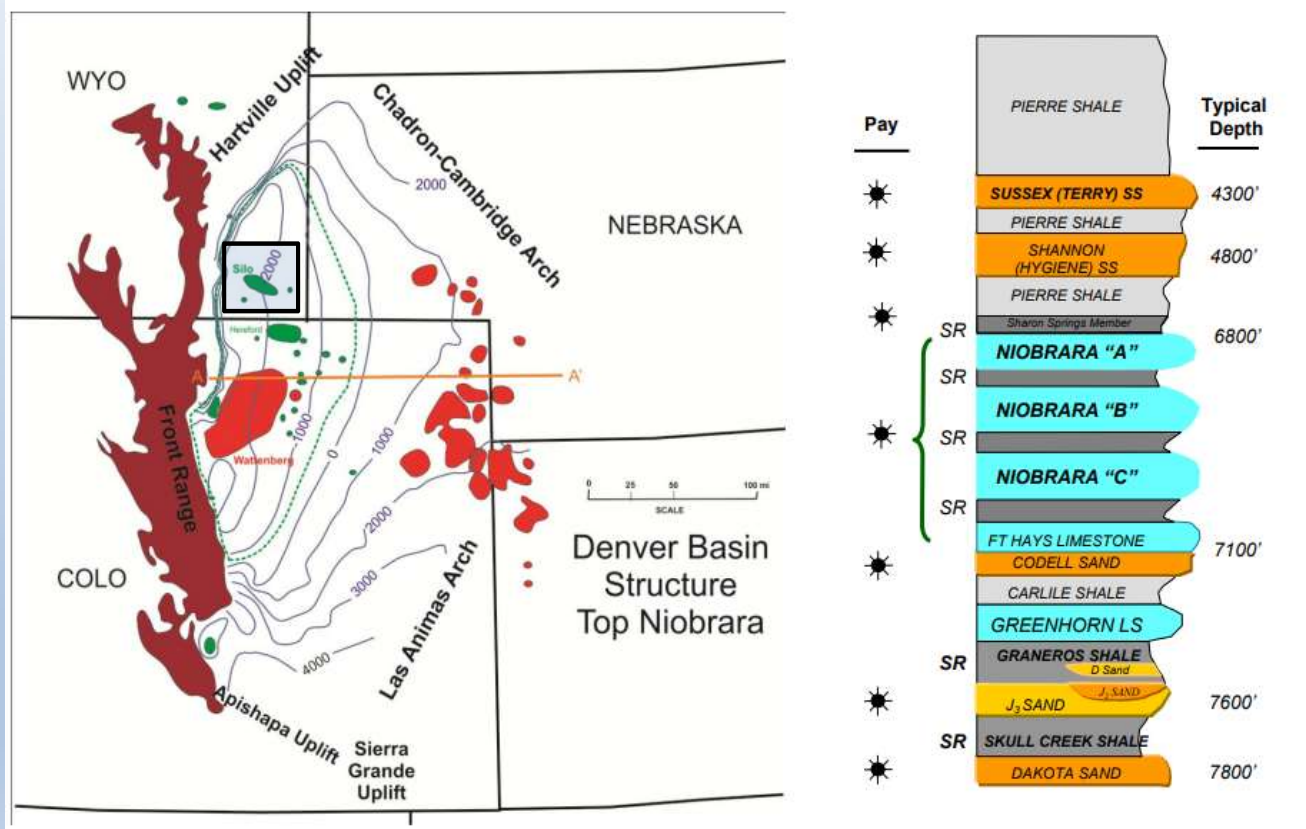
Matthew Keator, MS Geology, Anticipated Graduation: May 2023

RESERVOIR QUALITY AND CHARACTERIZATION OF THE CODELL SANDSTONE, NE SILO FIELD AREA

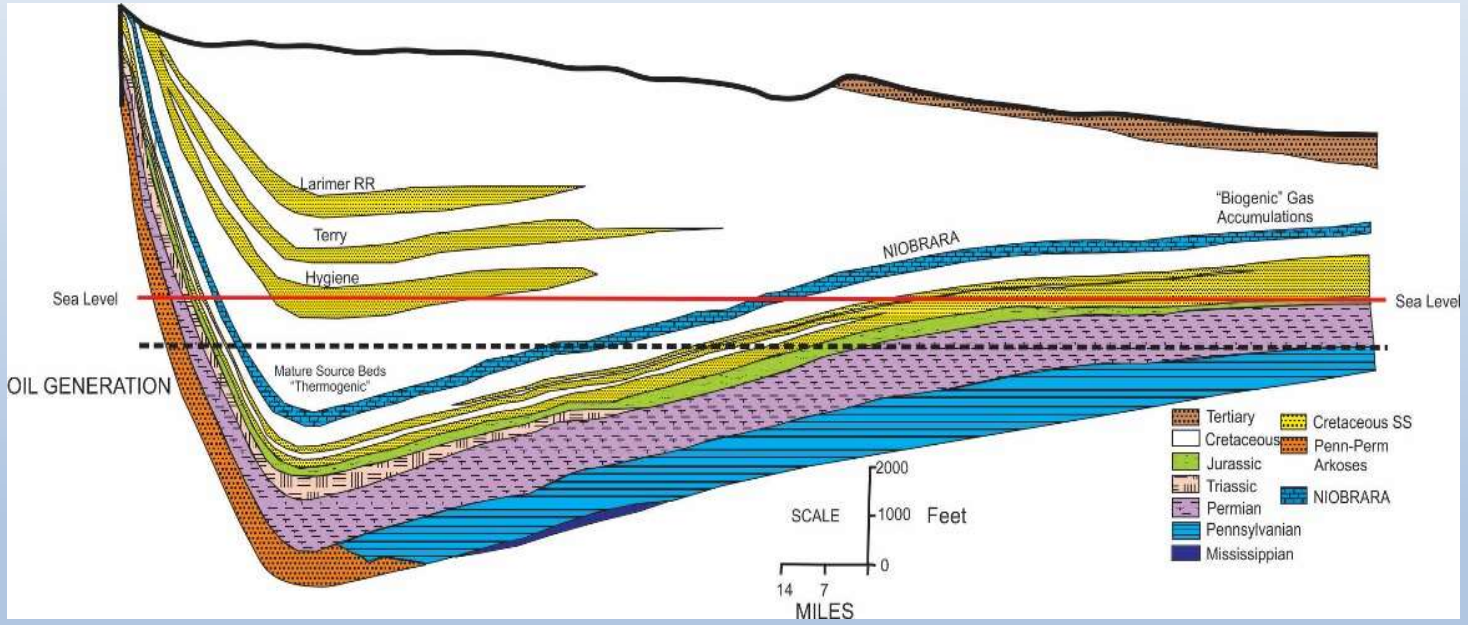
Location and Stratigraphy – Denver Basin



(Sonnenberg 2011)

- Silo Field is located in Laramie County, Wyoming
- Encompasses townships 15 and 16N and sections 63, 64, 65W
- Produces out of the Niobrara and Codell which is a tight sand reservoir
- Source rock intervals include the Sharon Springs Member, multiple benches of the Niobrara, Carlile, and Graneros
- Oil migrates into the Codell from one of the mentioned source rock intervals

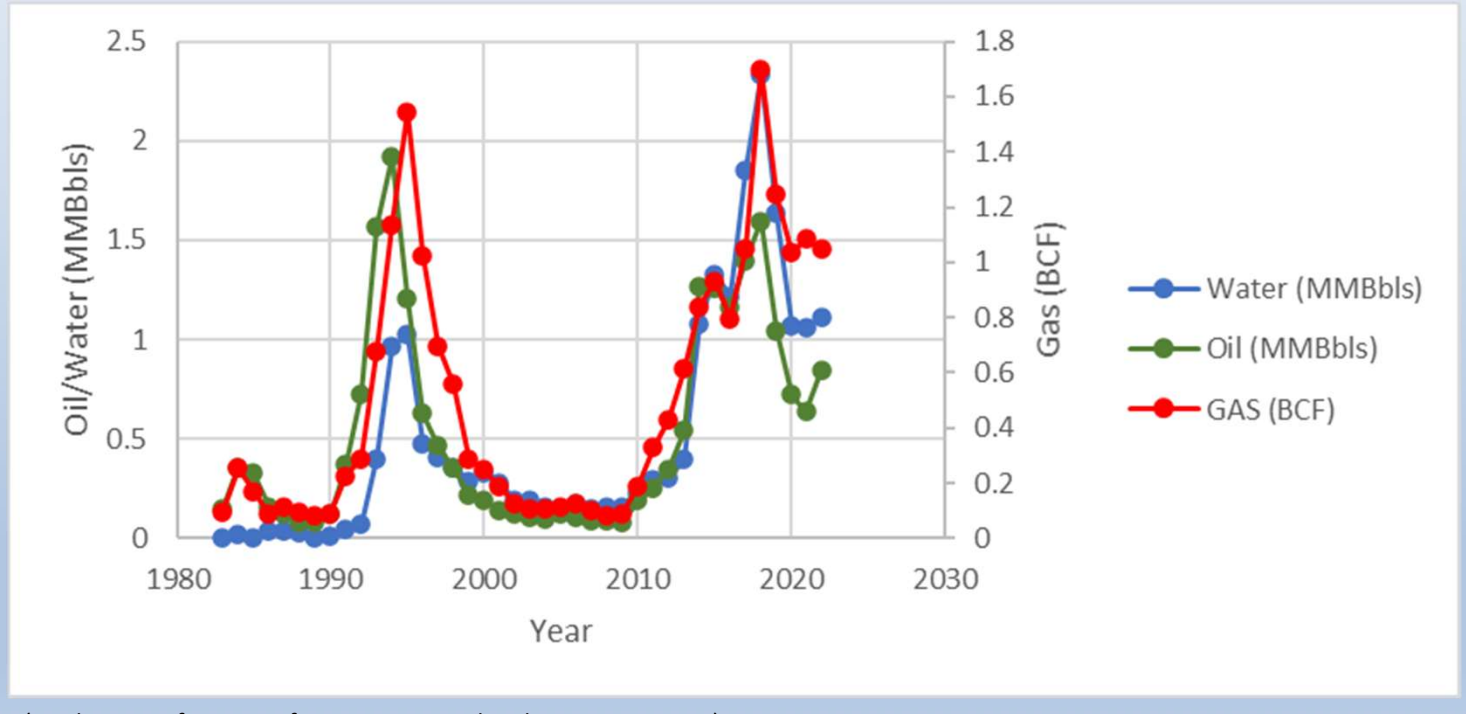
Typical Cross Section – Denver Basin



(Sonnenberg 2011)

- Codell lies uncomformably below the Niobrara and above the Carlile Shale and Greenhorn Limestone
- Denver Basin is deepest in the western portion and shallows to the east, typical foreland basin structure
- Formations shallowly dip to the west in the eastern portion of the basin
- Burial history has provided enough pressure and temperature for thermogenically mature source rocks to charge the petroleum system

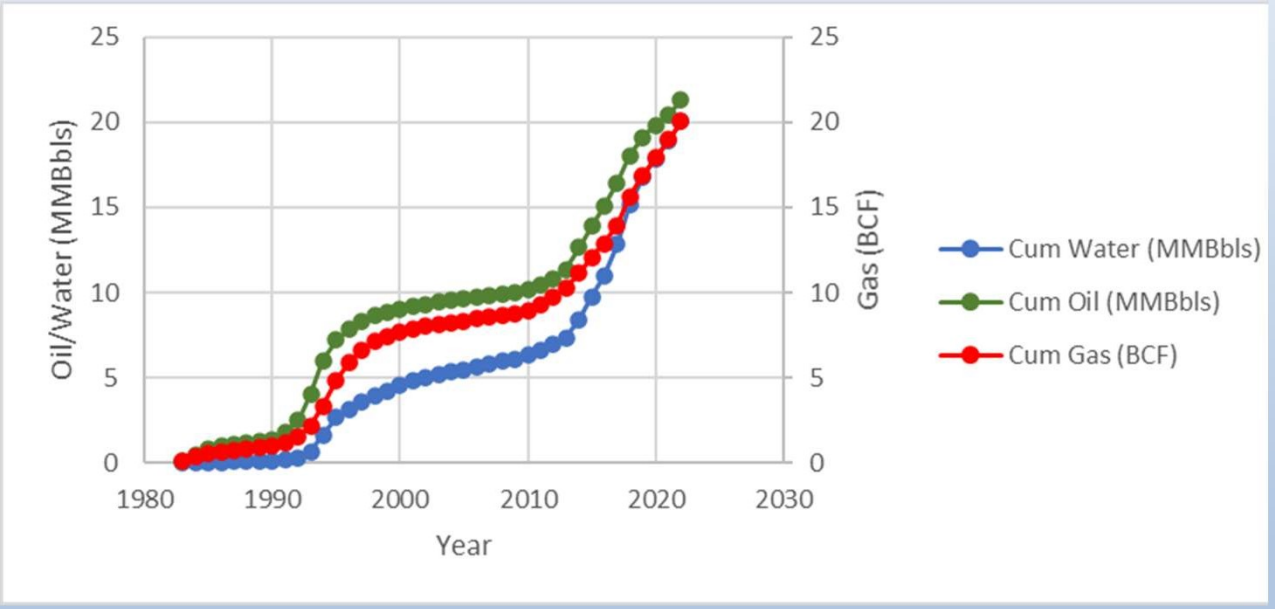
Silo Field Yearly Production Through Time



(Production Information from Wyoming Oil and Gas Commission)

- Amoco Champlin discovery well was drilled in 1981 and completed in the Fort Hays Limestone
- Horizontal drilling in 1990 (single stage water fracking) and unconventional development (multi-stage hydraulic fracturing) in 2009 increased yearly production rates

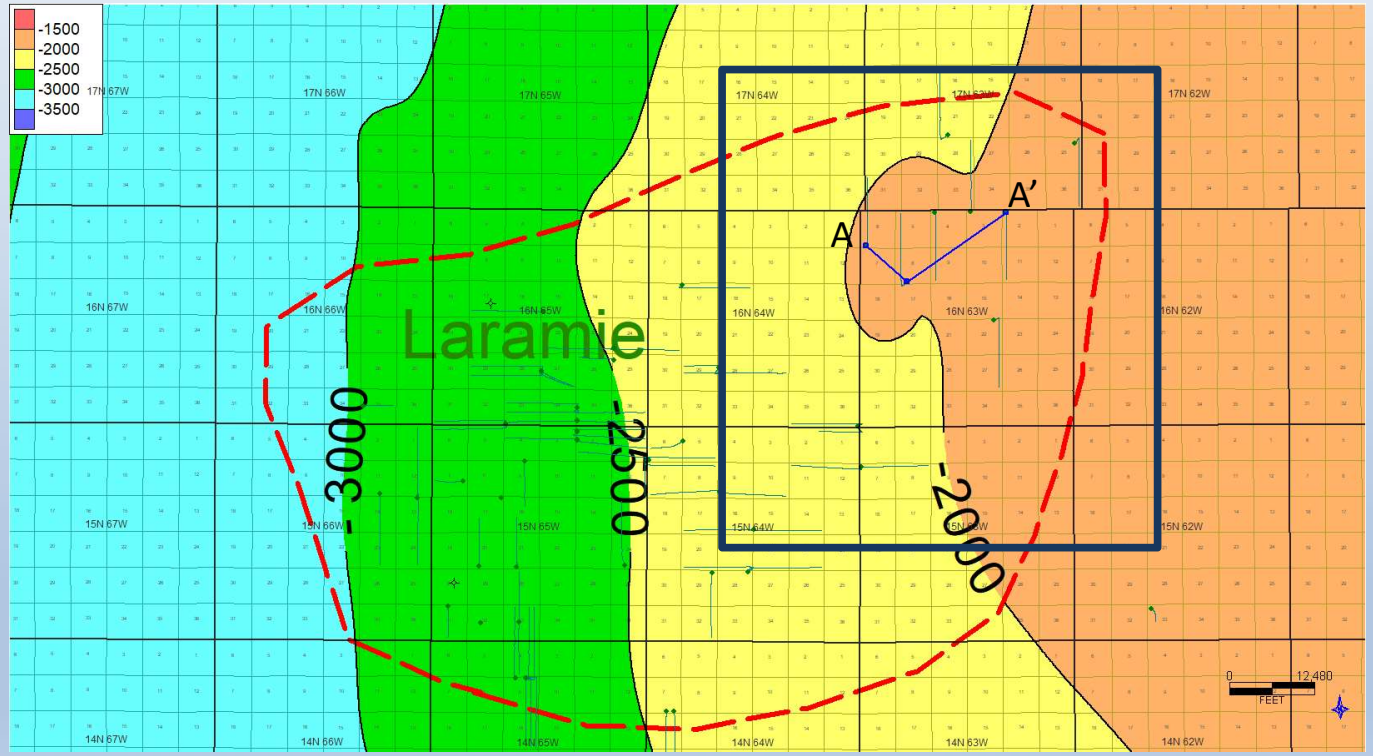
Silo Field Cumulative Production



(Production Information from Wyoming Oil and Gas Commission)

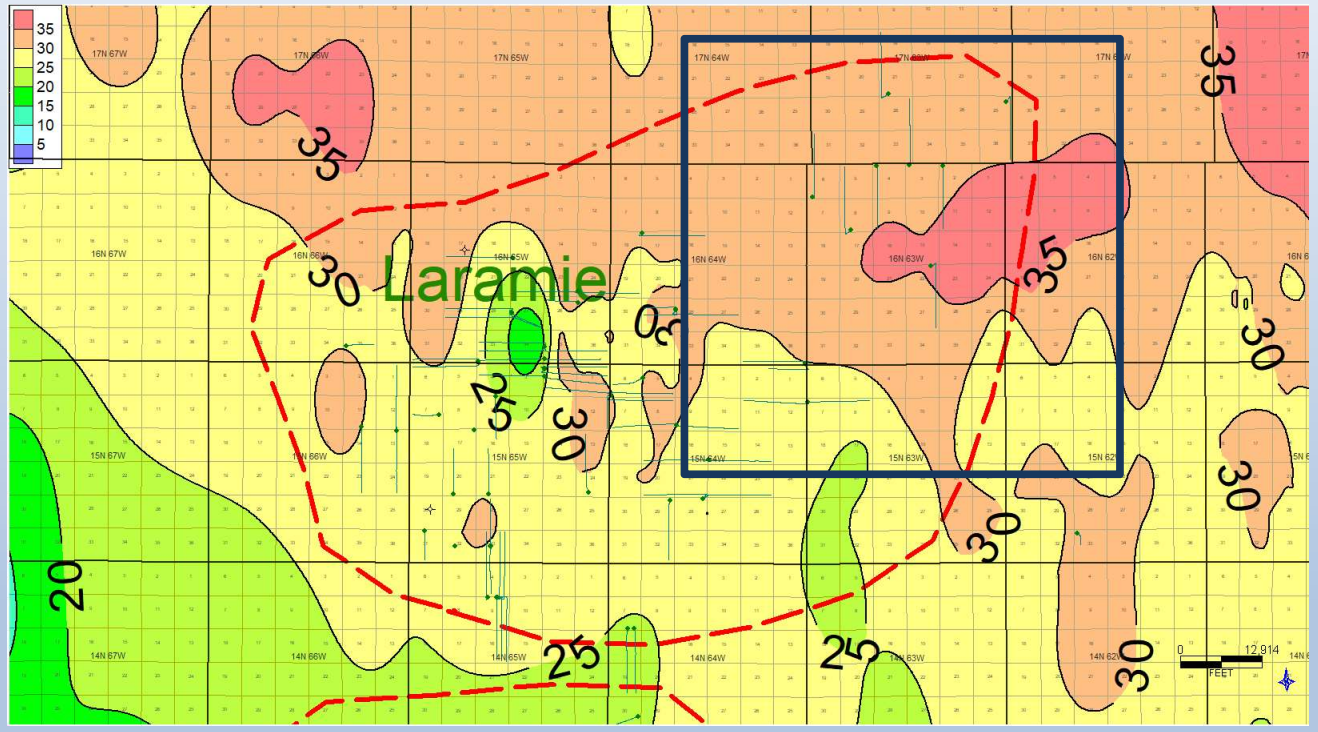
- Cumulative Oil Production – 21 MMBbls
- Cumulative Gas Production – 20 BCF
- Cumulative Water Production – 20 MMBbls
- Production increased after 1st stage horizontal drilling in 1990 (single stage water fracking) and unconventional boom in 2009 due to multi-stage hydraulic fracking

Codell Structure Map (SS) – Silo Field



- Codell subsea depth in Silo Field ranges from approximately -2000 to -3000 feet , with subsea depth in NE Silo Field near -2000 feet
- Follows general structure of DJ Basin
- Silo Field sits on the eastern part of the basin, so the Codell dips gently to the west

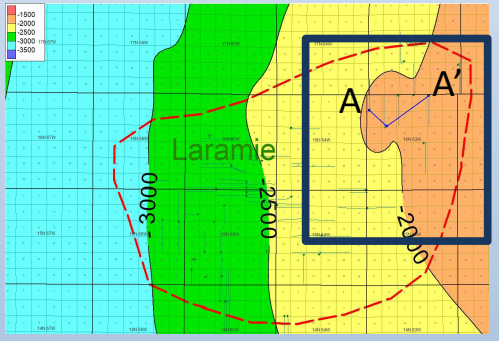
Codell Isopach Map – Silo Field

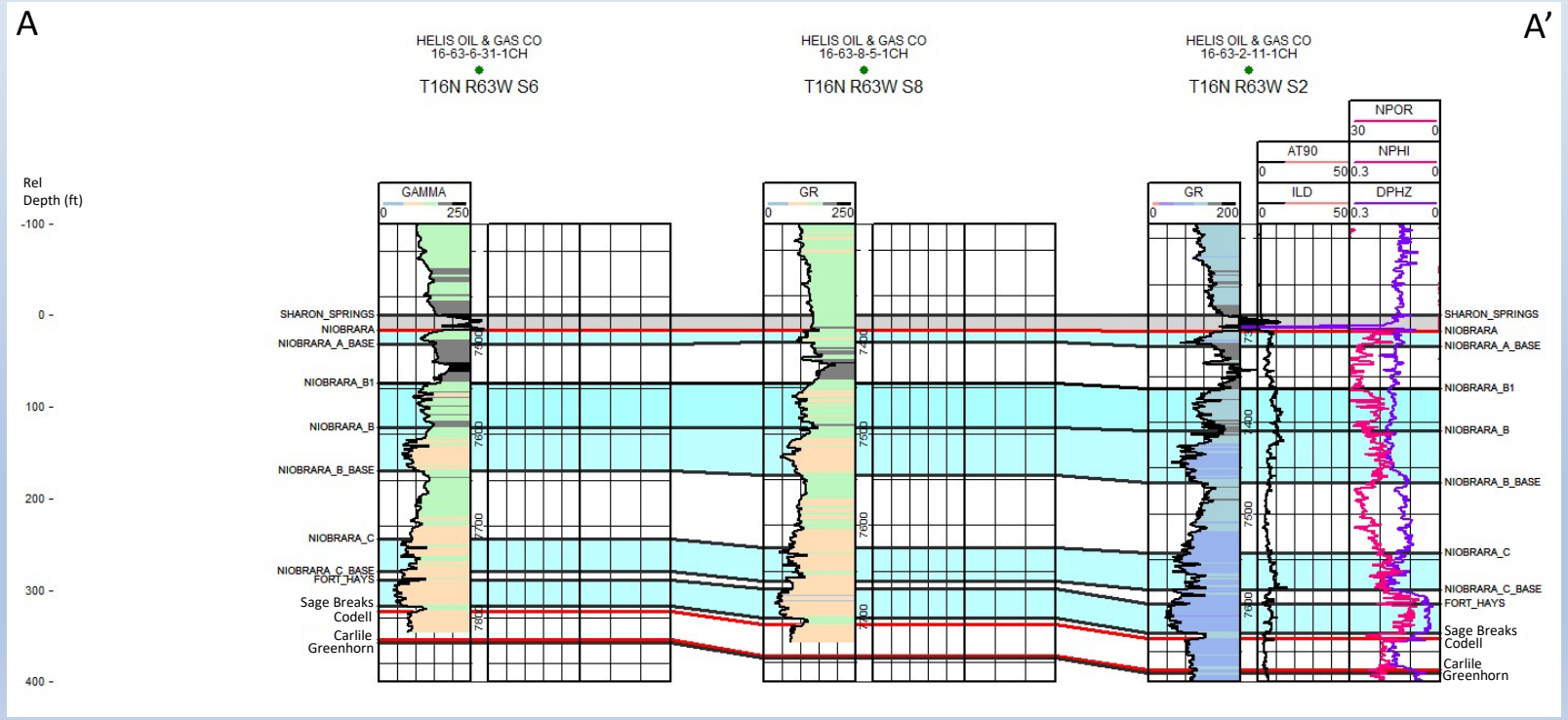


Codell Total Thickness Isopach Map

- Codell approximately 25-30 feet thick in Silo Field
- 30 feet thick in NE Silo Field
- Thickens to the north

Cross Section – NE Silo Field

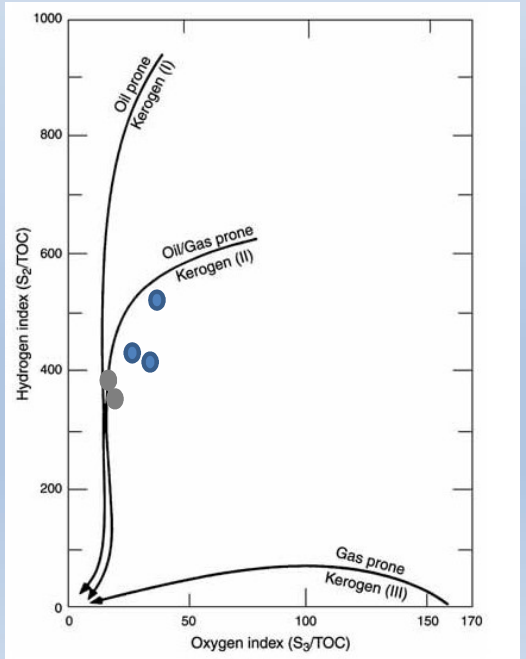




SRA Niobrara C Marl & Greenhorn Limestone

Sample ID						Source Rock Analyses											
Project / Sample ID	Rock ID	Well Name	Formation Name	Upper Depth (ft)	Sample Type	Percent Carbonate (wt%)	Leco TOC (wt%)	HAWK S1 (mg HC/g)	HAWK S2 (mg HC/g)	HAWK S3 (mg CO2/g)	HAWK Tmax (°C)	Calculated %Ro (RE TMAX)	Hydrogen Index (S2x100/TOC)	Oxygen Index (S3x100/TOC)	S2/S3 Conc. (mg HC/mg CO2)	S1/TOC Norm. Oil Content	Production Index (S1/(S1+S2)
RHOG-191001-001	1-1 GM	Cain 16-63-2-11-1CH	Niobrara C Marl	7,475.00	Core Chunk	33.59	1.79	0.48	7.77	0.35	425	0.49	434	20	22	27	0.06
RHOG-191001-002	1-2 GM	Cain 16-63-2-11-1CH	Niobrara C Marl	7,508.30	Core Chunk	31.56	1.43	0.43	5.73	0.39	427	0.53	401	27	15	30	0.07
RHOG-191001-003	1-3 GM	Cain 16-63-2-11-1CH	Niobrara C Marl	7,530.10	Core Chunk	54.68	1.72	0.49	8.90	0.60	425	0.49	517	35	15	28	0.05
RHOG-191001-004	1-4 GM	Cain 16-63-2-11-1CH	Codell Sandstone	7,648.80	Core Chunk												
RHOG-191001-005	1-5 GM	Cain 16-63-2-11-1CH	Codell Sandstone	7,654.50	Core Chunk												
RHOG-191001-006	1-6 GM	Cain 16-63-2-11-1CH	Greenhorn Limestone	7,677.00	Core Chunk	43.92	1.80	0.75	7.06	0.26	429	0.56	392	14	27	42	0.10
RHOG-191001-007	1-7 GM	Cain 16-63-2-11-1CH	Greenhorn Limestone	7,679.00	Core Chunk	50.49	1.51	0.44	5.64	0.28	428	0.54	374	19	20	29	0.07

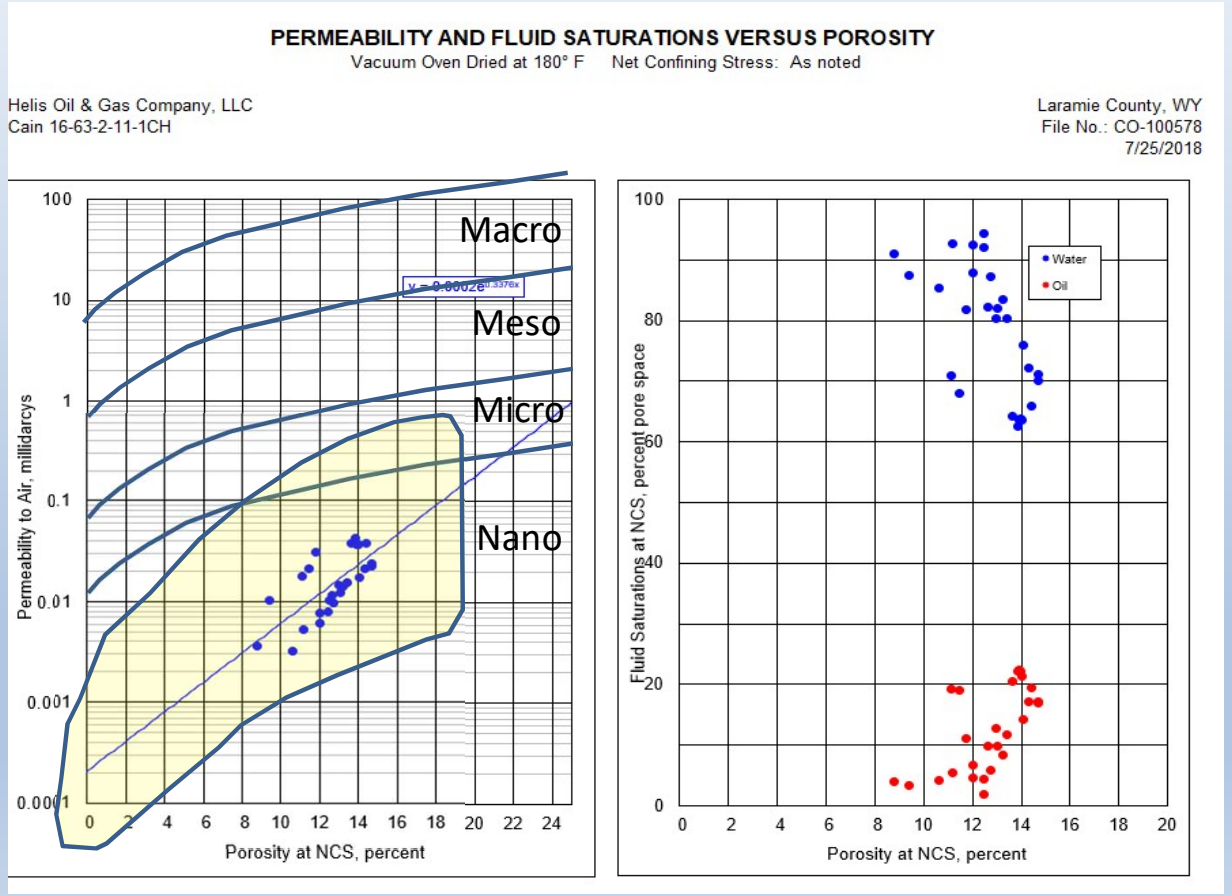
- Ro values from Niobrara sidewall cores average values near 0.5 - thermally immature
- Ro values from Greenhorn average near 0.55 – thermally immature
- S1 and S2 peaks indicate low levels of free hydrocarbons and high levels of hydrocarbons that formed during pyrolysis indicating high generating potential
- High HI and low OI indicate marine source
- Tmax below 430 (°C) represents immature organic matter



- HI and OI values indicate an oil/gas prone Type II kerogen source
- PI < 0.1 indicates thermally immature

Niobrara
Greenhorn

Porosity Versus Permeability - Core



- Fluid Saturation vs. Porosity indicates a porosity range of approximately 8 - 15% for oil and water saturated pore spaces
- Porosity vs. permeability crossplot indicates nano pores, which coincide with tight sand reservoirs
- Estimated tight sand pore size outlined in yellow (Chatellier 2018)
- Total well production
  - 280 MBbls oil
  - 211 MMCF gas
  - 585 Mbbls water

XRD (Weight%) – Codell, Cain 16-63-2-11-1CH

Sample Number	Sample Top Depth (ft)	Sample Bottom Depth (ft)	TECTOSILICATES			CARBONATES			PHYLLOSILICATES (CLAY GROUP MINERALS)				ADDITIONAL MINERALS			TOTAL				CALCULATED
			Quartz	K-spar	Plag.	Calcite[1]	Dolomite (Fe/Ca+)-1[2]	Dolomite (Fe/Ca+)-2[2]	Chlorite	Kaolinite	Illite/Mica	Mx I/S*	Pyrite	Marcasite	Apatite	TECTOSILICATES	CARBONATES	PHYLLOSILICATES	ADDITIONAL	GRAIN DENSITY g/cc^
1-14P	7343.00	7343.30	12.2	Tr	1.1	48.9	0.0	1.2	0.8	2.0	13.5	12.0	8.3	Tr	0.0	13.3	50.1	28.3	8.3	2.79
1-44P	7373.45	7373.70	7.3	Tr	1.0	75.6	0.0	1.5	Tr	1.2	3.1	7.7	2.6	Tr	0.0	8.3	77.1	12.0	2.6	2.72
1-60P	7389.05	7389.30	6.7	Tr	1.0	70.6	0.0	1.2	Tr	1.9	4.5	8.6	5.5	Tr	0.0	7.7	71.8	15.0	5.5	2.76
1-74P	7403.00	7403.15	8.3	Tr	1.0	73.4	0.0	1.5	Tr	0.8	4.9	7.9	2.2	Tr	0.0	9.3	74.9	13.6	2.2	2.72
1-90P	7419.70	7420.00	3.6	Tr	0.8	89.5	0.0	Tr	Tr	Tr	0.6	4.7	0.8	0.0	0.0	4.4	89.5	5.3	0.8	2.70
1-108P	7437.15	7437.45	3.4	Tr	0.9	90.9	0.0	Tr	Tr	Tr	0.7	3.3	0.8	0.0	0.0	4.3	90.9	4.0	0.8	2.71
1-126P	7454.90	7455.10	8.2	Tr	1.4	64.1	0.0	1.4	Tr	1.7	4.4	16.7	1.4	0.7	0.0	9.6	65.5	22.8	2.1	2.69
1-142P	7471.00	7471.30	20.3	0.6	1.7	31.2	0.0	2.4	1.5	2.4	15.2	21.8	2.9	Tr	Tr	22.6	33.6	40.9	2.9	2.69
1-206P	7534.95	7535.15	7.5	Tr	0.7	74.1	0.0	Tr	Tr	0.9	4.1	10.6	2.1	0.0	0.0	8.2	74.1	15.6	2.1	2.70
1-214P	7543.00	7543.30	5.9	Tr	0.9	77.4	0.0	Tr	Tr	Tr	2.1	11.8	1.9	0.0	0.0	6.8	77.4	13.9	1.9	2.70
1-224P	7553.00	7553.25	3.6	Tr	0.8	86.7	0.0	Tr	Tr	Tr	1.0	6.2	1.7	0.0	0.0	4.4	86.7	7.2	1.7	2.71
1-240P	7569.00	7569.30	4.3	Tr	1.2	85.8	0.0	Tr	Tr	Tr	0.9	6.4	1.4	Tr	0.0	5.5	85.8	7.3	1.4	2.71
1-248P	7577.05	7577.30	4.0	Tr	1.3	85.2	0.0	Tr	Tr	Tr	1.2	6.8	1.5	0.0	0.0	5.3	85.2	8.0	1.5	2.71
1-278P	7607.40	7607.60	7.9	Tr	0.8	75.8	0.0	2.2	Tr	Tr	4.2	9.1	Tr	0.0	0.0	8.7	78.0	13.3	Tr	2.69
1-297P	7626.40	7626.60	39.7	4.8	7.4	5.8	0.0	4.5	1.9	6.3	8.2	20.1	1.3	0.0	0.0	51.9	10.3	36.5	1.3	2.64
1-302P	7631.30	7631.55	57.7	4.5	6.0	11.5	0.0	3.4	1.2	6.1	0.9	7.8	0.9	0.0	0.0	68.2	14.9	16.0	0.9	2.65
1-305P	7634.00	7634.20	67.4	4.1	6.4	1.9	0.0	1.0	1.1	7.3	1.3	8.3	1.2	Tr	0.0	77.9	2.9	18.0	1.2	2.65
1-308P	7637.05	7637.25	66.8	5.1	8.6	1.5	0.0	1.1	0.6	6.8	1.0	7.6	0.9	0.0	0.0	80.5	2.6	16.0	0.9	2.64
1-311P	7640.00	7640.20	67.5	5.3	7.8	1.1	0.0	1.0	0.6	5.0	1.6	9.1	1.0	0.0	0.0	80.6	2.1	16.3	1.0	2.64
1-314P	7643.00	7643.20	66.3	5.6	8.1	1.1	0.0	1.8	0.7	4.2	1.2	9.9	1.1	0.0	0.0	80.0	2.9	16.0	1.1	2.64
1-317P	7646.00	7646.15	63.6	5.3	8.3	5.8	0.0	1.4	0.8	6.8	0.6	6.8	0.6	Tr	0.0	77.2	7.2	15.0	0.6	2.65
1-320P	7649.10	7649.35	65.4	5.4	7.8	2.2	0.0	1.1	0.6	5.7	1.0	9.8	1.0	0.0	0.0	78.6	3.3	17.1	1.0	2.64
1-323P	7652.40	7652.60	59.6	5.7	8.9	1.3	0.0	1.8	0.7	4.8	2.1	13.1	2.0	0.0	0.0	74.2	3.1	20.7	2.0	2.65
1-326P	7655.00	7655.25	65.1	5.0	6.3	5.2	0.0	0.9	1.2	5.9	1.4	7.8	1.2	0.0	0.0	76.4	6.1	16.3	1.2	2.65
1-328P	7657.00	7657.25	68.2	5.0	7.1	0.5	0.0	0.7	0.8	5.2	1.6	10.2	0.7	Tr	0.0	80.3	1.2	17.8	0.7	2.64
1-330P	7659.00	7659.20	67.7	5.4	7.2	1.1	0.0	0.9	0.7	5.9	1.3	8.7	0.5	0.6	0.0	80.3	2.0	16.6	1.1	2.64
1-335P	7664.00	7664.20	24.4	2.7	4.7	20.4	2.1	3.5	2.3	2.8	12.1	22.5	1.4	0.6	0.5	31.8	26.0	39.7	2.5	2.67
1-347P	7676.05	7676.25	19.4	1.5	2.4	35.5	2.7	2.6	1.7	3.8	10.3	19.1	1.0	Tr	Tr	23.3	40.8	34.9	1.0	2.67
1-357P	7686.00	7686.20	17.9	1.5	2.6	37.1	2.1	3.2	1.5	2.8	7.1	22.7	1.5	Tr	Tr	22.0	42.4	34.1	1.5	2.66

Suggestions for Future Work

- Detailed core description of the Cain 16-63-2-11-1CH
- Thin section descriptions and FE-SEM analysis on cored Codell interval
- SRA work on shale-rich intervals within the cored Greenhorn, Codell, and Niobrara intervals
- Resistivity mapping and petrophysical analysis
- Detrital zircon geochronology (?)

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