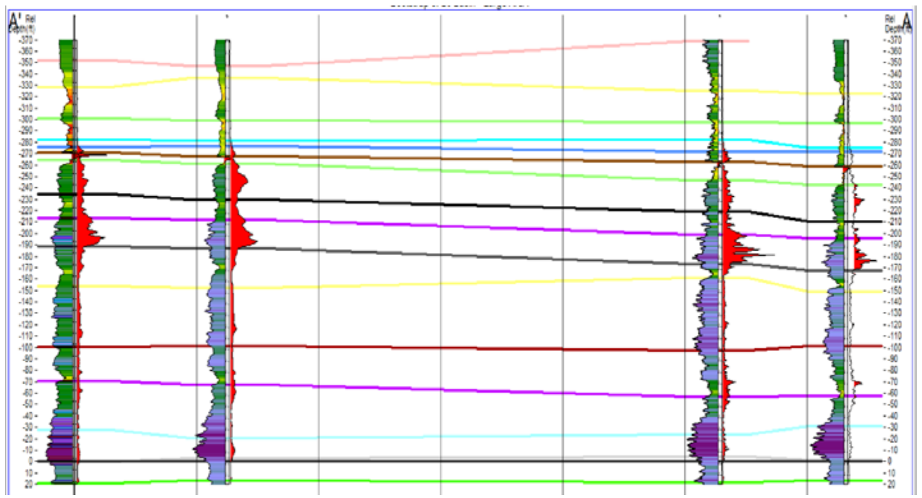
	Niobrara Monophasic Sample 1.01 2010		Niobrara Recombined Sample 2018			Codell Recombined Sample 2018		
	At Saturation Point (2051 psi and 230F)		At Saturation Point (2093 psi and 190F)			At Saturation Point (1918 psi and 195F)		
Bo	1.416	RB/STB	Bo	1.36	RB/STB	Bo	1.337	RB/STB
Rs	591	SCF/STB	Rs	583.84	SCF/STB	Rs	522.34	SCF/STB
	Gas at 1615 psi and 230F		Gas at 1715 psi and 190F			Gas at 1615 psi and 195F		
Bg	0.010343	RCF/SCF	Bg	0.0093	RCF/SCF	Bg	0.0101	RCF/SCF

Shrink Factor (OIL) 1.3

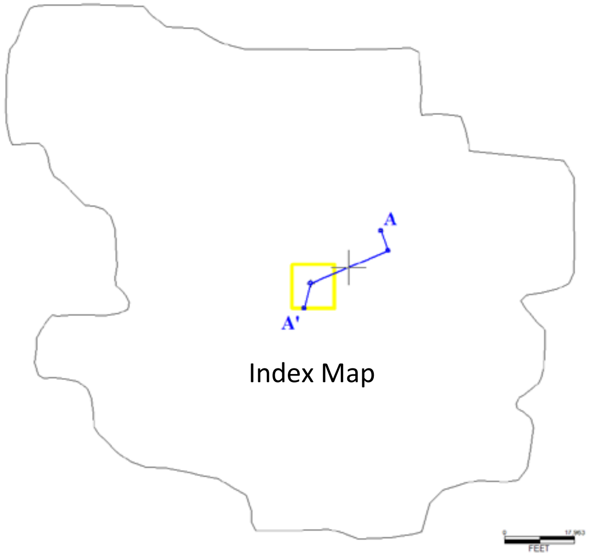
Reservoir Volumes

		Adsobred Gas in Place Vol (Gs scf/area) = 1359.7*Area*h*BlulK Den (p)	SIMX EFF and Sat - Free Gas in Place Volume - (Gf) = 43560*Area*(h)*ϕeffective*(Sg - Sat Gas - (1-Swe))* (1/Bg)	SIMX EFF and Sat - Oil in Place Volume - (OOIPstb) =7758*(h)*(ϕeffective* (1-Swe))*	SIMX EFF and ASQ Shale Sand SWE Sat - Free Gas in Place Volume - (Gf) = 43560*Area*(h)*ϕeffective*(Sg = Sat Gas = (1-	SIMX EFF and ASQ SWEt - Oil in Place Volume - (OOIPstb) =7758*(h)*(ϕeffective* (1-Swe))* (1/BOI)	Formation		Mem Thickness
		26,874,984,658.63	18,723,226,220.71	23,855,151.83	28,819,063,979.30	36,718,199.03	NIO Gen	7321	274
		1,462,024,108.69	1,047,085,173.20	1,334,085.03	1,775,514,885.42	2,262,173.02	A Ch	7324	13
		2,444,293,988.24	893,501,832.39	1,138,405.40	1,620,241,089.10	2,064,339.59	A MARL	7337	16
		3,454,294,455.07	4,961,696,354.76	6,321,667.99	6,558,411,637.05	8,356,033.49	B1 CH	7353	33
		1,498,008,720.93	1,898,894,218.08	2,419,369.90	2,632,018,836.29	3,353,439.64	B1 MARL	7386	14
A/2 DSU	320	2,445,664,226.70	5,804,115,049.49	7,394,988.67	6,897,496,814.57	8,788,059.91	B CH	7400	28
A DSU	640	1,763,049,393.64	852,068,621.60	1,085,615.59	1,497,013,861.43	1,907,336.51	B MARL	7428	19
		4,492,909,107.65	866,989,731.24	1,104,626.49	2,348,650,631.86	2,992,401.88	C CH	7447	48
		6,651,418,871.22	4,241,426,769.96	5,403,976.77	6,270,779,180.30	7,989,562.68	C MARL	7495	43
		1,996,900,784.41	873,786,513.65	1,113,286.23	1,856,261,099.42	2,365,051.29	C MARL BASE	7538	27
		891,995,575.84	-2,594,548,890.44	-3,305,699.40	-2,515,333,666.17	-3,204,771.75	Ft HYS	7565	30
		scf	scf	BO	scf	BO	Ft HYS BASE	7595	
Total HC - FT HYS		25,982,989,082.79	21,317,775,111.15	27,160,851.23	31,334,397,645.47	39,922,970.78			
		614,428,514.05	681,645,539.31	943,188.56	1,431,795,362.92	1,981,166.05	Codell	7596	17
		326,971,407.65	-4,356,924.99	-6,028.65	363,231,710.27	502,601.39	Upper Codell		8
		303,598,099.39	696,950,063.55	964,365.33	1,102,505,346.96	1,525,529.57	Lower Codell	7604	9
							Codell BASE	7613	

AVE Statistics (In Place) - 640 Ac



Example Model Wells



Index Map

B Chalk:
Low case : 6.2 MMBO
High case: 7.35 MMBO
Low case : 5.1 BCF
High case: 5.8 BCF

Codell
Low case : 454 MBO
High case: 1.3MMBO
Low case : 696 MMCF
High case: 1.1 BCF

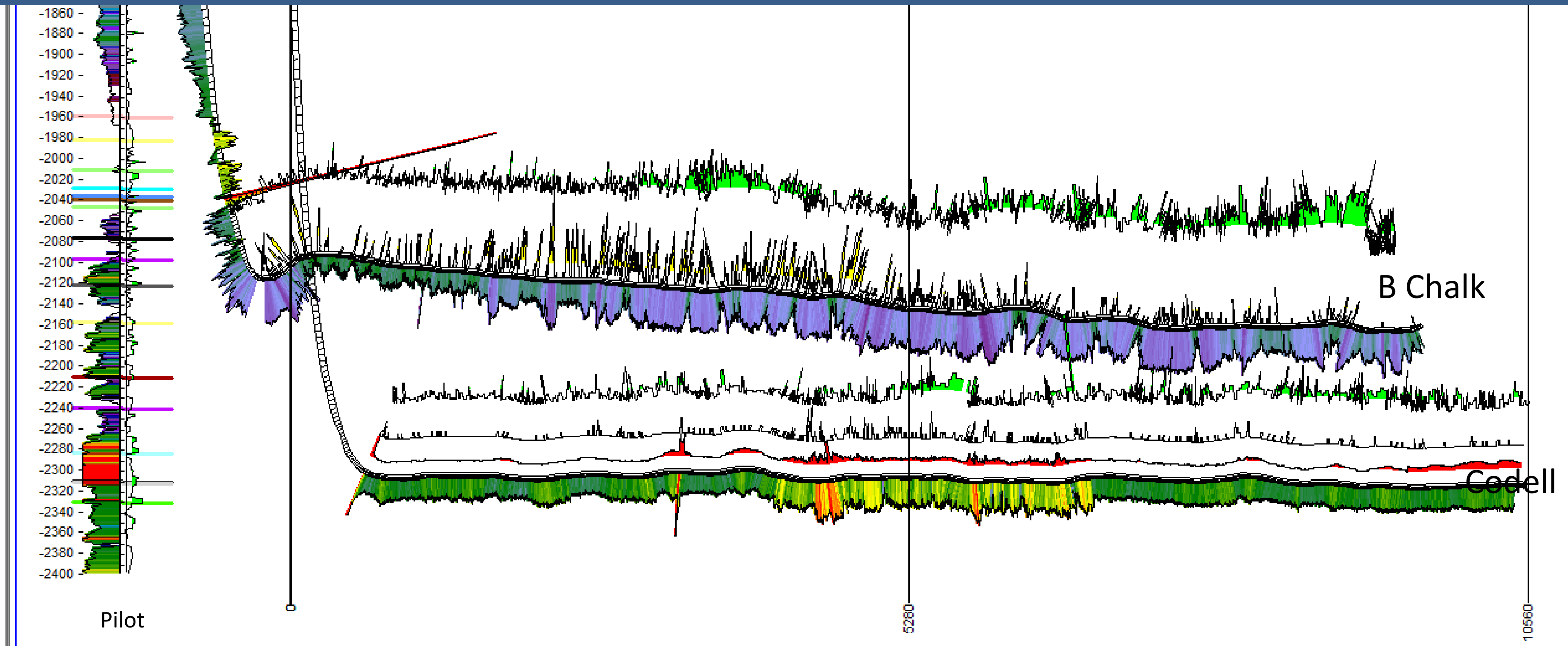
B1 Chalk:
Low case : 5.3 MMBO
High case: 6.9 MMBO
Low case : 4.9 BCF
High case: 6.5 BCF

C Marl:
Low case : 3.5 MMBO
High case: 5.4 MMBO
Low case : 4.2 BCF
High case: 6 BCF

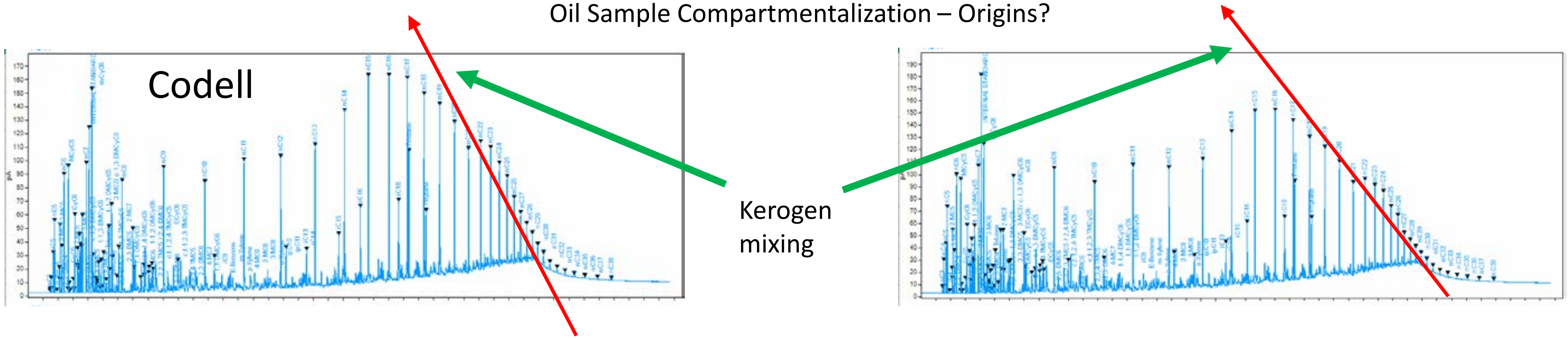
Connecting regional observations to pore-scale observations

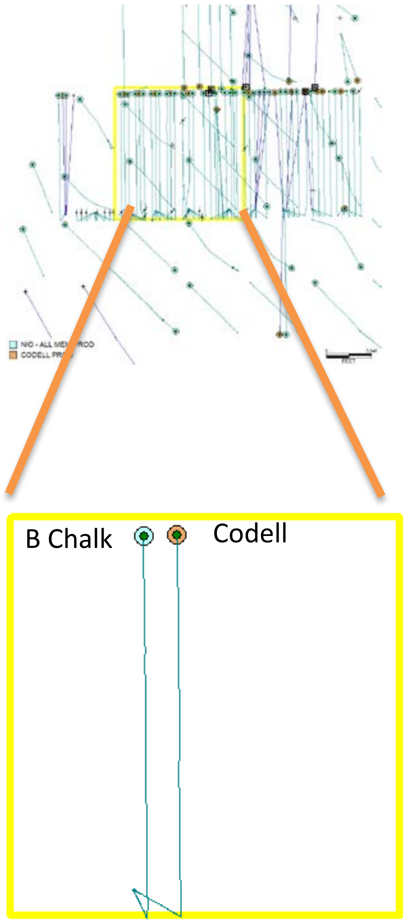
DETAILED ANALYSIS OF FIBER-OPTIC WELLS: CHALK BLUFF STUDY AREA

Fiber Wells



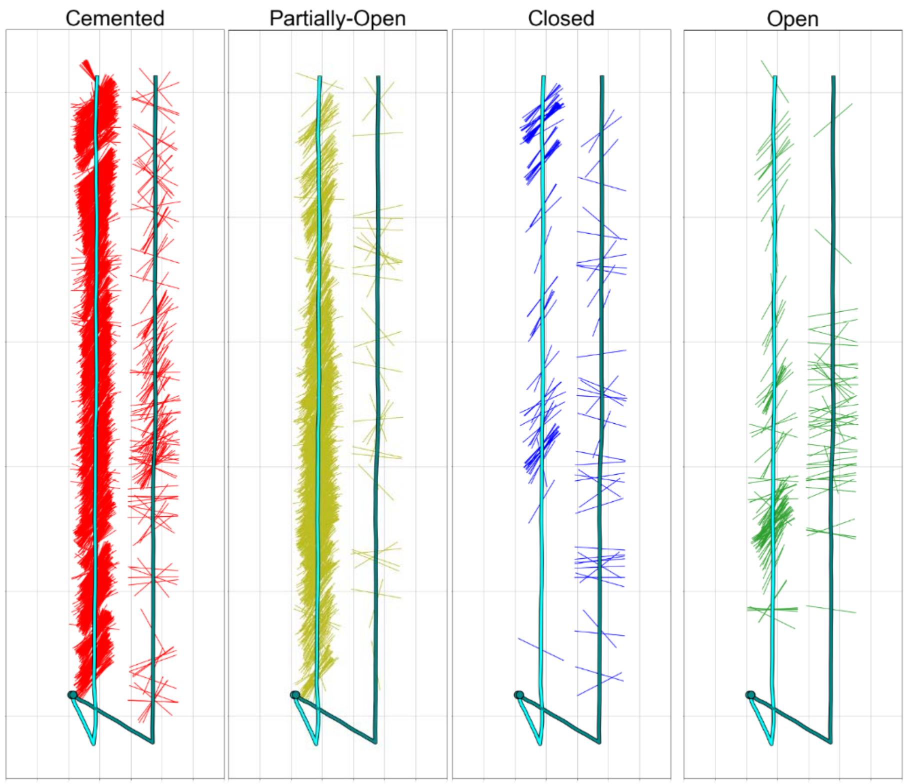
Oil Sample Compartmentalization – Origins?

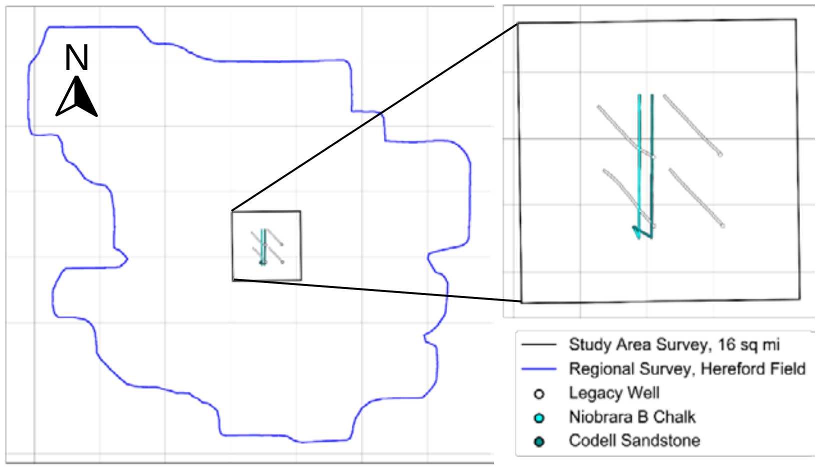


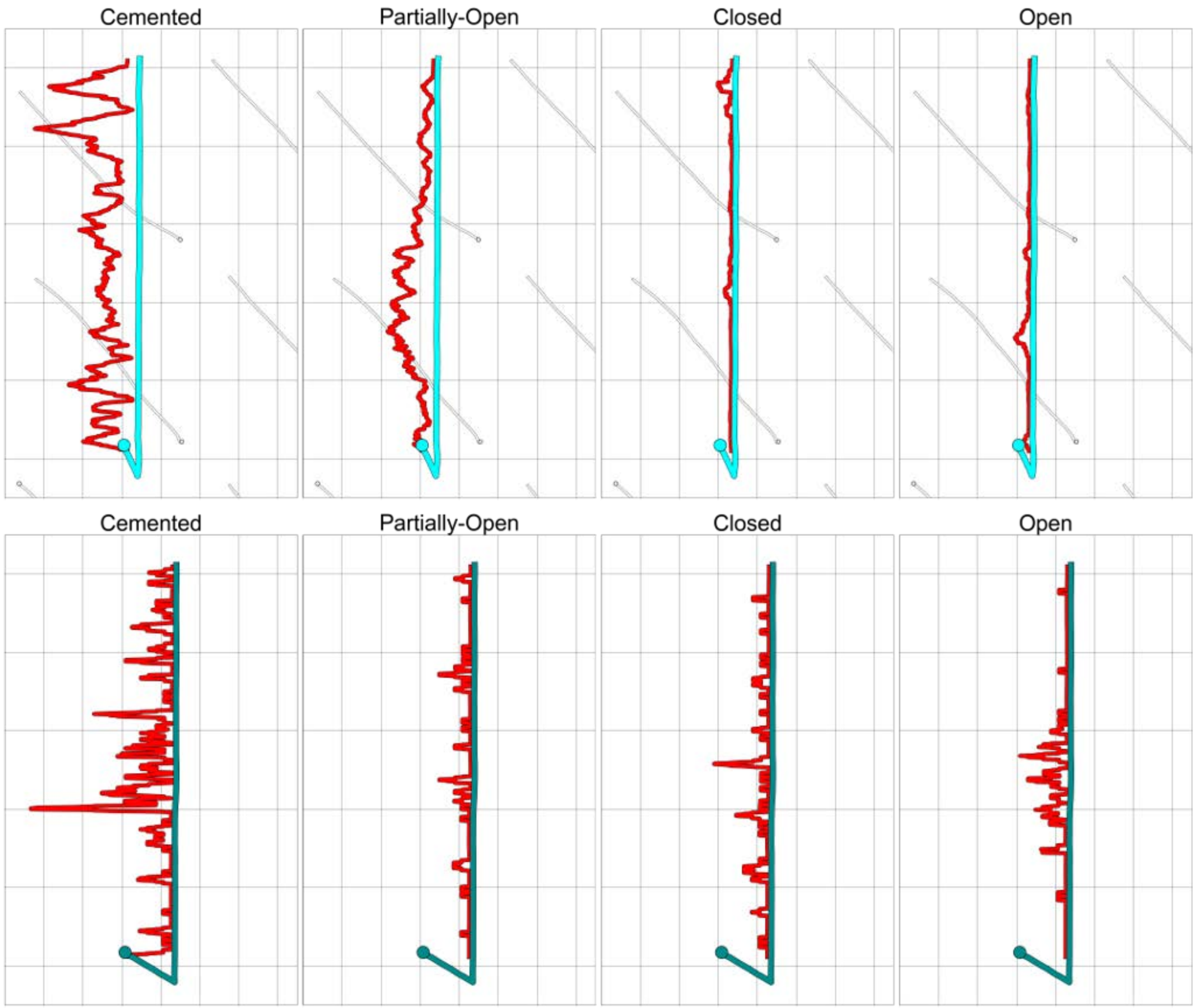


INDEX

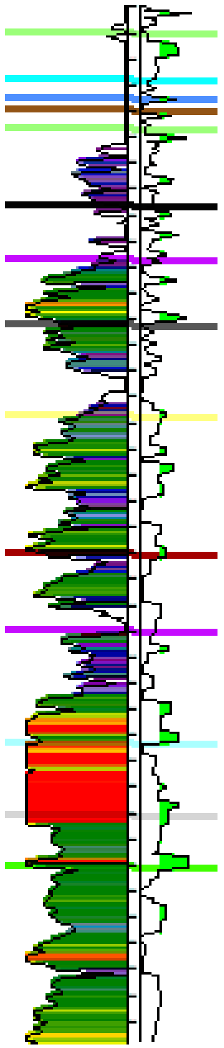
Present-Day Expression of Fractures





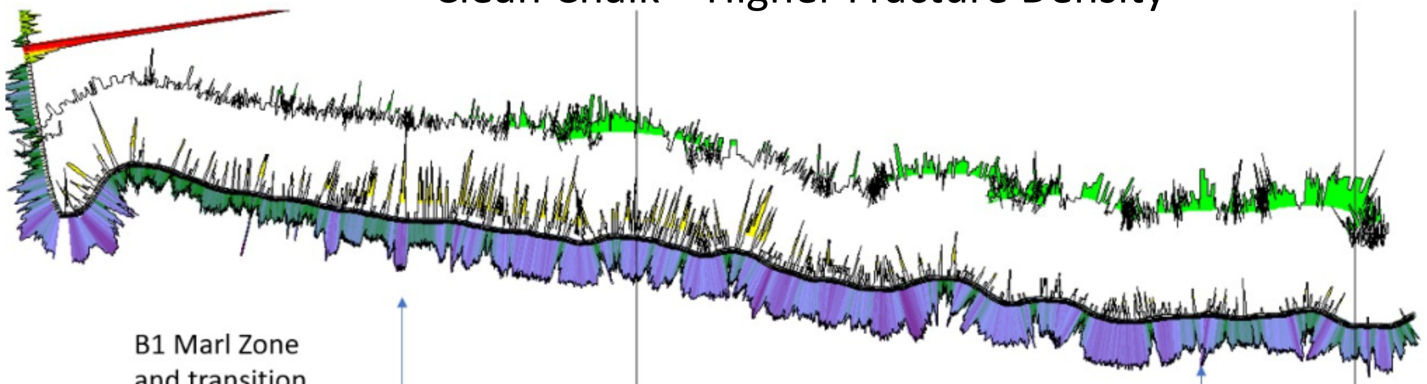


Niobrara B Chalk



Pilot

Clean Chalk = Higher Fracture Density

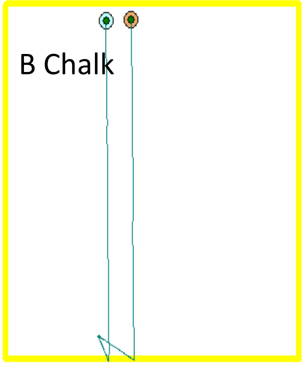


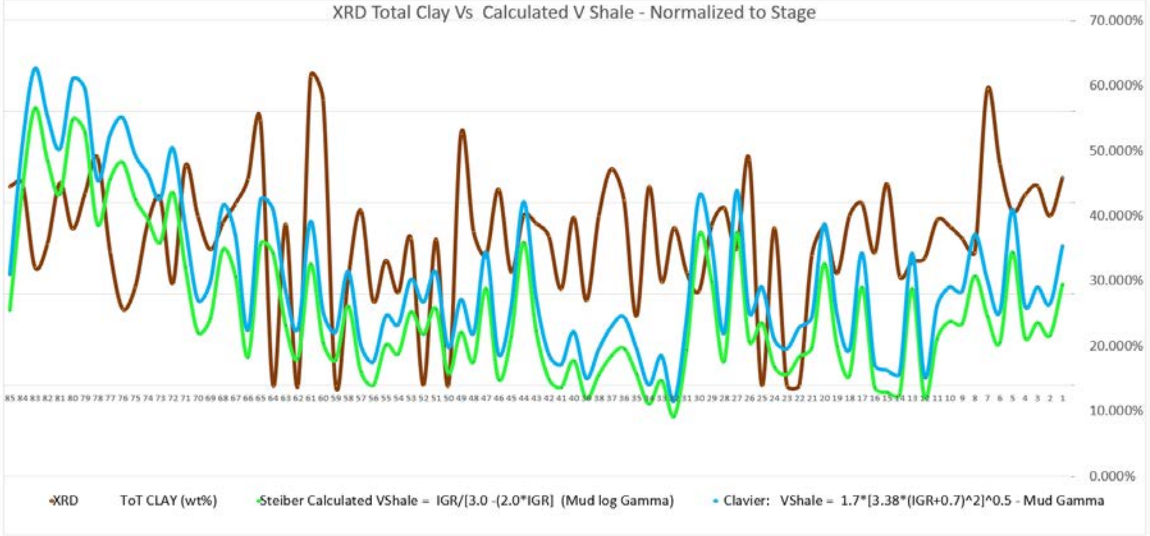
B1 Marl Zone
and transition

Zones 66 or 67
to 85

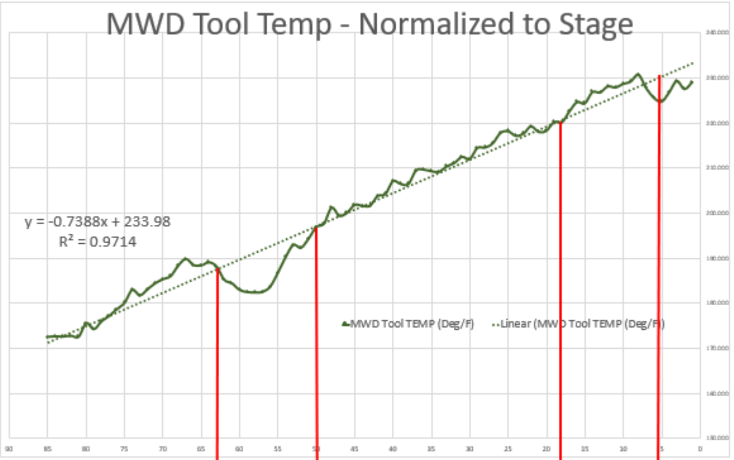
B Chalk Zone

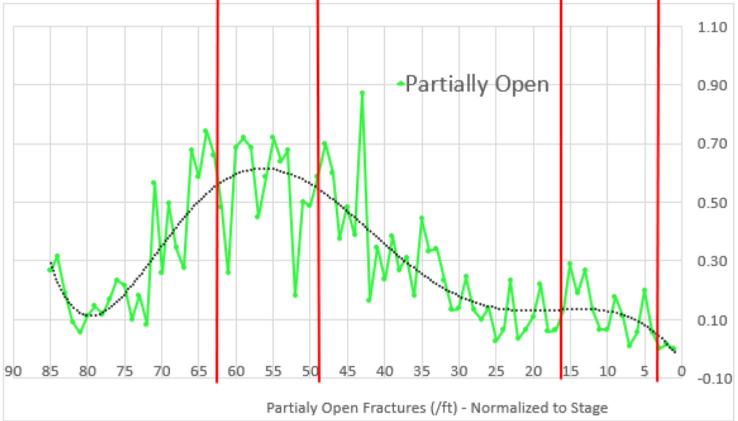
B Marl Zone
and transition
Zones 1 to16



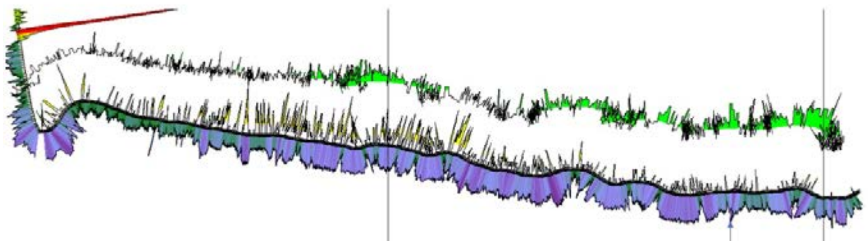


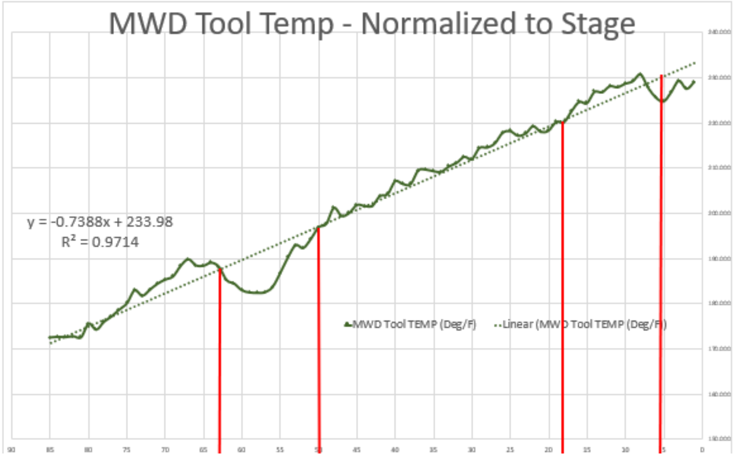
Stage by Stage analysis - Steering Evaluation

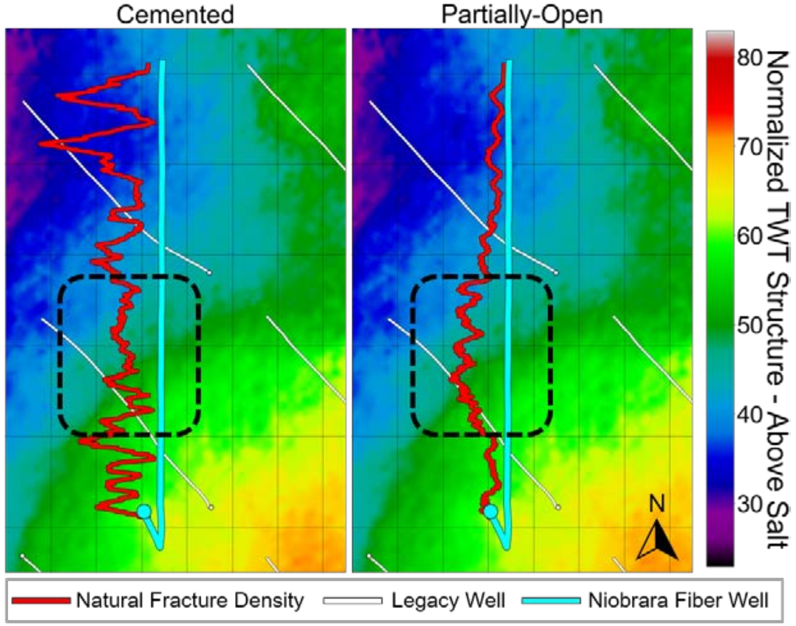


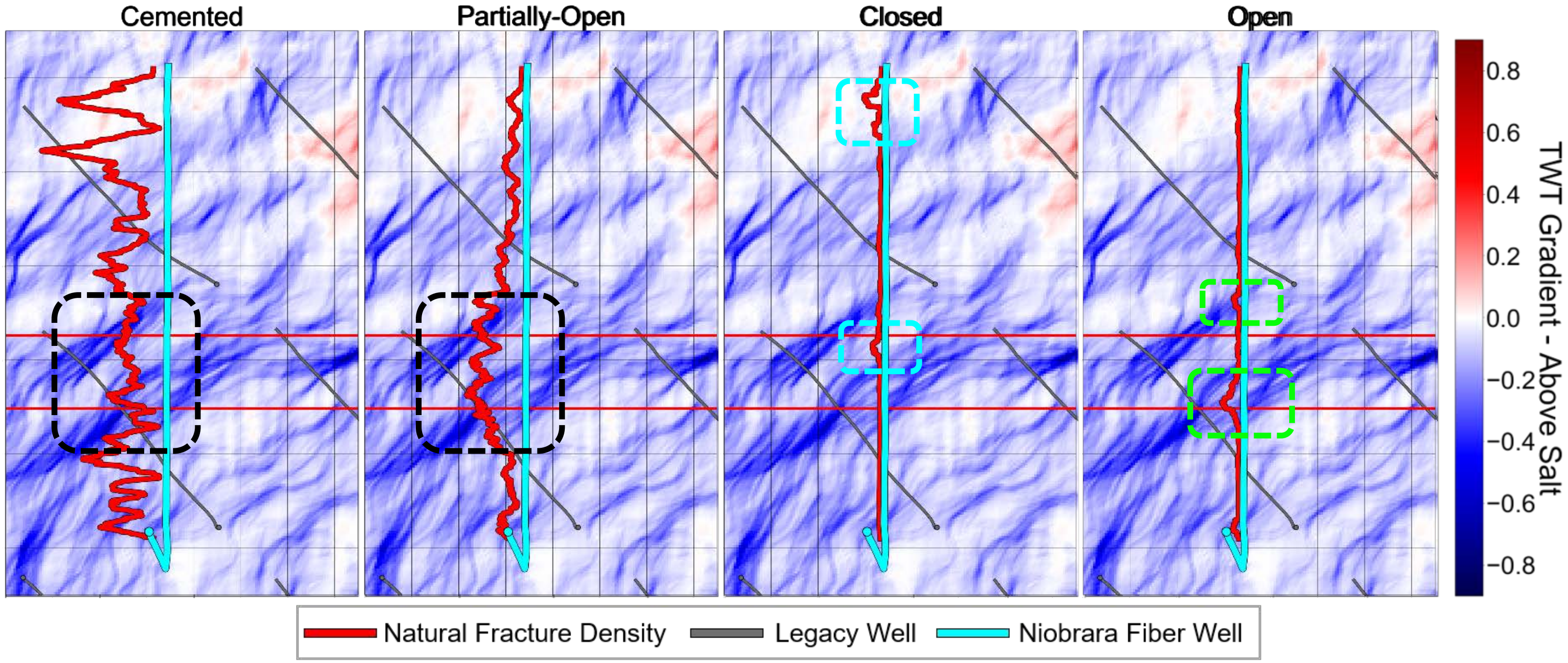


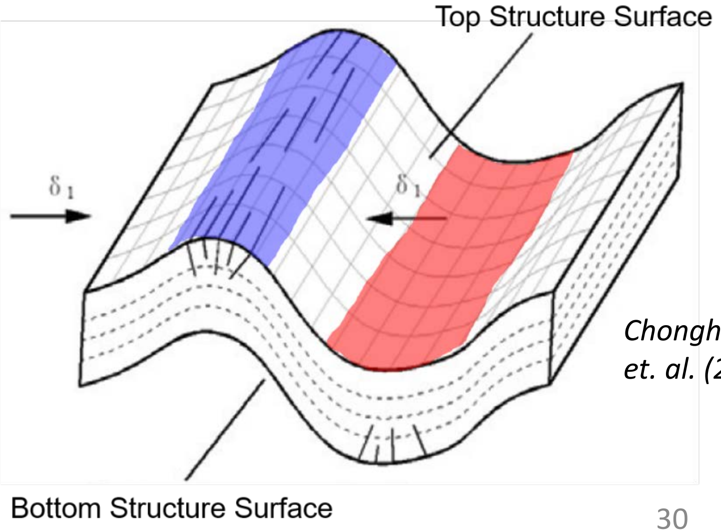
Controls on Open Fractures in the Niobrara





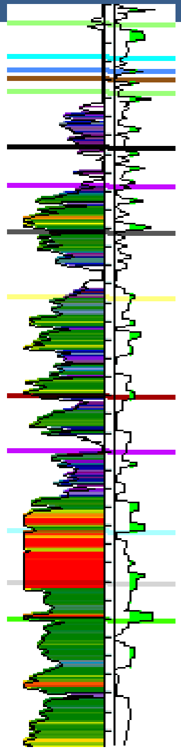




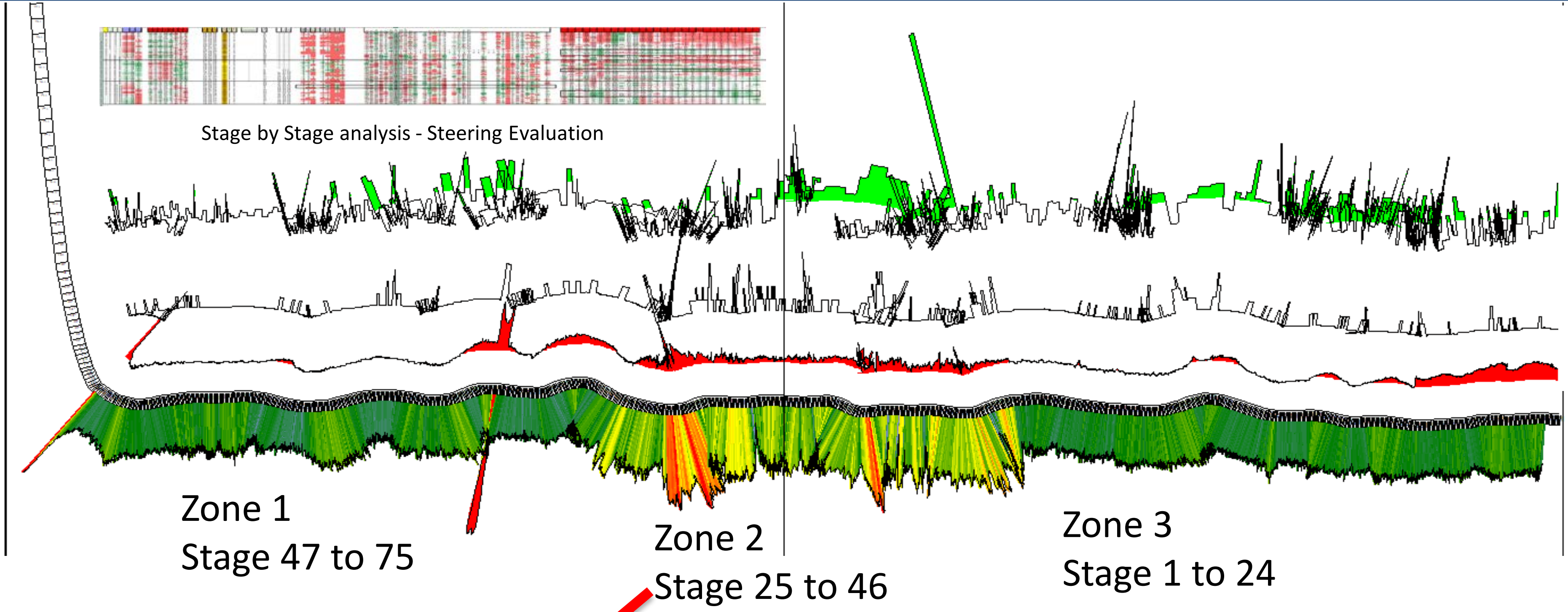


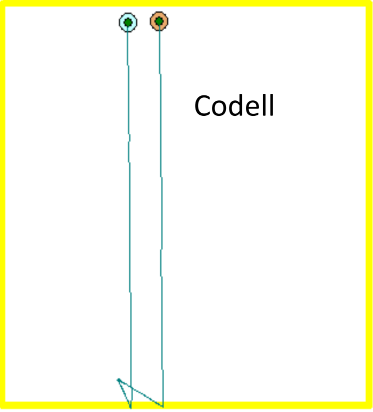
Chonghui, et. al. (2012)

Codell

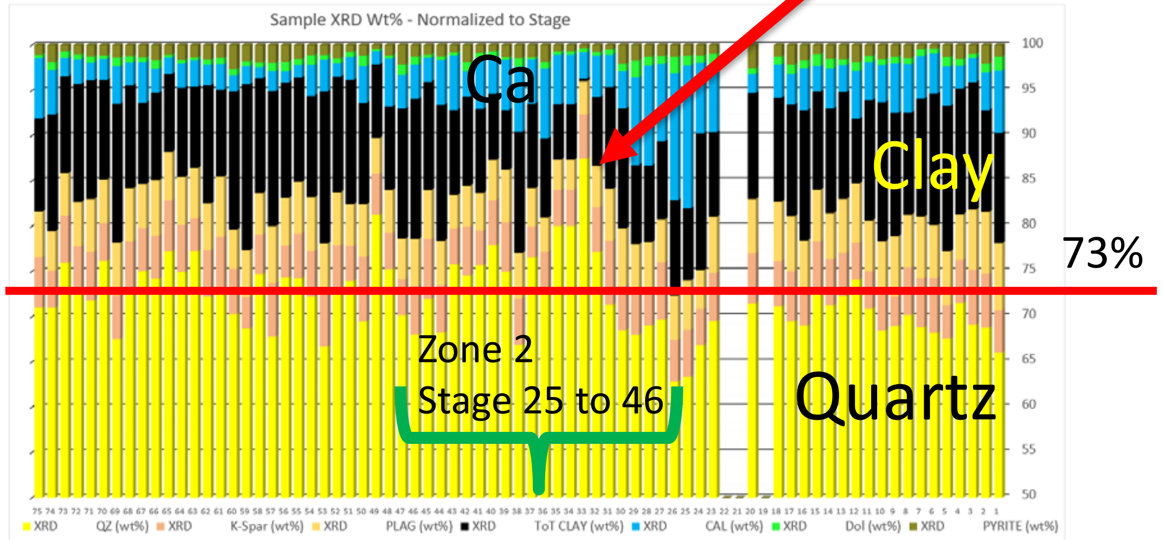


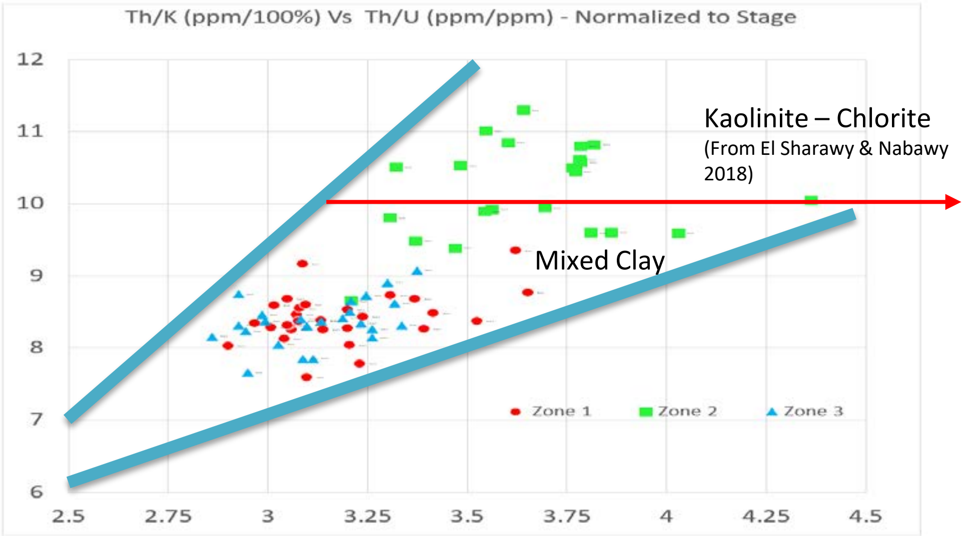
Pilot



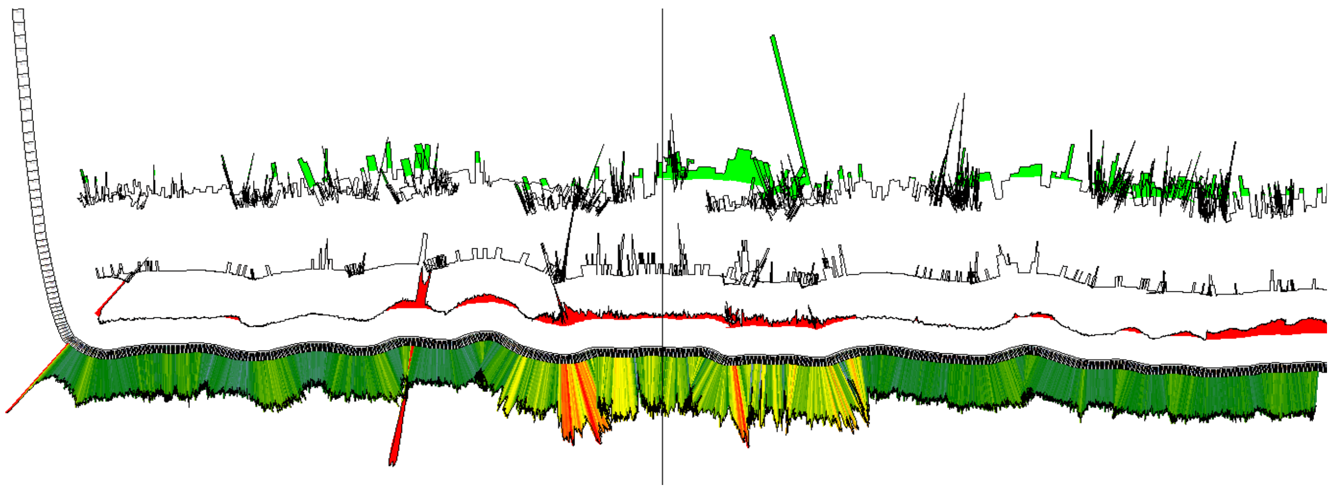


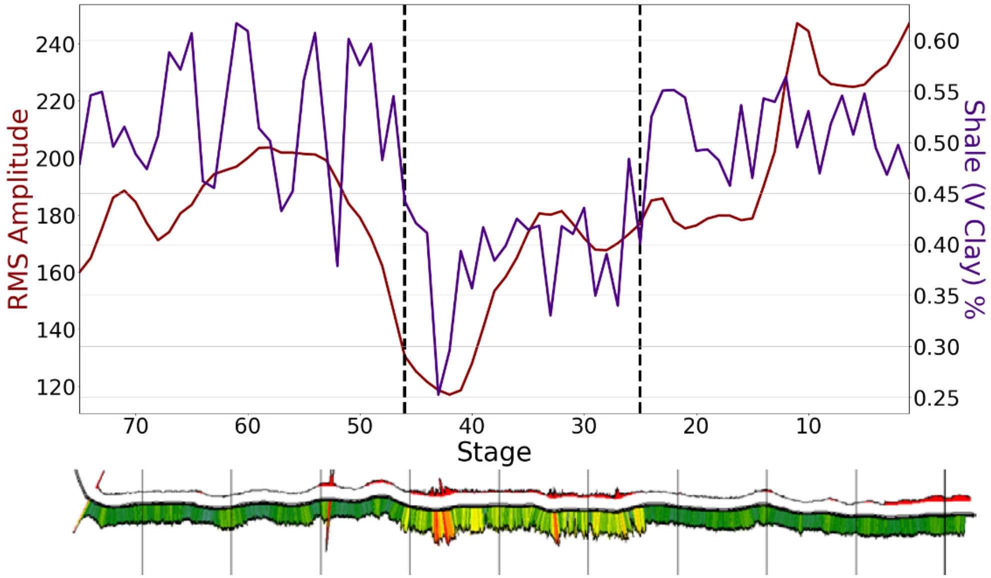
Higher Resistivity = Better Reservoir Quality
(Shaded > or = 4 ohm/m)

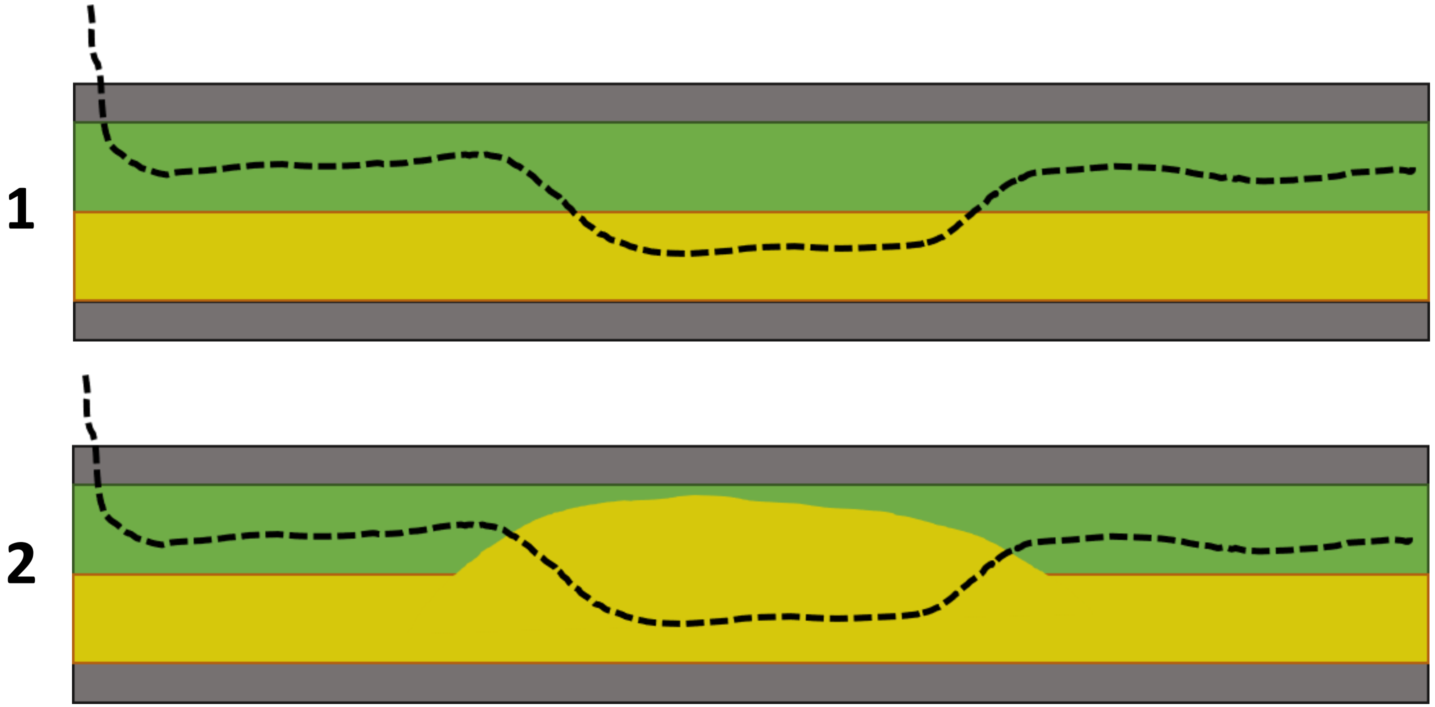


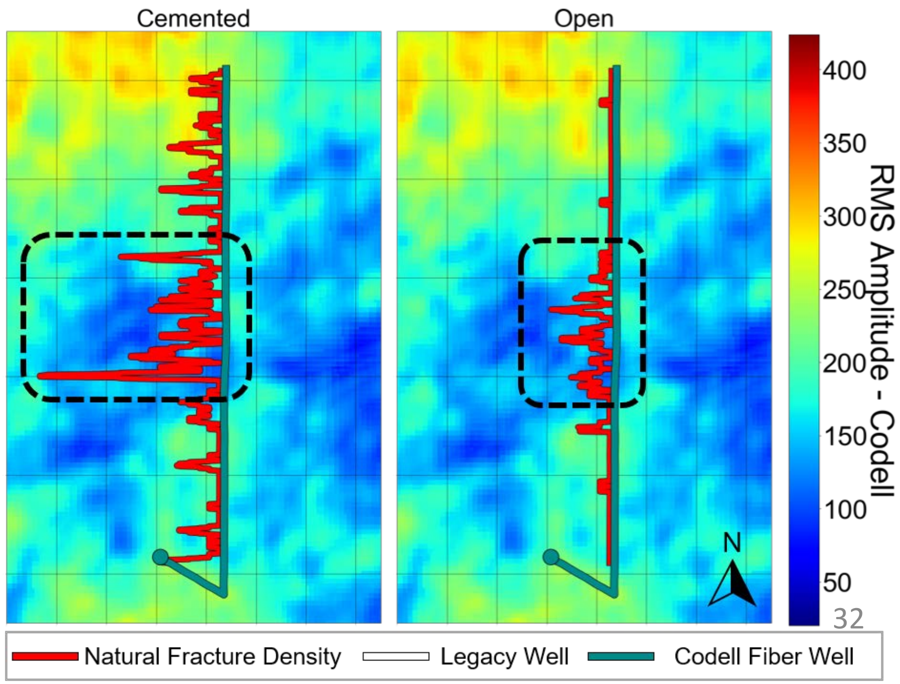


Seismic sensitive to thicker pay zone?

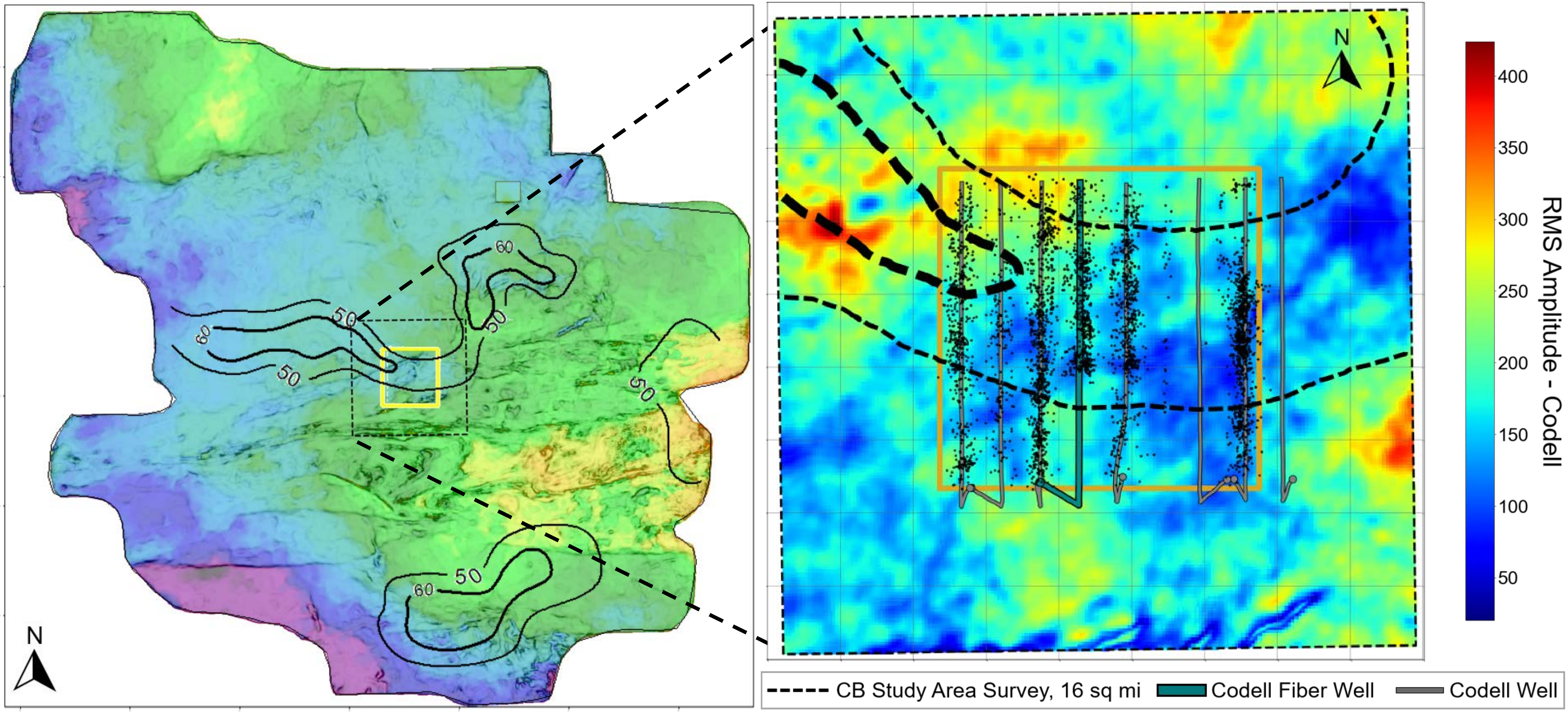








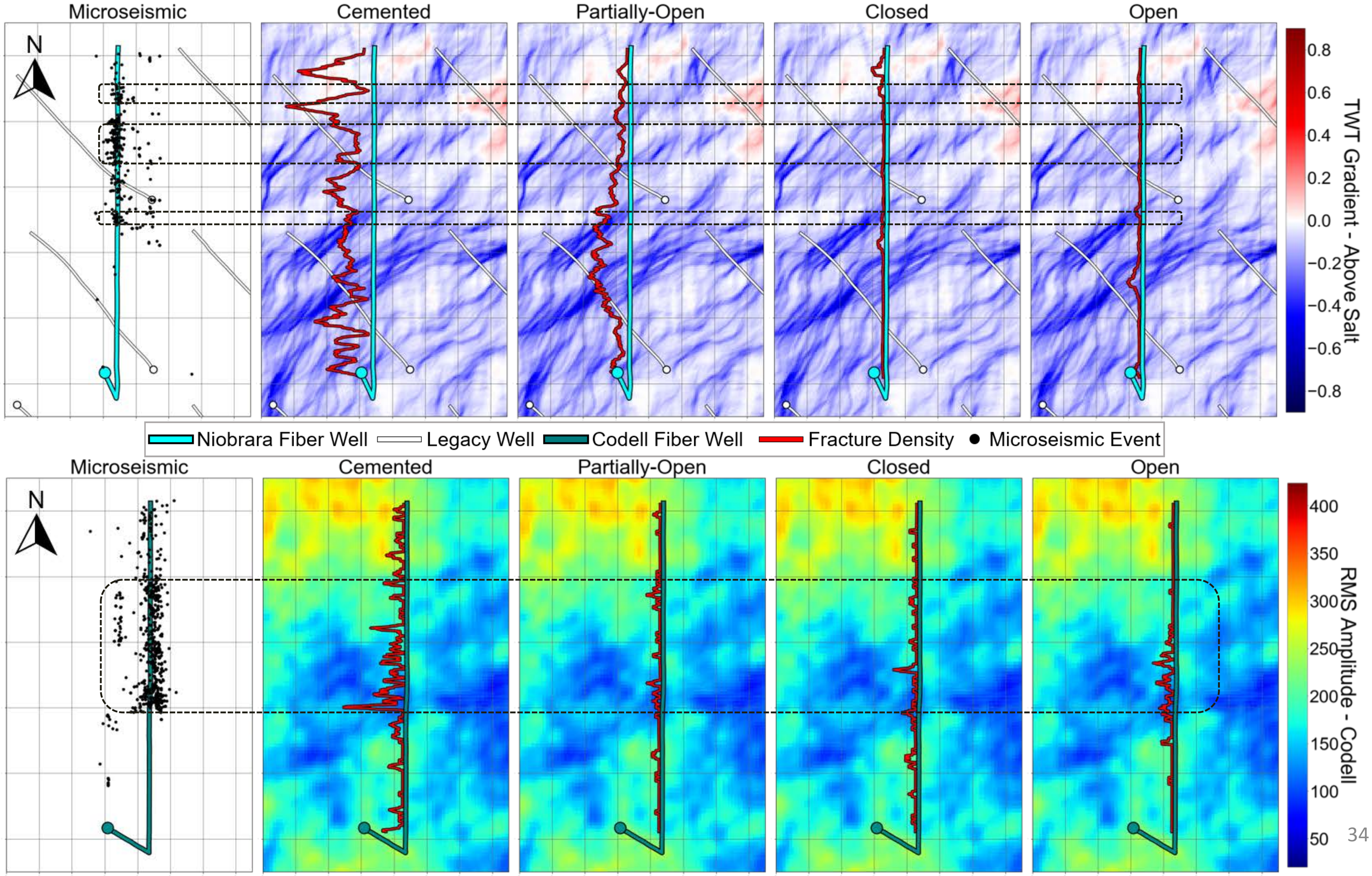
Codell Pay Zone Relationship to RMS Amplitudes



Fracture Impacts on Microseismic Events

Niobrara B Chalk

Codell Sandstone



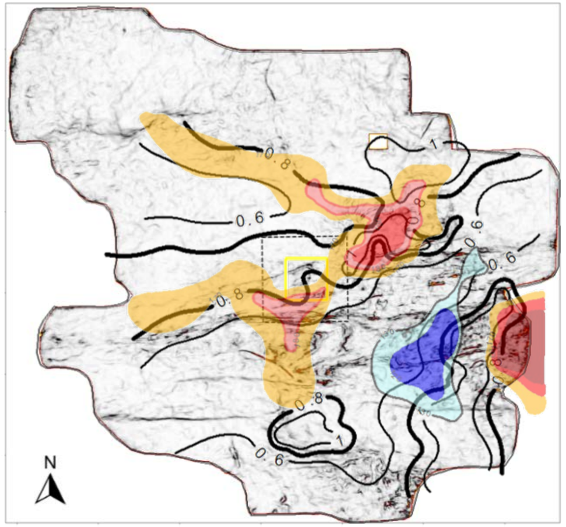
Summary

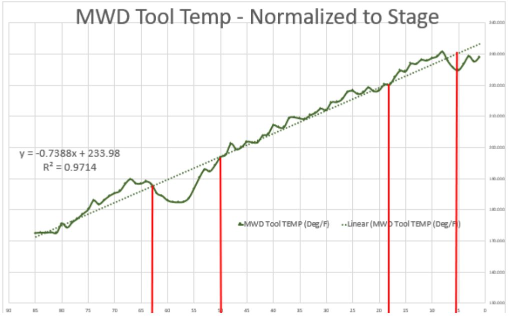
Niobrara

- Structurally-controlled
  - definable fracture fairways
- Fracture depletion
  - redefine reservoir quality for new phases of production
- Upside potential in the Niobrara
  - additional targets in the B1 Chalk and C Marl (should commodity prices allow)

Codell

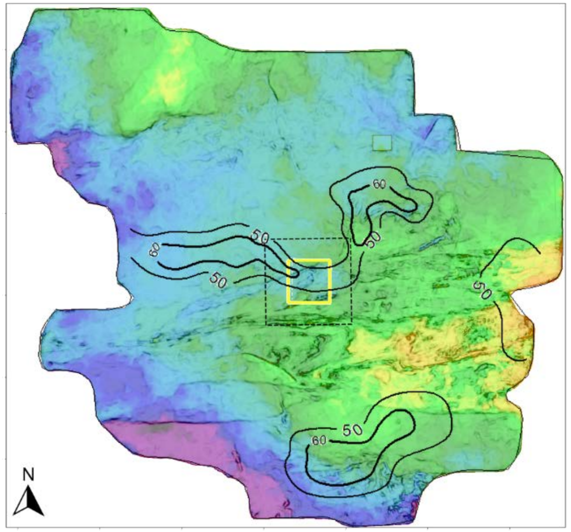
- Stratigraphically-controlled
  - lower-Codell brittle pay zone
- Oil mixing
  - Potential to develop deeper source intervals
- Upside potential
  - predictable pay across the region, mappable with well and seismic

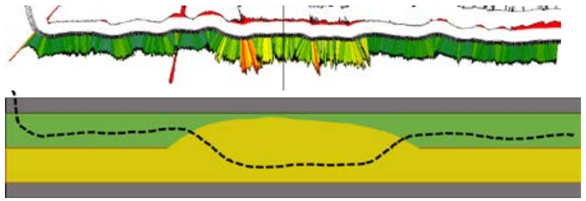


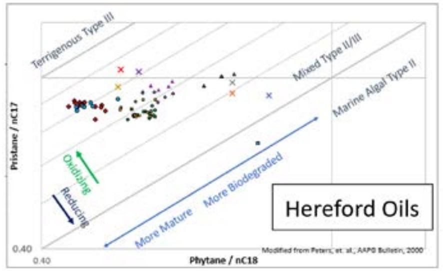


B1 Chalk:
Low case : 5.3 MMBO
High case: 6.9 MMBO
Low case : 4.9 BCF
High case: 6.5 BCF

C Marl:
Low case : 3.5 MMBO
High case: 5.4 MMBO
Low case : 4.2 BCF
High case: 6 BCF







Recommendations

- Optimization
  - Adjust completions in the Niobrara to avoid depleted fractures and maximize exposure to saturated matrix and un-depleted fractures
- Drilling
  - More attention on geosteering to target pay (especially in Codell)
  - Basic MWD tools diagnostic for reservoir characterization
- Enhanced Oil Recovery
  - Significant volumes remaining in place
  - Opportunities in both formations but more definable recovery factor in Codell

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Spring 2021

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