Reservoir Quality and Characterization of the Codell Sandstone, NE Silo Field Area

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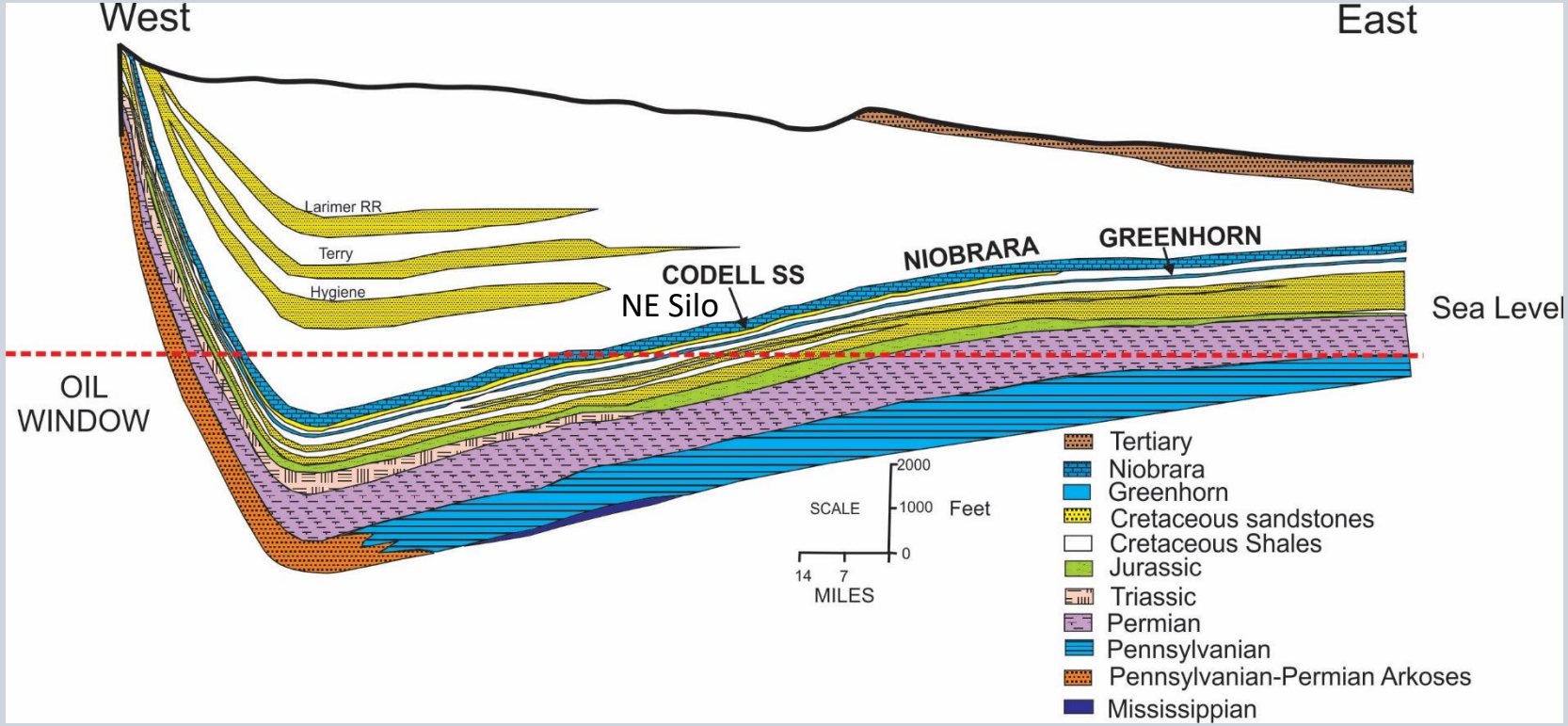
MS 2023

COLORADO SCHOOL OF MINES
MUDTOC

Outline

- Denver Basin cross section and geologic background
- Production update Cain 16-63-2-11-1CH
- Subsurface maps
- Facies distribution and description
- Core analysis and XRD
- Future work

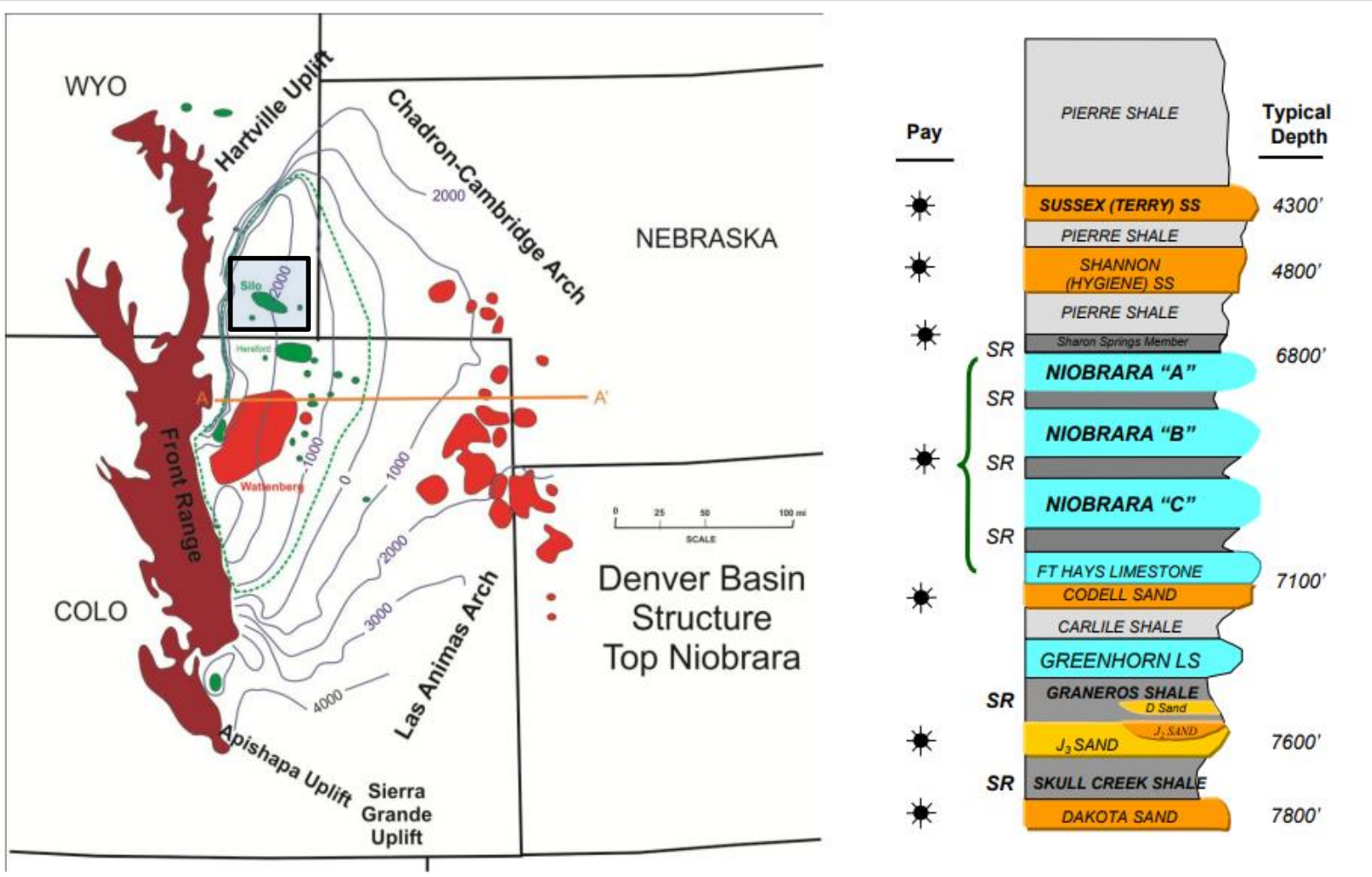
Typical Cross Section – Denver Basin



(Sonnenberg 2015)

- 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
- Formations shallowly dip to the west in the eastern portion of the basin

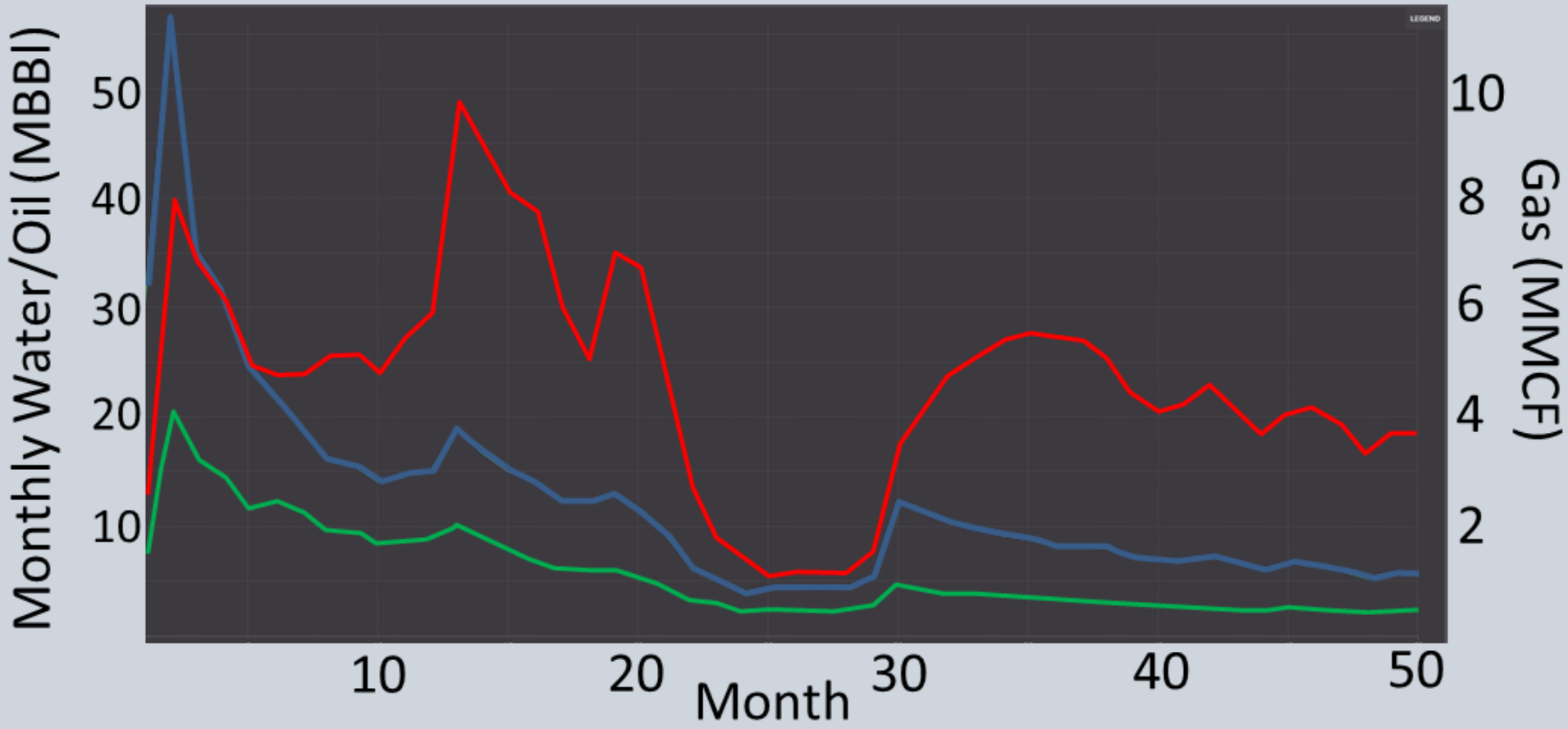
Location and Stratigraphy – Denver Basin



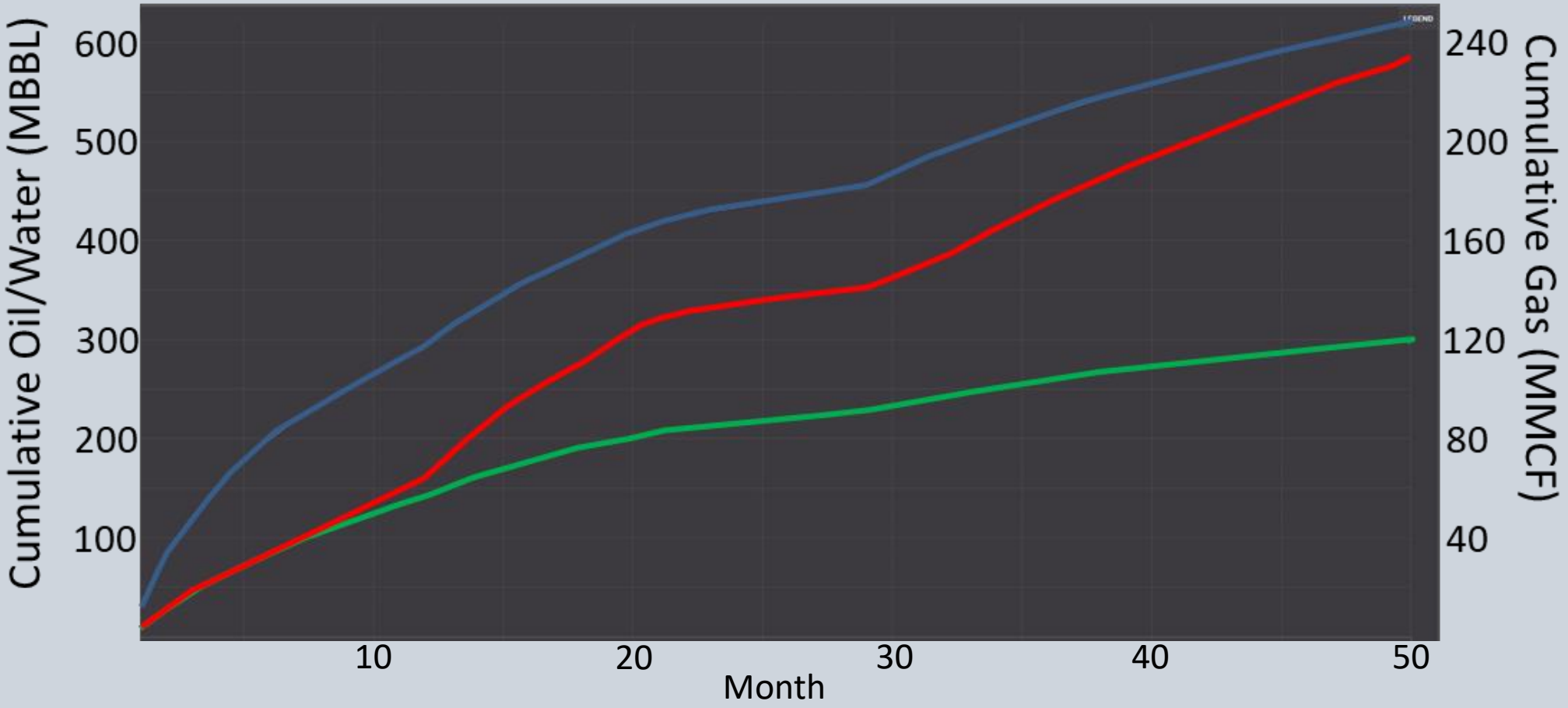
(Sonnenberg 2011)

- 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

Monthly Production – Cain 16-63-2-11-1CH

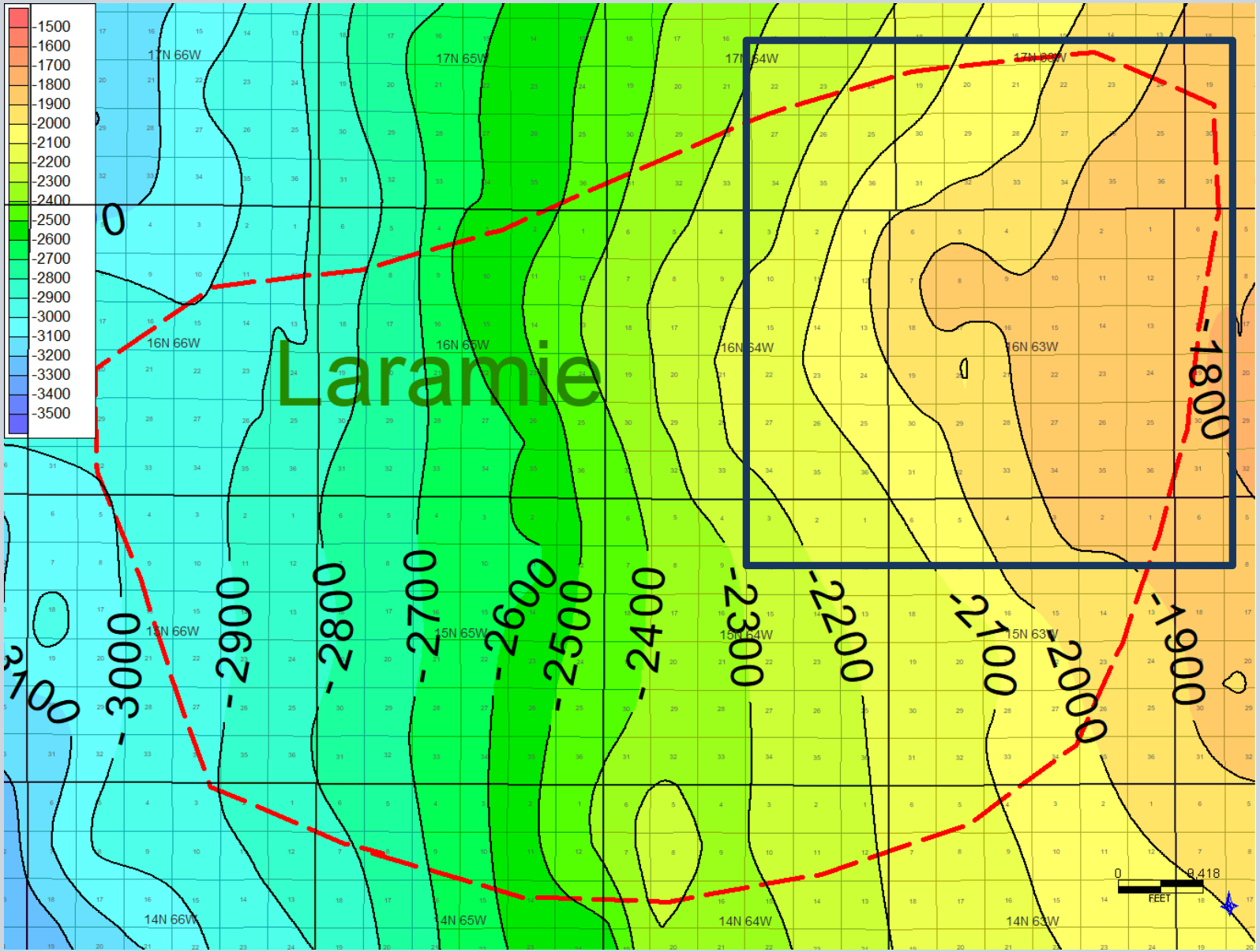


Cumulative Production – Cain 16-63-2-11-1CH



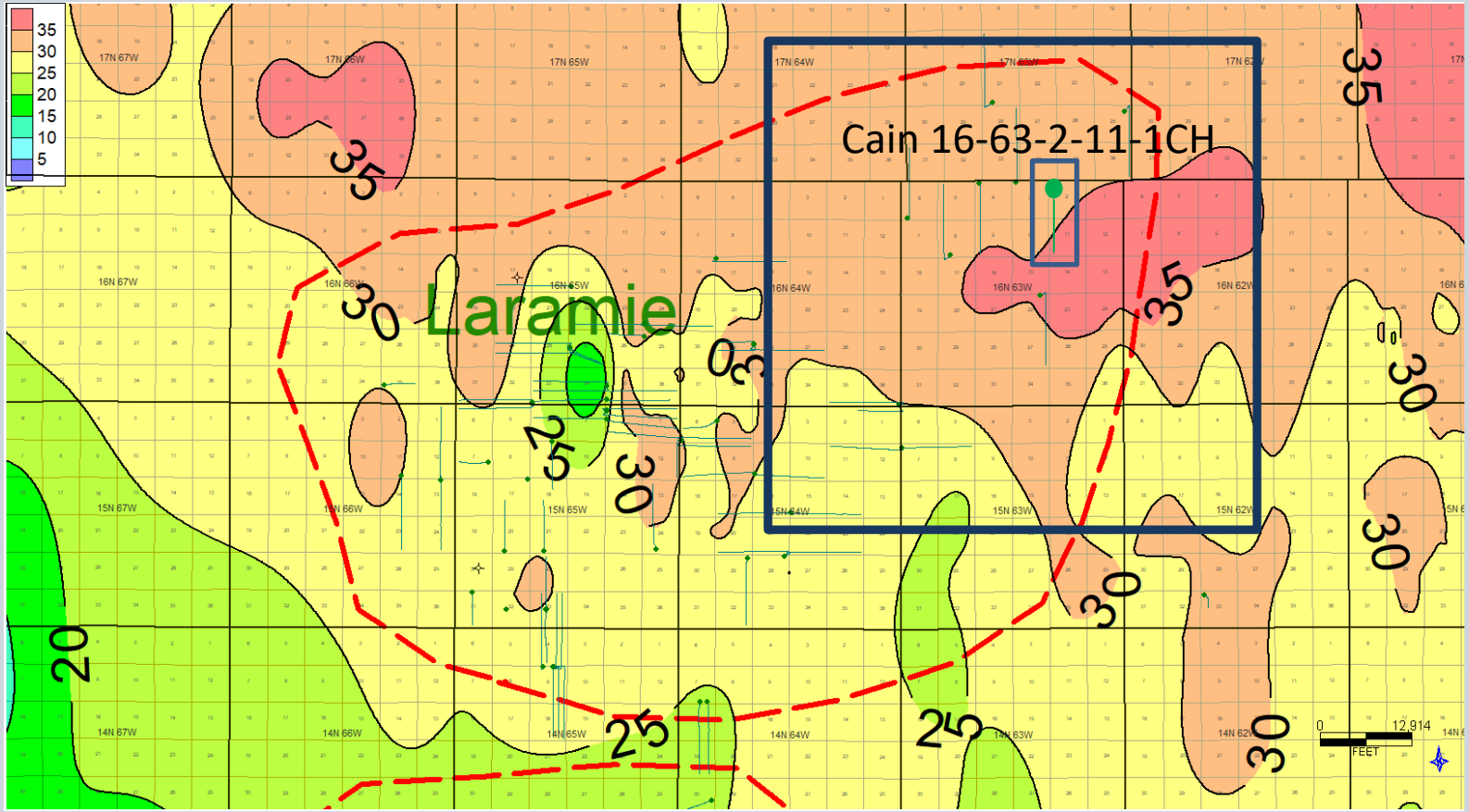
Oil: 300,000 BBl
Gas: 240 MMCF
Water: 600,000 BBl

Codell Structure Map (SS) – Silo Field



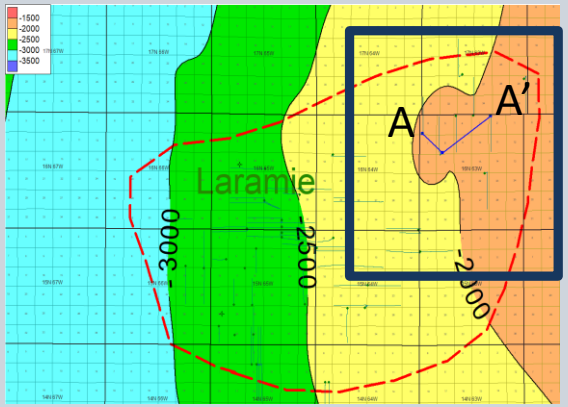
- Codell subsea depth in Silo Field ranges from approximately -2000 to -3000 feet , with subsea depth in NE Silo Field near -2000 feet
- Follows general structure of Denver Basin
- Silo Field sits on the eastern part of the basin, so the Codell dips gently to the west

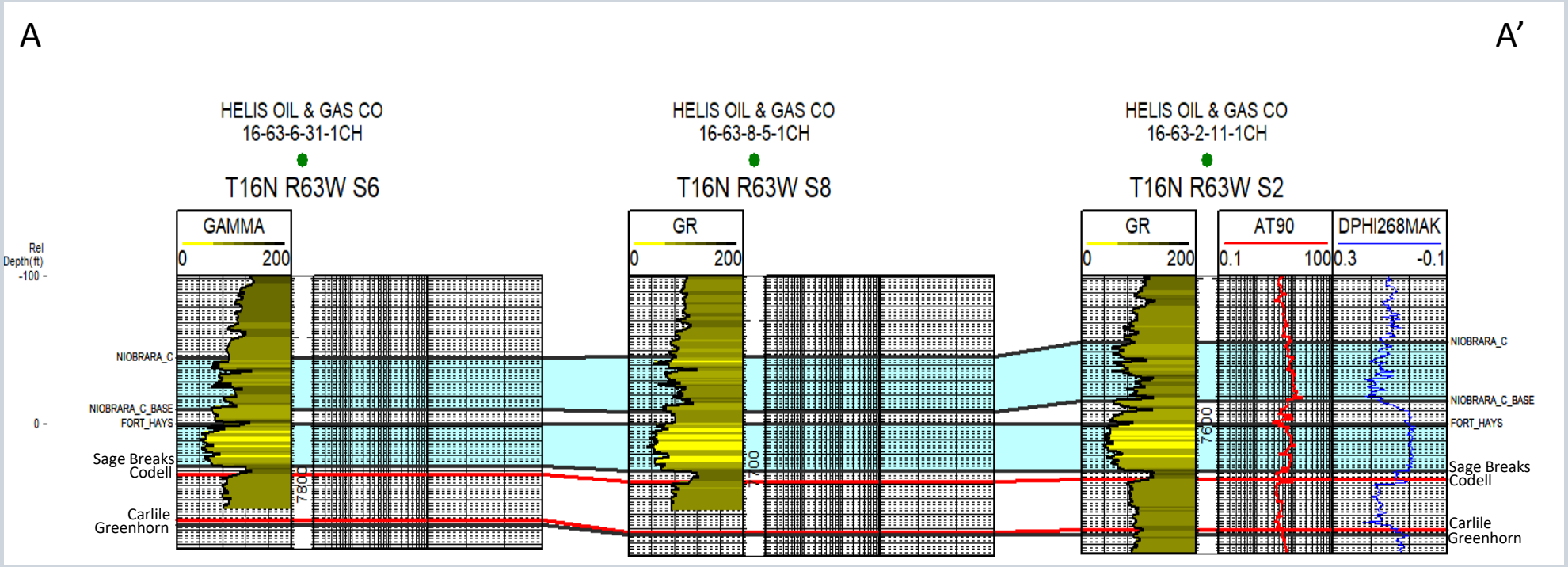
Codell Isopach Map – Silo Field



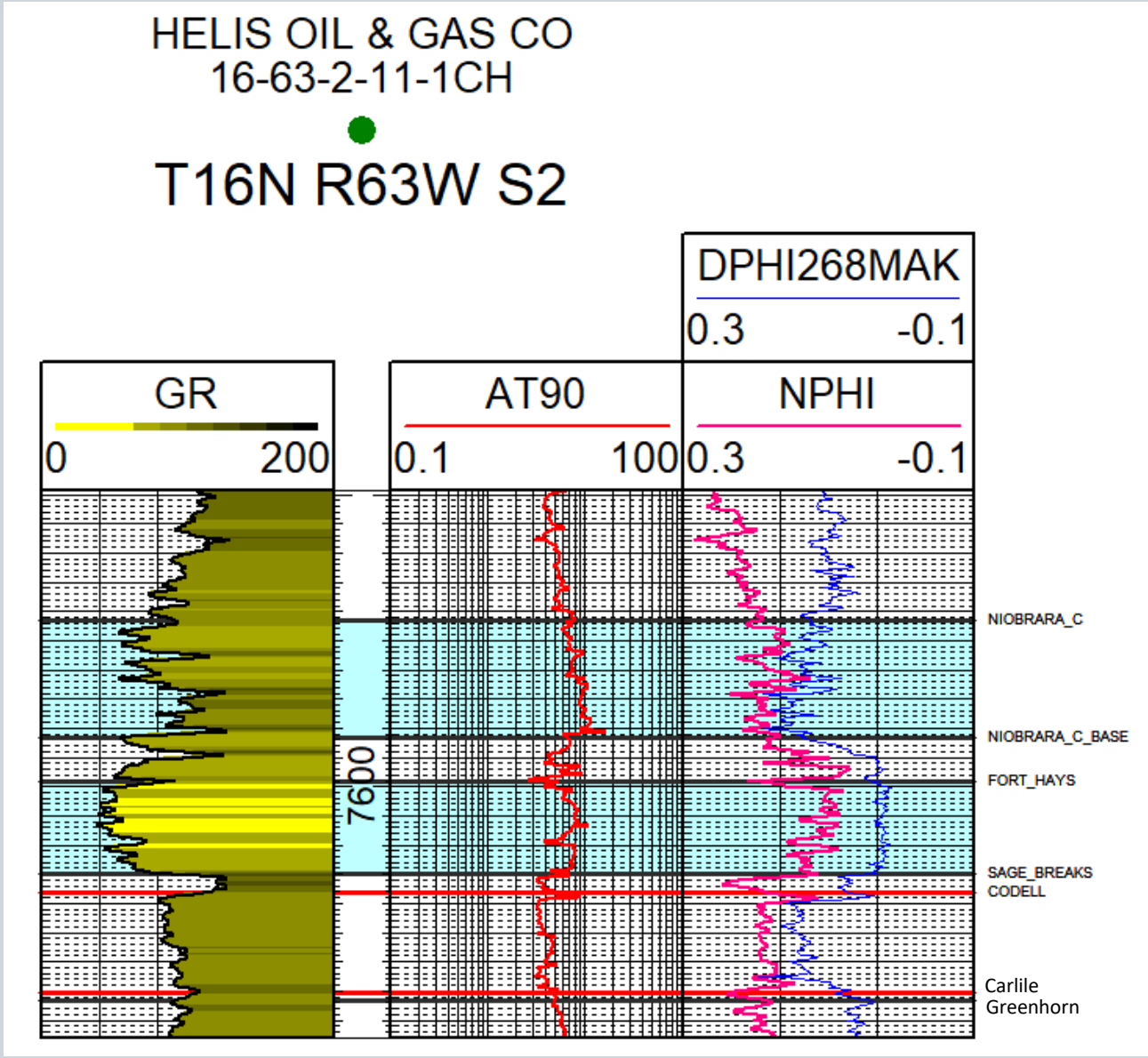
- Codell approximately 25-30 feet thick in Silo Field
- 30 feet thick in NE Silo Field
- Thickens to the north

Cross Section – NE Silo Field

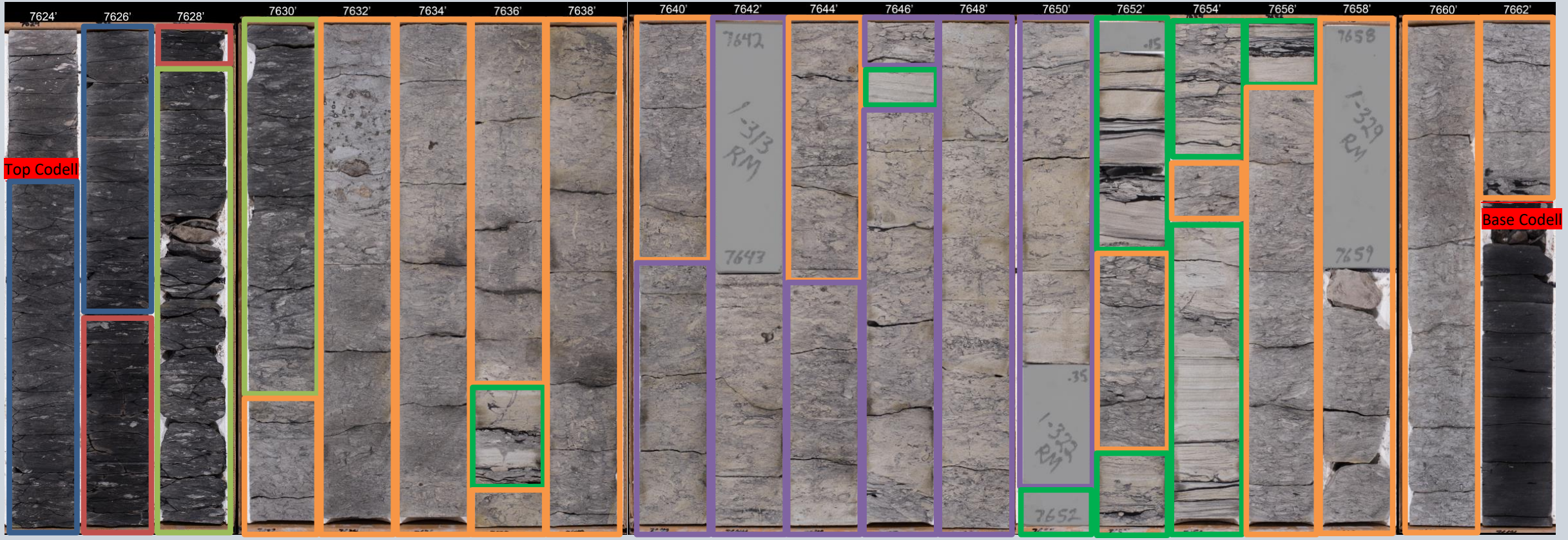




Cain 16-63-2-11-1CH



Facies Distribution



Facies 1 - Sandy Siltstone

Facies 2 - Shale

Facies 3 - Sandy Siltstone

Facies 4 - Silty Sandstone

Facies 5 - Low Angle Cross Strat.

Facies 6 – Silty Sandstone

Core Facies Description

Facies 1

- Very fine-grained Sandy siltstone, poorly sorted, heavily bioturbated, with inoceramid fragments, with pyrite nodules, not oil stained under UV light

Core Facies Description

Facies 2

- Mudrock with mostly clay sized particles, some burrows are filled with very fine sand, with vertical fractures

Core Facies Description

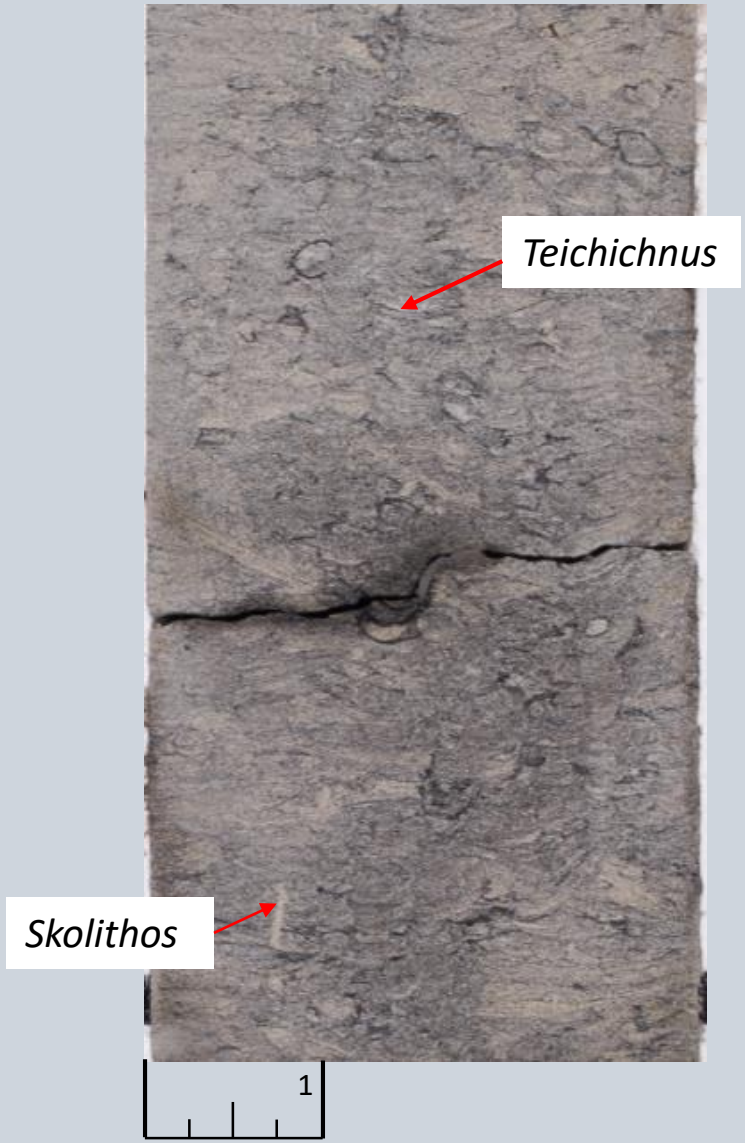
Facies 3

- Very fine-grained Sandy siltstone, poorly sorted, heavily bioturbated, with inoceramid fragments, with pyrite nodules, not oil stained under UV light, higher sand content than Facies 1

Core Facies Description

Facies 4

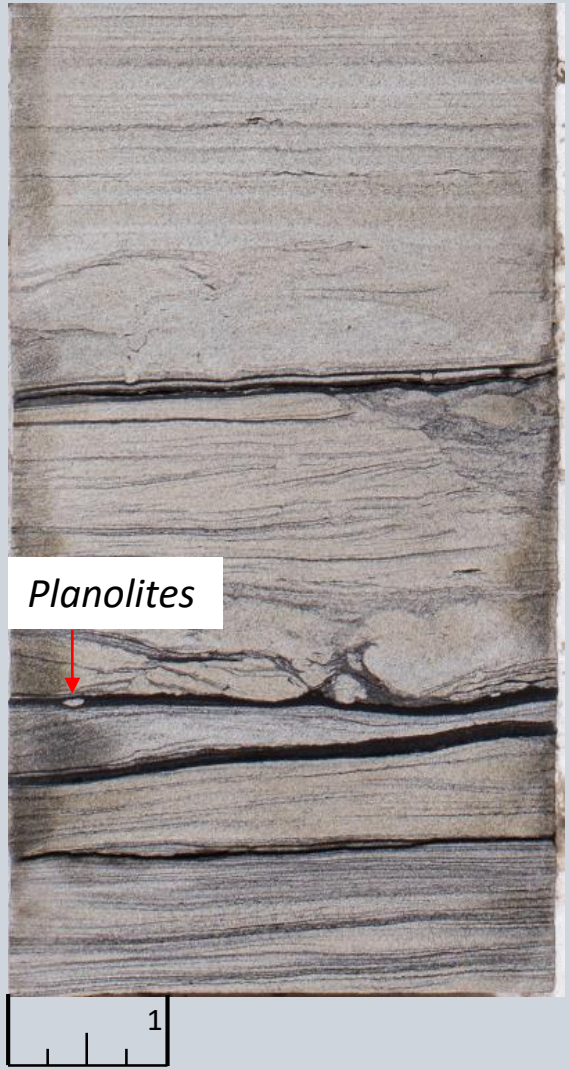
- Heavily bioturbated, very fine-grained silty sandstone, poorly sorted, with Teichichnus and Skolithos burrows, shows oil staining in core



Core Facies Description

Facies 5

- Low angle cross stratified to ripple stratified very fine-grained sandstone, moderate to well-sorted, with organic rich shale beds and clay drapes, with Planolites and Skolithos burrows, shows avid oil staining

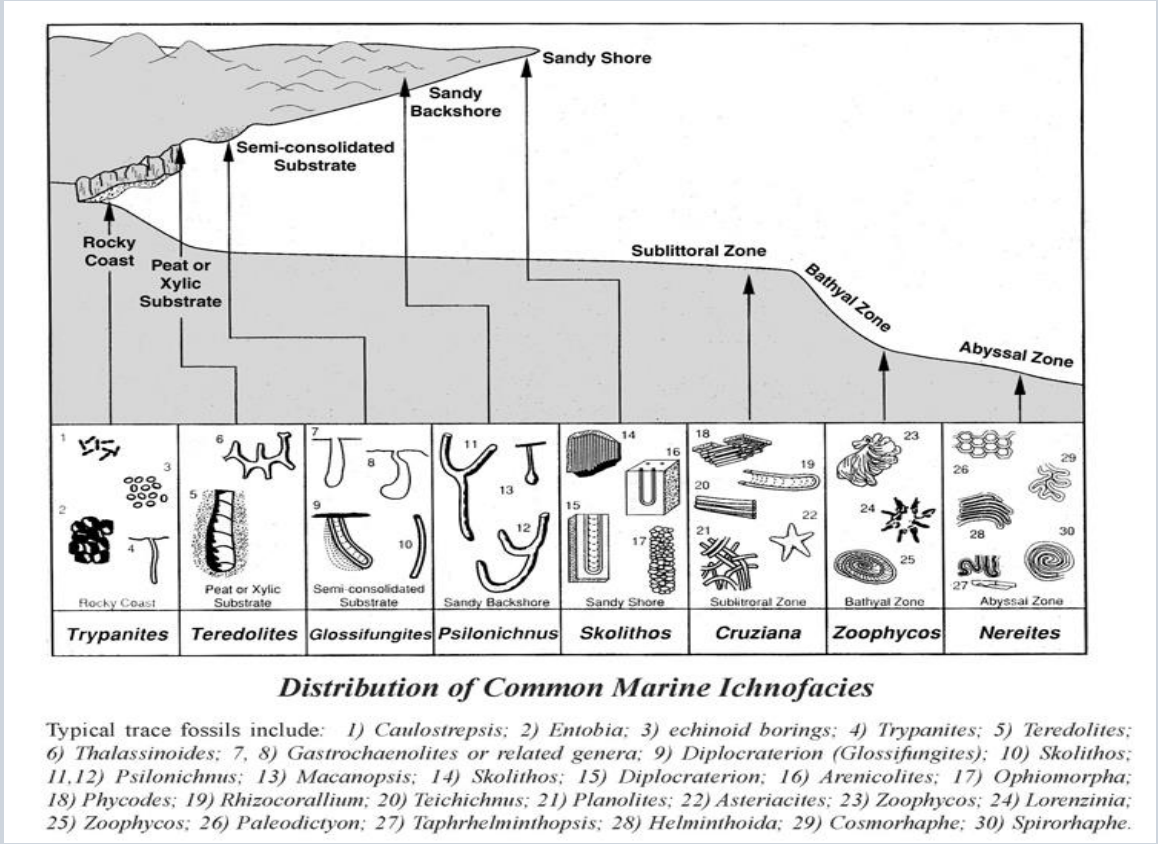


Core Facies Description

Facies 6

- Very fine-grained silty sandstone, moderately poorly sorted, heavily bioturbated, with a higher sand content than Facies 4, shows heavier oil staining than Facies 4 under UV light

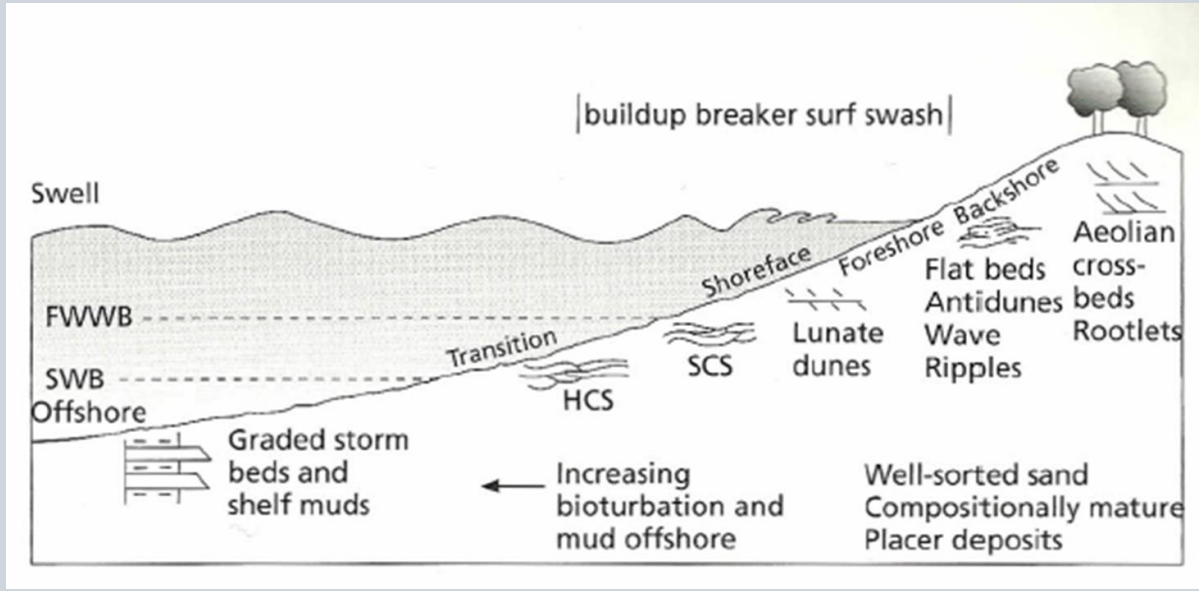
Depositional Environment



Distribution of Common Marine Ichnofacies

Typical trace fossils include: *1) Caulostrepsis; 2) Entobia; 3) echinoid borings; 4) Trypanites; 5) Teredolites; 6) Thalassinoides; 7, 8) Gastrochaenolites or related genera; 9) Diplocraterion (Glossifungites); 10) Skolithos; 11,12) Psilonichnus; 13) Macanopsis; 14) Skolithos; 15) Diplocraterion; 16) Arenicolites; 17) Ophiomorpha; 18) Phycodes; 19) Rhizocorallium; 20) Teichichnus; 21) Planolites; 22) Asteriacites; 23) Zoophycos; 24) Lorenzinia; 25) Zoophycos; 26) Paleodictyon; 27) Taphrhelminthopsis; 28) Helminthoida; 29) Cosmorhaphe; 30) Spirorhaphe.*

Seilacher, 2007

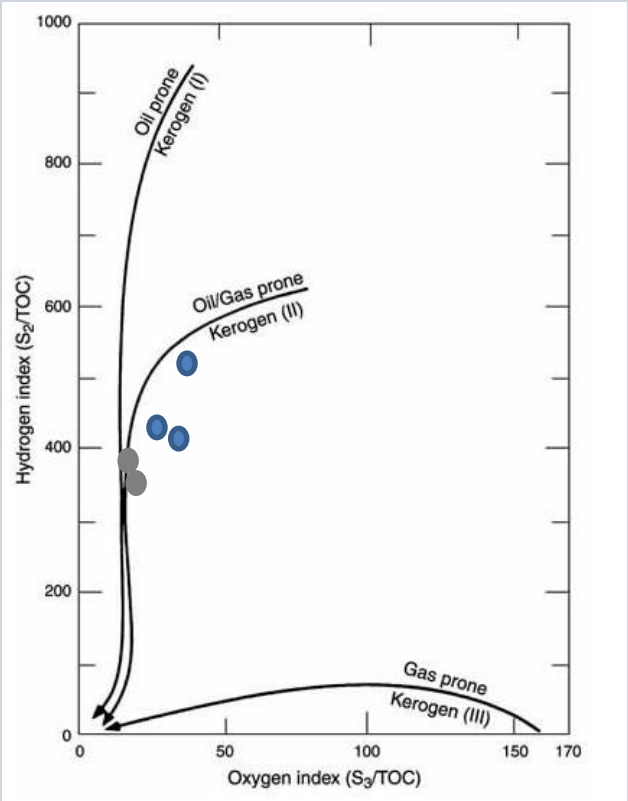


Tucker, 2007

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

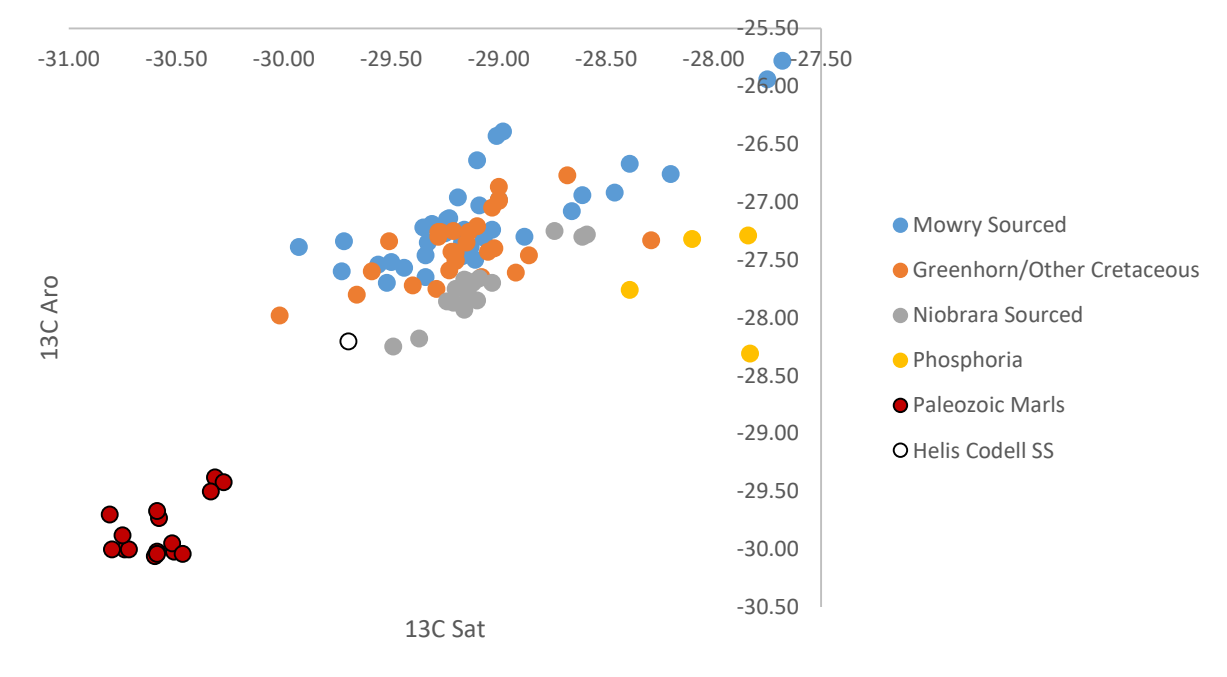
GeoMark Geochem Analysis

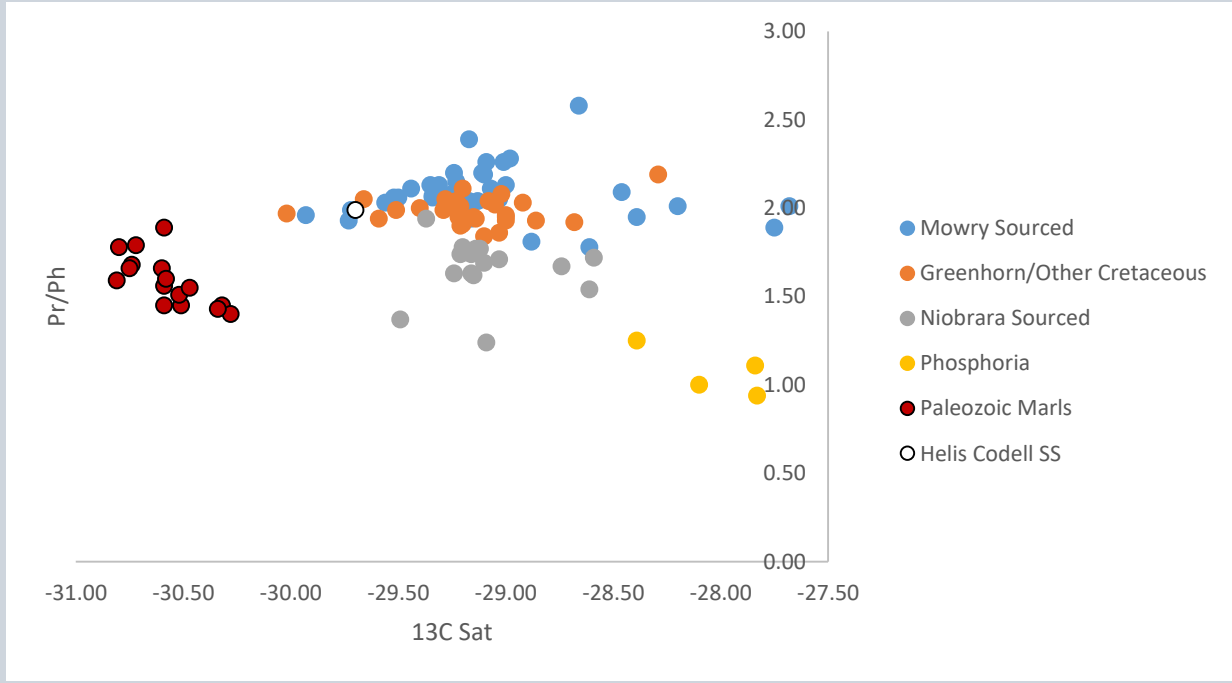
GeoMark ID	Well Name	Helis Sample ID	Sample Type	Formation	Depth 1 (ft)	Depth 2 (ft)
RHOG-191002-001	Sandberg 16-63-6-31-1CH	49-021-23965	Oil	Codell Sandstone		
RHOG-191002-002	Cain 16-32-2-11-1CH	49-021-23371	Oil	Codell Sandstone		
RHOG-191002-003	Lerwick 17-63-21-16-1CH	49-021-24013	Oil	Codell Sandstone		

Oil GC Ratios	Sandberg 16-63-6-31-1CH	Cain 16-32-2-11-1CH	Lerwick 17-63-21-16-1CH
Pristane / Phytane	1.99	2.01	1.91
Pristane / n C17	0.68	0.67	0.67
Phytane / n C18	0.39	0.39	0.41
n C18 / (n C18 + n C19)	0.52	0.52	0.53
n C17 / (n C17 + n C27)	0.74	0.75	0.75
Carbon Preference Index	1.02	1.02	1.00

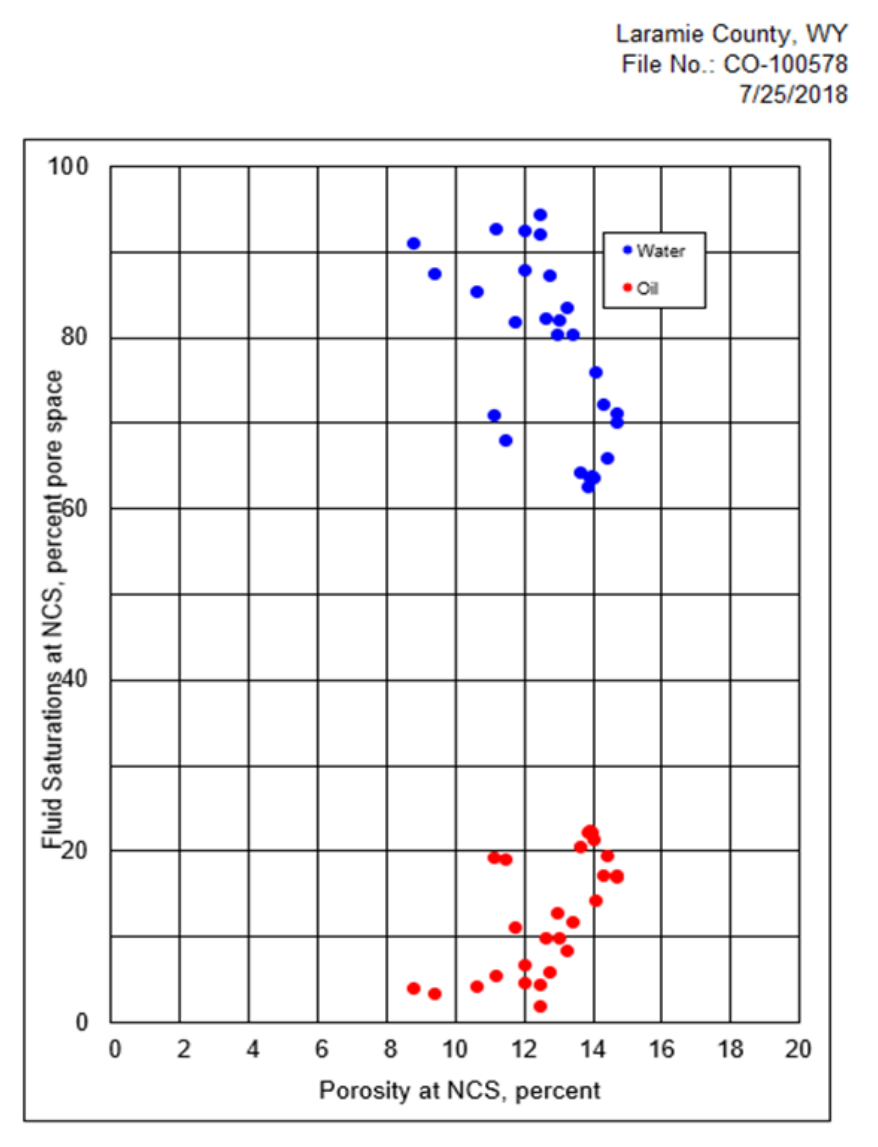
- In total, three produced oils were analyzed using high resolution gas chromatography (HRGC)
- The three produced oils were from the Codell Sandstone

GeoMark Denver Basin Database



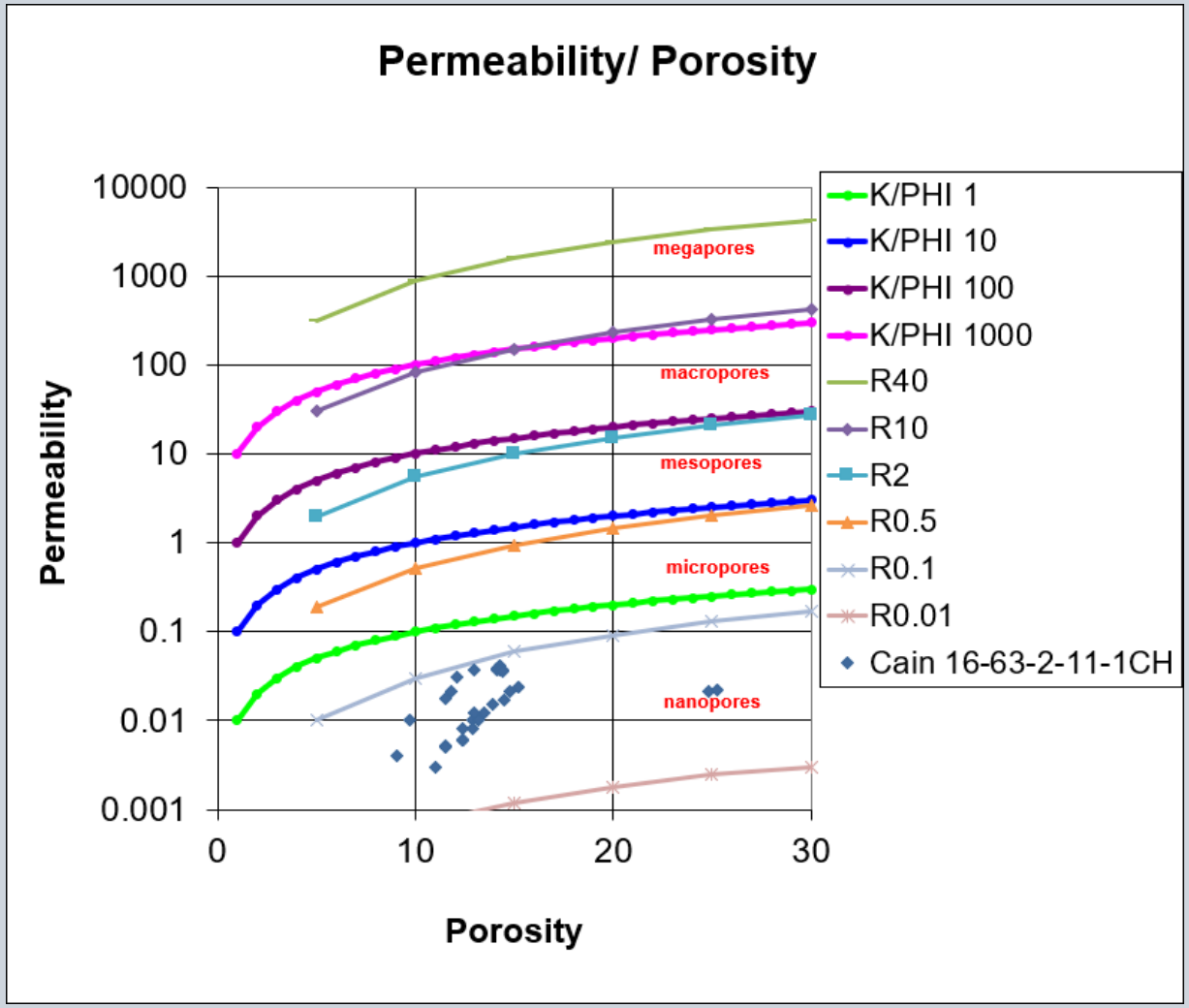


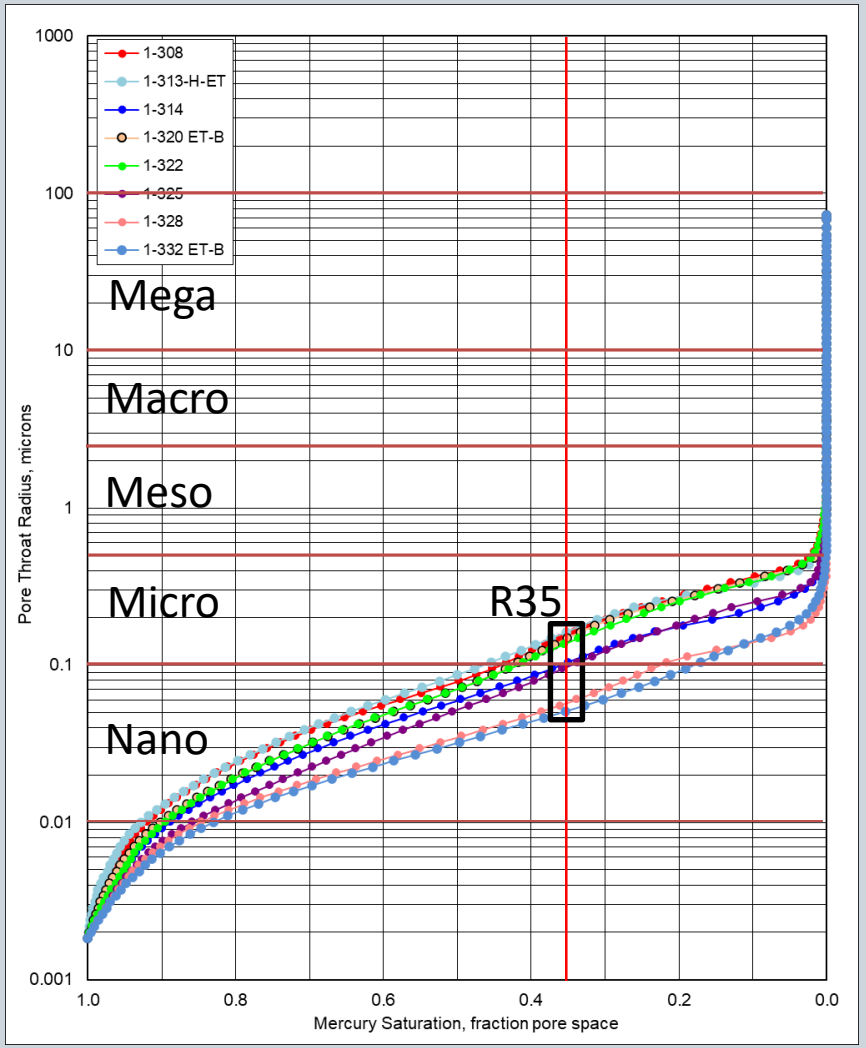
Porosity Versus Fluid Saturations - Core



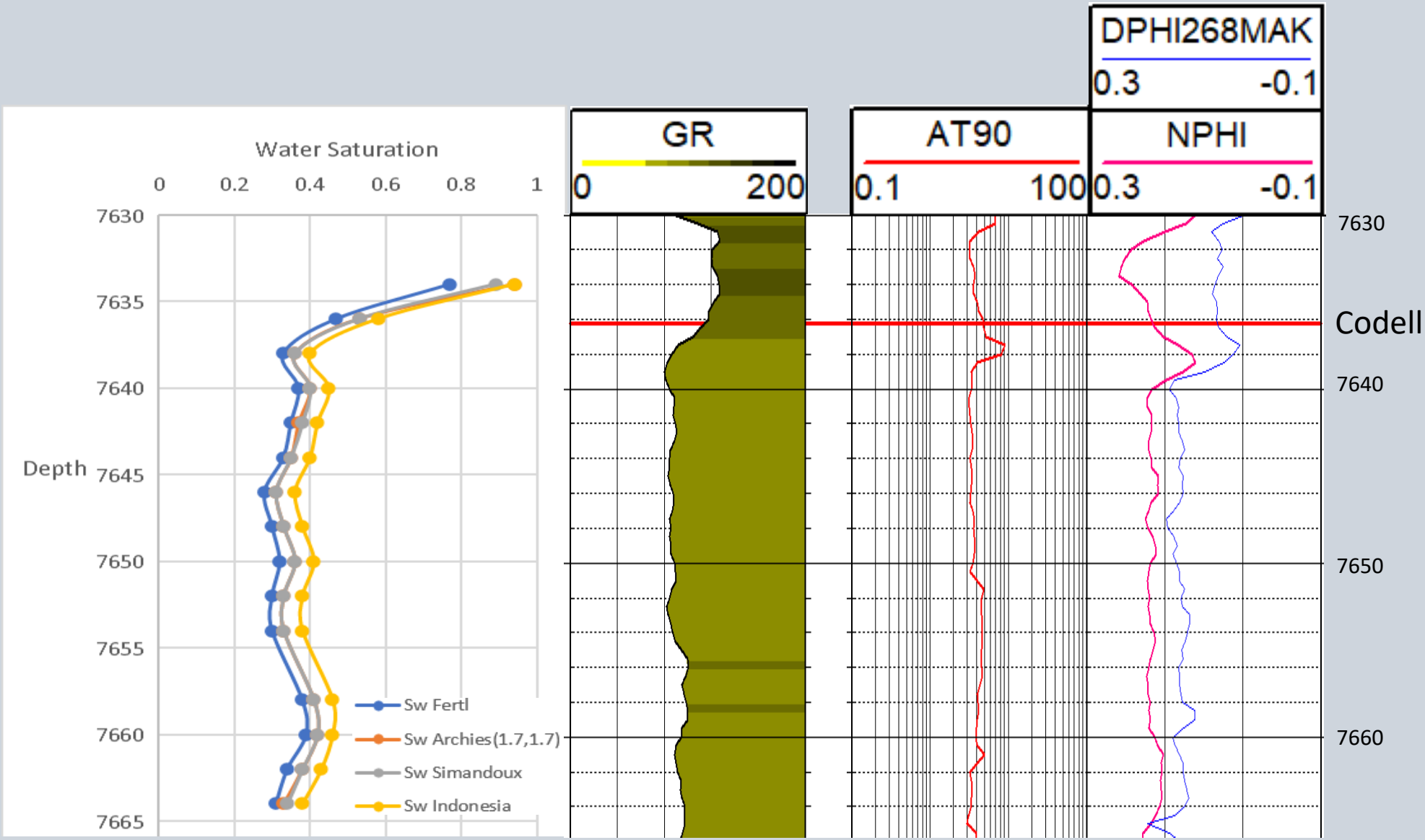
- Fluid Saturation vs. Porosity indicates a porosity range of approximately 12 - 15% for oil and water saturated pore spaces

MICP

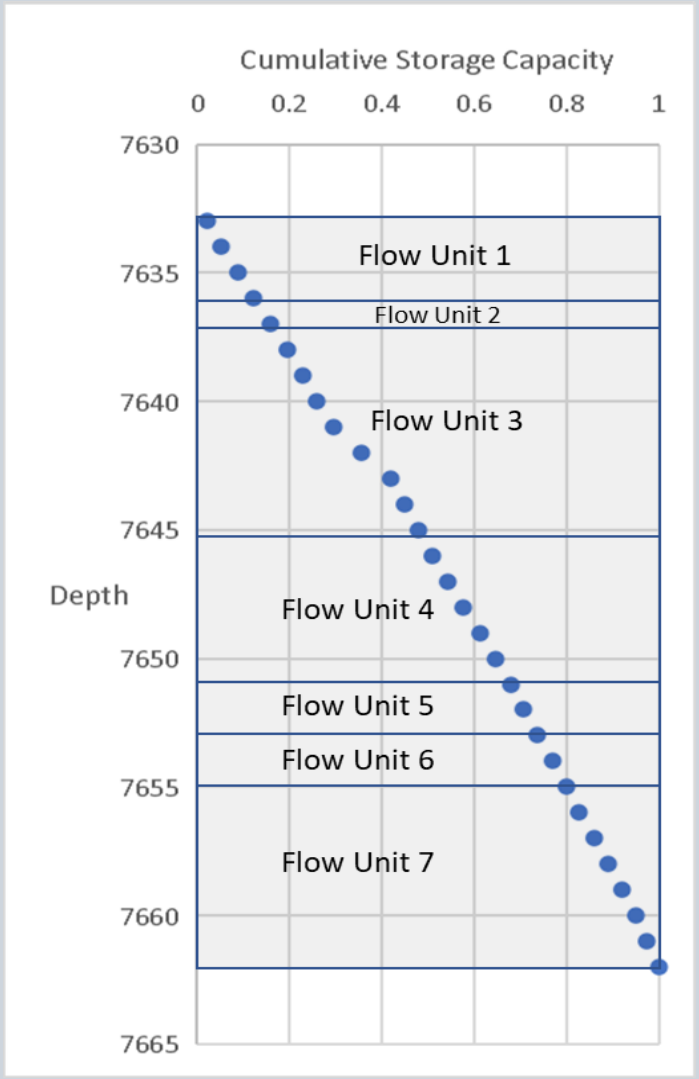

Permeability/ Porosity
Permeability
10000
1000
100
10
1
0.1
0.01
0.001
0
10
20
30
Porosity
megapores
macropores
mesopores
micropores
nanopores
K/PHI 1
K/PHI 10
K/PHI 100
K/PHI 1000
R40
R10
R2
R0.5
R0.1
R0.01
Cain 16-63-2-11-1CH

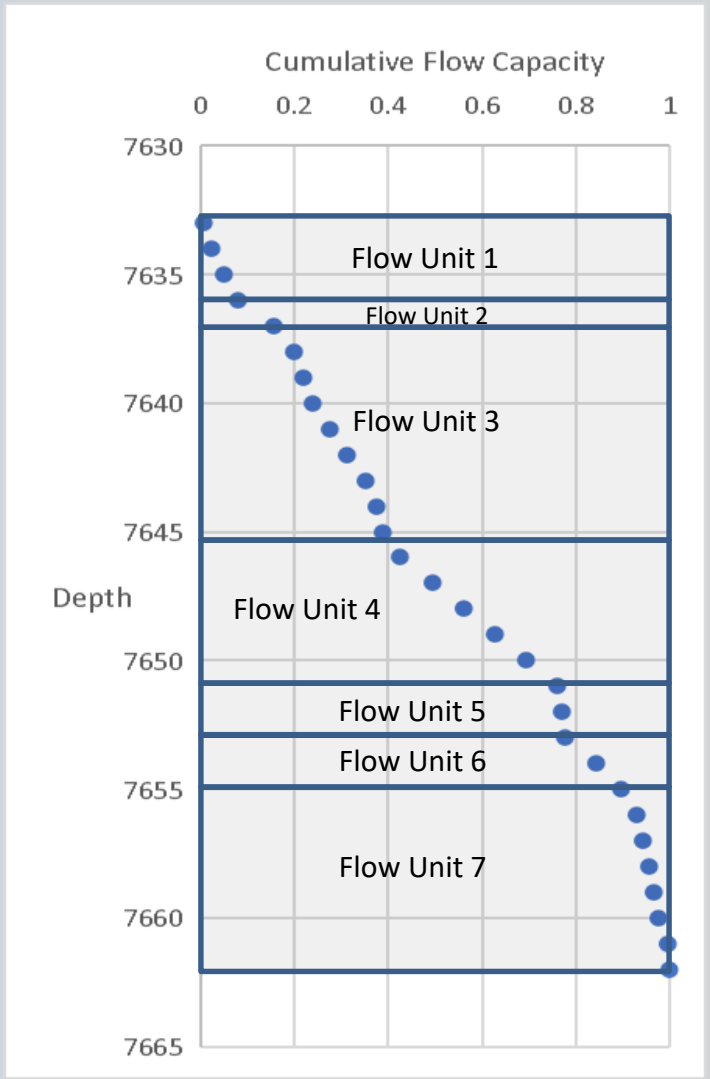

1-308
1-313-H-ET
1-314
1-320 ET-B
1-322
1-325
1-328
1-332 ET-B
Mega
Macro
Meso
Micro
Nano
R35
Pore Throat Radius, microns
1000
100
10
1
0.1
0.01
0.001
1.0
0.8
0.6
0.4
0.2
0.0
Mercury Saturation, fraction pore space

Water Saturation

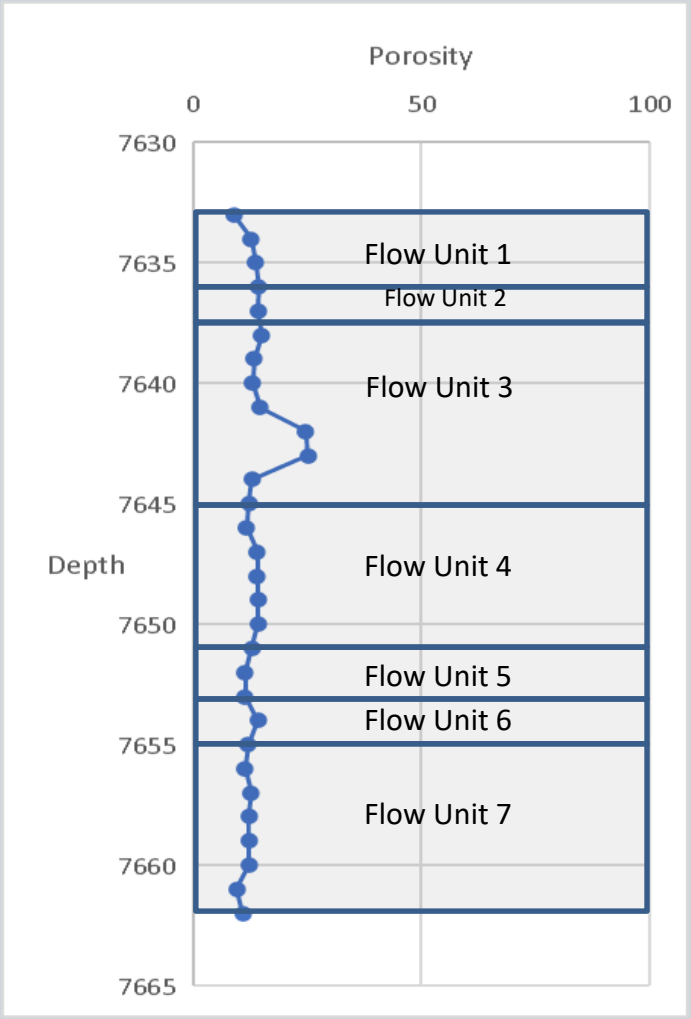


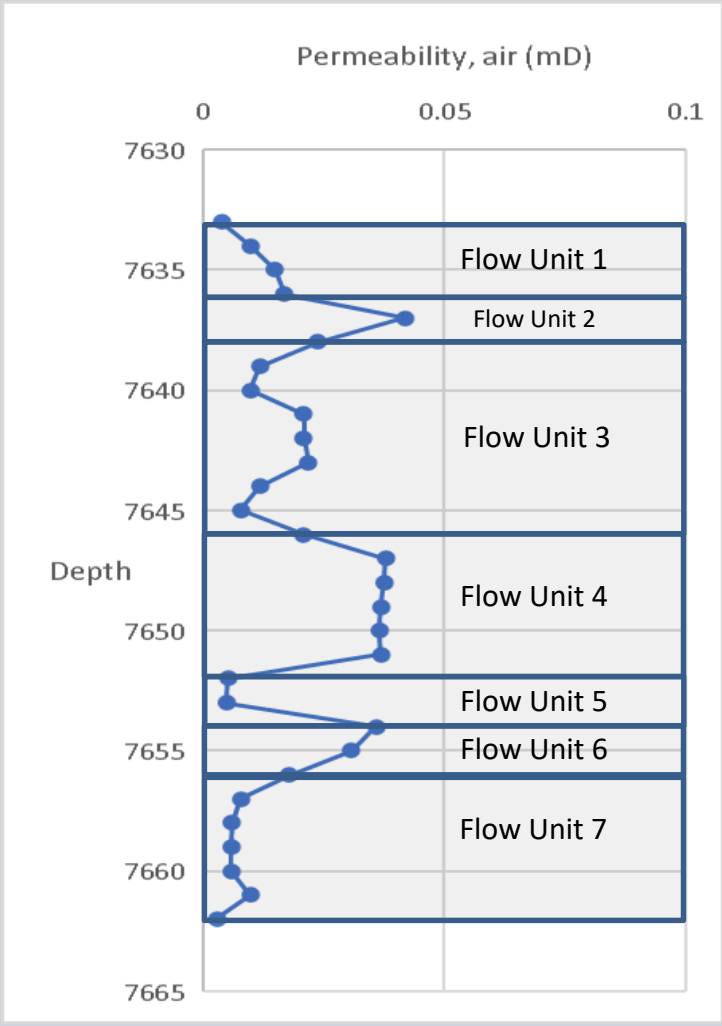
Flow Capacity and Storage Capacity Vs. Depth



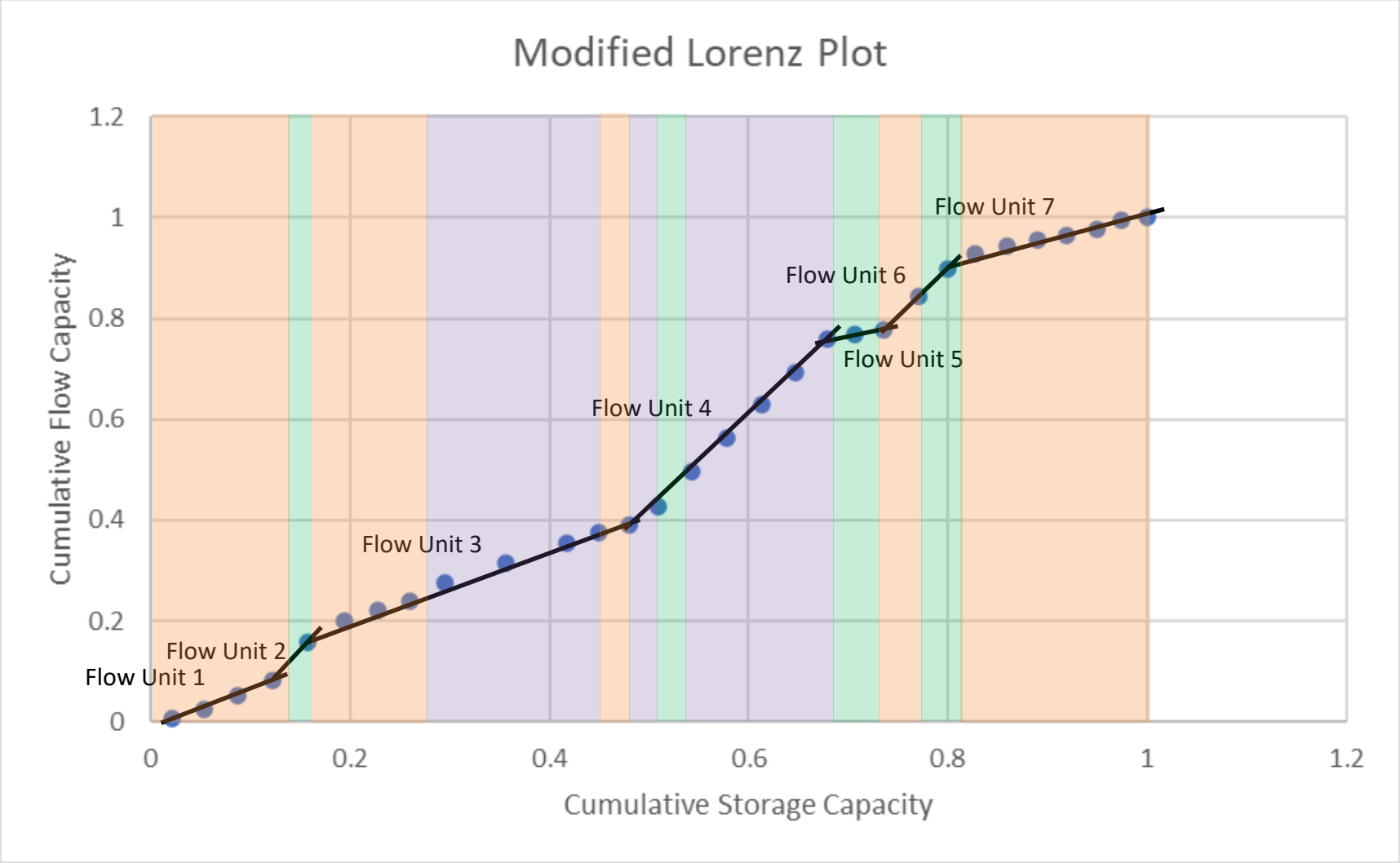


Porosity and Permeability Vs. Depth





Flow Units



F4, Sandy Siltstone

F5, Low Angle Cross Strat.

F6, Sandy Siltstone, Higher Sand Content

XRD (Weight%) – Codell

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^
1-248P	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

Future Work

- XRF analysis (core scanned with 6-inch resolution)
- Thin Section and FESEM analysis based on interpreted facies in the Cain 16-63-2-11-1CH core
- Detailed core descriptions from the Cirque V.O. Child #30-9 and Cirque Berry Unit 13-9 wells stored at the USGS CRC
- SRA work on shale-rich intervals within the cored Codell interval
- Detailed resistivity mapping to help delineate the edge of production in NE Silo Field

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