Reservoir Quality Controls on Tight-Gas Sand Productivity Insights from the Canyon Creek Field, Sweetwater County, Wyoming*

Brent W. Greenhalgh[1]

Search and Discovery Article #20469 (2019)**
Posted December 11, 2019

*Adapted from oral presentation given at 2019 AAPG Rocky Mountain Section Meeting, Cheyenne, Wyoming, September 15-18, 2019
 DOI:10.1306/20469Greenhalgh2019

[1]Wexpro Company, Provo, Utah (brent.greenhalgh@dominionenergy.com)

Abstract

The Canyon Creek Field is a Laramide-age four-way closure draped with gas-charged Almond Formation sandstones. Gas production from the Almond Formation sandstones does not conform to a simple accumulation model with uniform charge to a structural spill point. For economic field development to proceed, a more detailed understanding of the controls on this complex production behavior is required.

Two cores were cut in the same parasequence (one updip, one downdip) to understand the reservoir quality controls on production variability. Initial production from the updip well had a cored zone IP of 300 mcfd based on production logs, while the downdip zone IP was 44 mcfd. Core analyses demonstrate that routine porosity and Dean Stark water saturations are indistinguishable from an updip to a downdip position. Grain size and facies are generally consistent between the two cores. Routine permeability data fall within the same range.

Each well had a high and low porosity sample selected for porous plate capillary pressure tests. Each sample was drained to 400 PSI and the relative permeability to gas (Krg) was measured at the endpoint saturation of the test. For the high porosity samples, the updip well has a Krg that is three orders of magnitude higher than the downdip well. Average grain size in the updip sample is medium, while in the downdip sample the average grain size is fine. Thin section analysis demonstrates that the updip sample has a greater abundance of pores which are not occluded by diagenetic minerals, while the downdip sample has porosity that is mostly occluded by fibrous illite. Based on these data we demonstrate that the presence of diagenetic illite in the pore system has a strongly negative effect on Krg in the Canyon Creek Field, but negligible effect on other routine permeability measurements. We conclude that early gas charge into relatively high-quality reservoirs, with larger grain size and lower capillary entry pressure, prevented fibrous illite growth and preserved thin, higher permeability pathways in the reservoir, leading to improved flow rates. In the absence of early charge, reservoirs in downdip positions had significant fibrous illite growth which, when combined with the relatively high Almond Formation water saturation, led to sub-economic gas flow rates.

References Cited

DigitalGlobe 2011. Image USDA Farm Service Agency. Imagery Date July 4th, 2009.

Google Earth V 7.1.2.2041, October 7, 2013, Sweetwater County, Wyoming, 40° 59' 42.35" N, 108° 32' 23.69"W, Eye alt 33.49 miles.

Hendricks, M.L., 1994, Ravinement Surface Control on Hydrocarbon Accumulation in Transgressive Systems Tracts: Almond Formation, Green River Basin, Wyoming, *in* J.C. Dolson, M.L. Hendricks, and W.A. Wescott (eds.), Unconformity-Related Hydrocarbons in Sedimentary Sequences, A Guidebook for Petroleum Exploration and Exploitation in Clastic and Carbonate Sediments: Rocky Mountain Association of Geologists Guidebook, p. 209-218.

Johnson, R.C., T.M. Finn, and L.N.R. Roberts, 2005, Chapter 8 - The Mesaverde Total Petroleum System, Southwestern Wyoming Province, *in* USGS Southwestern Wyoming Province Assessment Team (compilers), Petroleum Systems and Geologic Assessment of Oil and Gas in the Southwestern Wyoming Province, Wyoming, Colorado, and Utah: US Geological Survey Digital Data Series DDS-69-D, 38 p.

Lander, R.H., and L.M. Bonnell, 2010, A Model for Fibrous Illite Nucleation and Growth in Sandstones: American Association of Petroleum Geologists Bulletin, v. 94/8, p. 1161-1187.

Lynds, R.M., and D.T. Lichtner, 2016, Stratigraphy and Hydrocarbon Potential of the Fort Union and Lance Formations in the Great Divide and Washakie Basins, South-Central Wyoming: Wyoming State Geological Survey Report of Investigations 73, 70 p., 2 pls.

Shanley, K.W., and R.M. Cluff, 2015, The Evolution of Pore-Scale Fluid-Saturation in Low-Permeability Sandstone Reservoirs: American Association of Petroleum Geologists Bulletin, v. 99/10, p. 1957-1990.

Tobin, R.C., T. McClain, R.B. Lieber, A. Ozkan, L.A. Banfield, A.M.E. Marchand, and L.E. McRae, 2010, Reservoir Quality Modeling of Tight Gas Sands in Wamsutter Field: Integration of Diagenesis, Petroleum Systems and Production Data: American Association of Petroleum Geologists Bulletin, v. 94/8, p. 1229-1266. doi:10.1306/04211009140

Reservoir Quality Controls on Tight-Gas Sand Productivity

Insights from the Canyon Creek Field, Sweetwater County, Wyoming

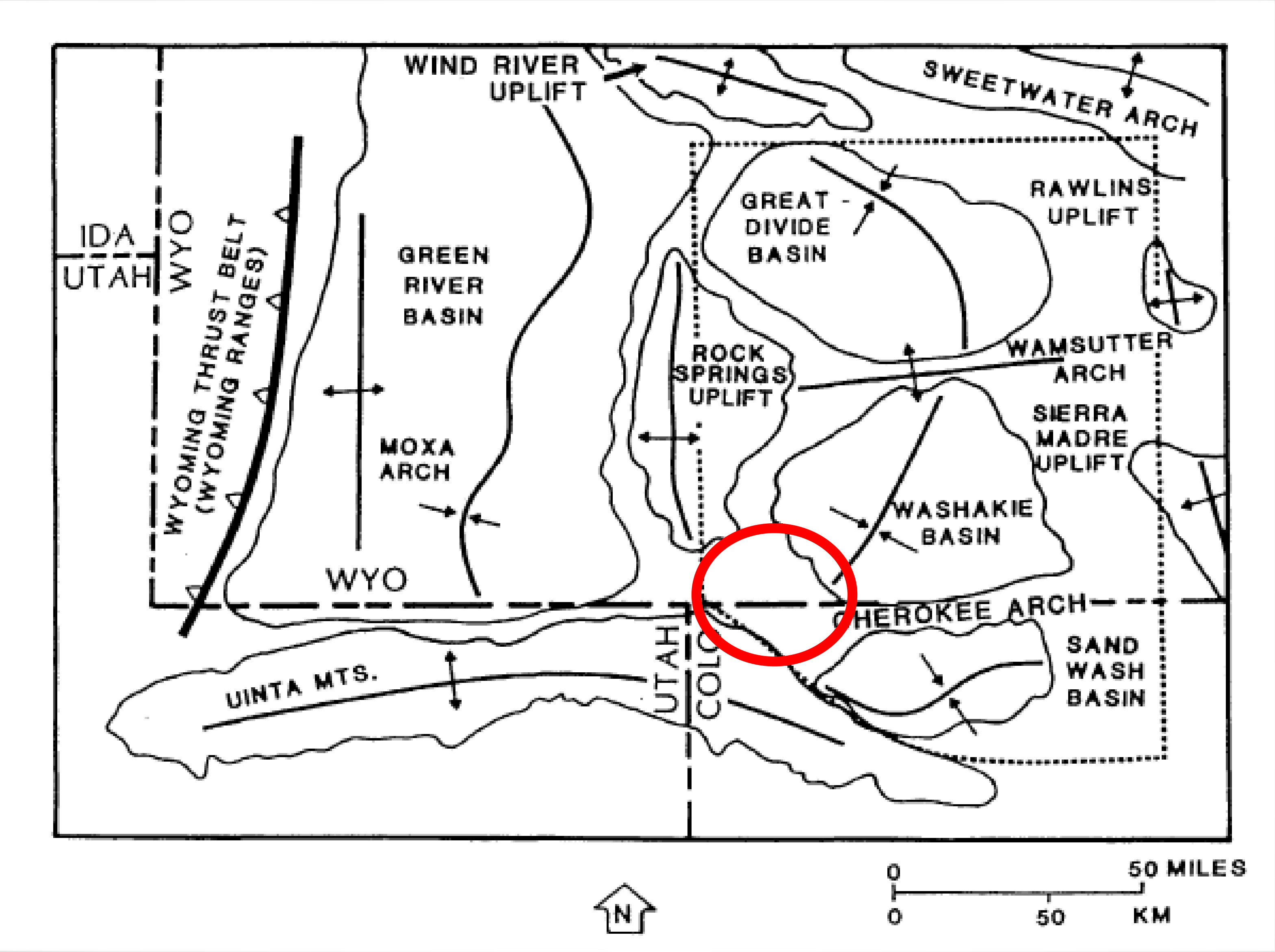
Brent W. Greenhalgh

Acknowledgements

Core Lab

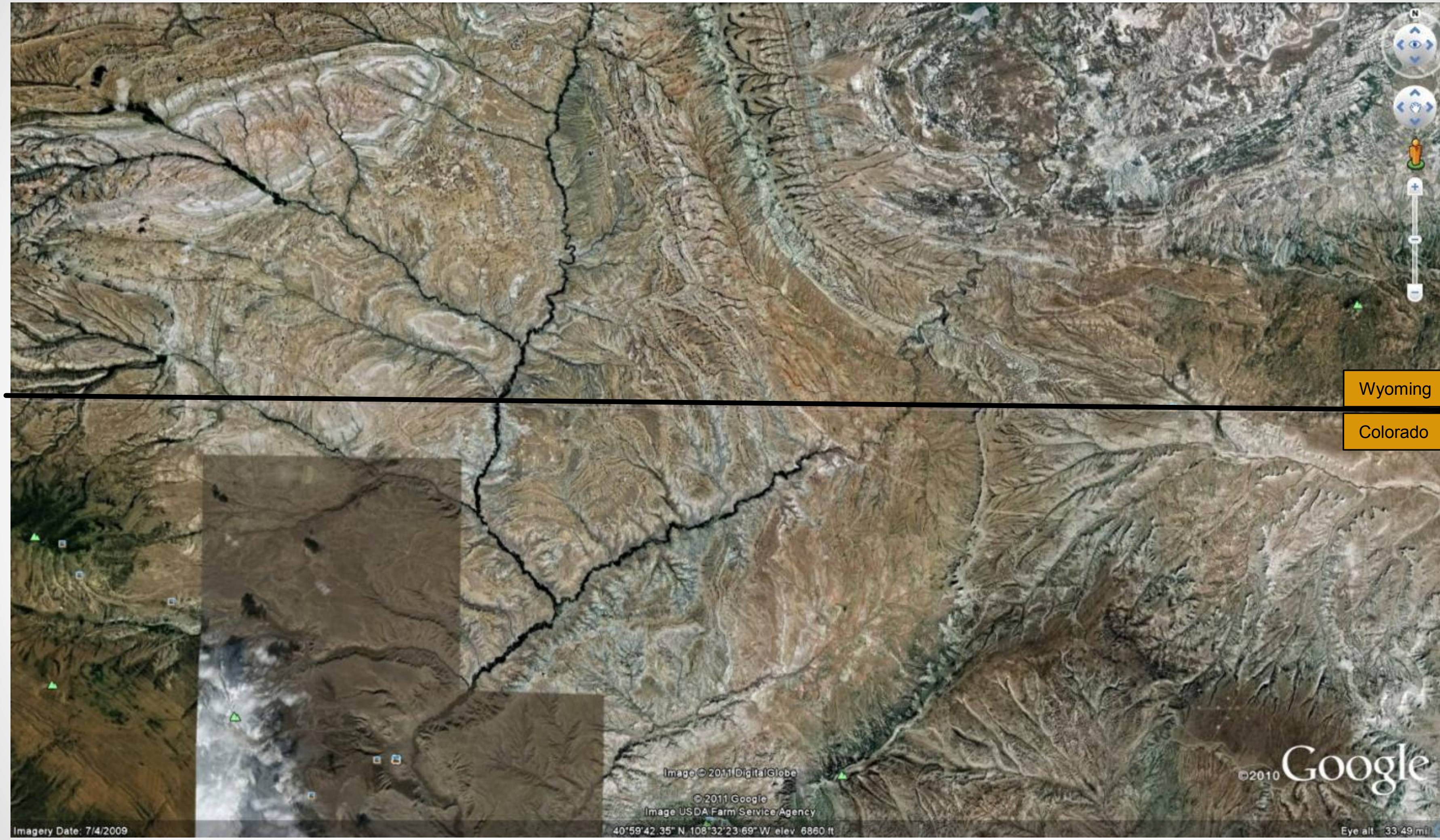
STRATUM
RESERVOIR

Vermillion Basin



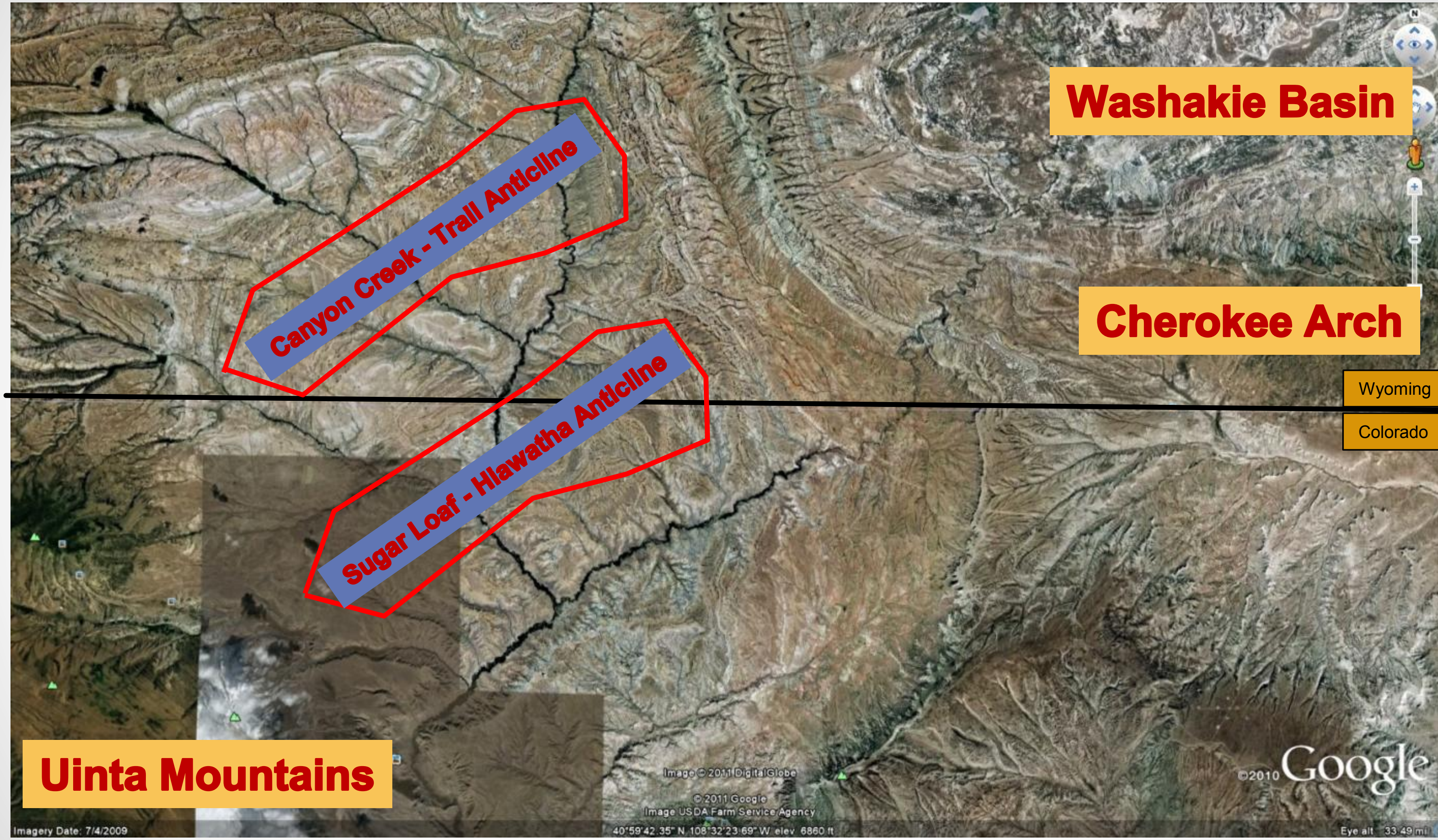
Modified after Hendricks, 1994

Vermillion Basin Satellite Image



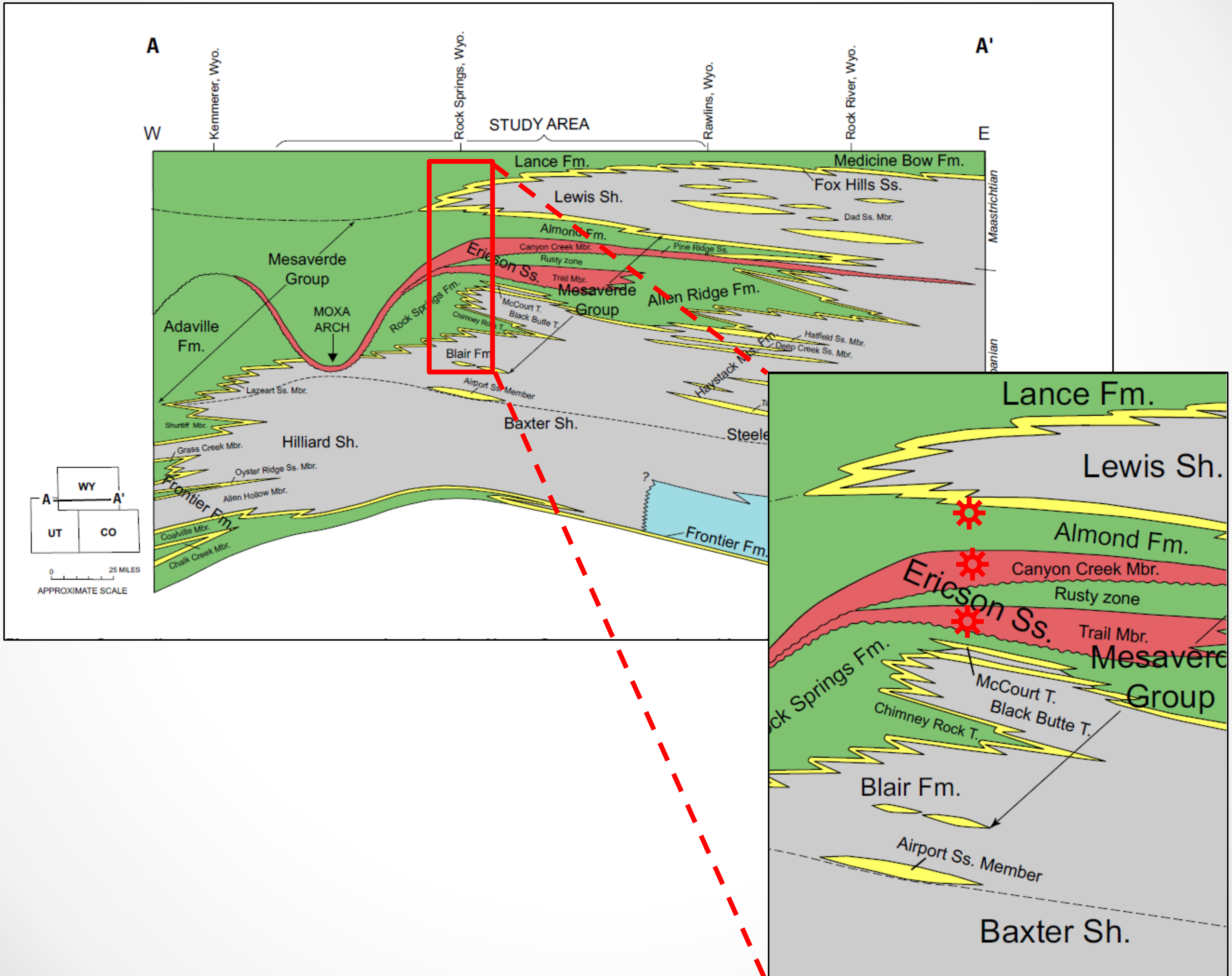
Google Earth, 2016

Vermillion Basin Satellite Image



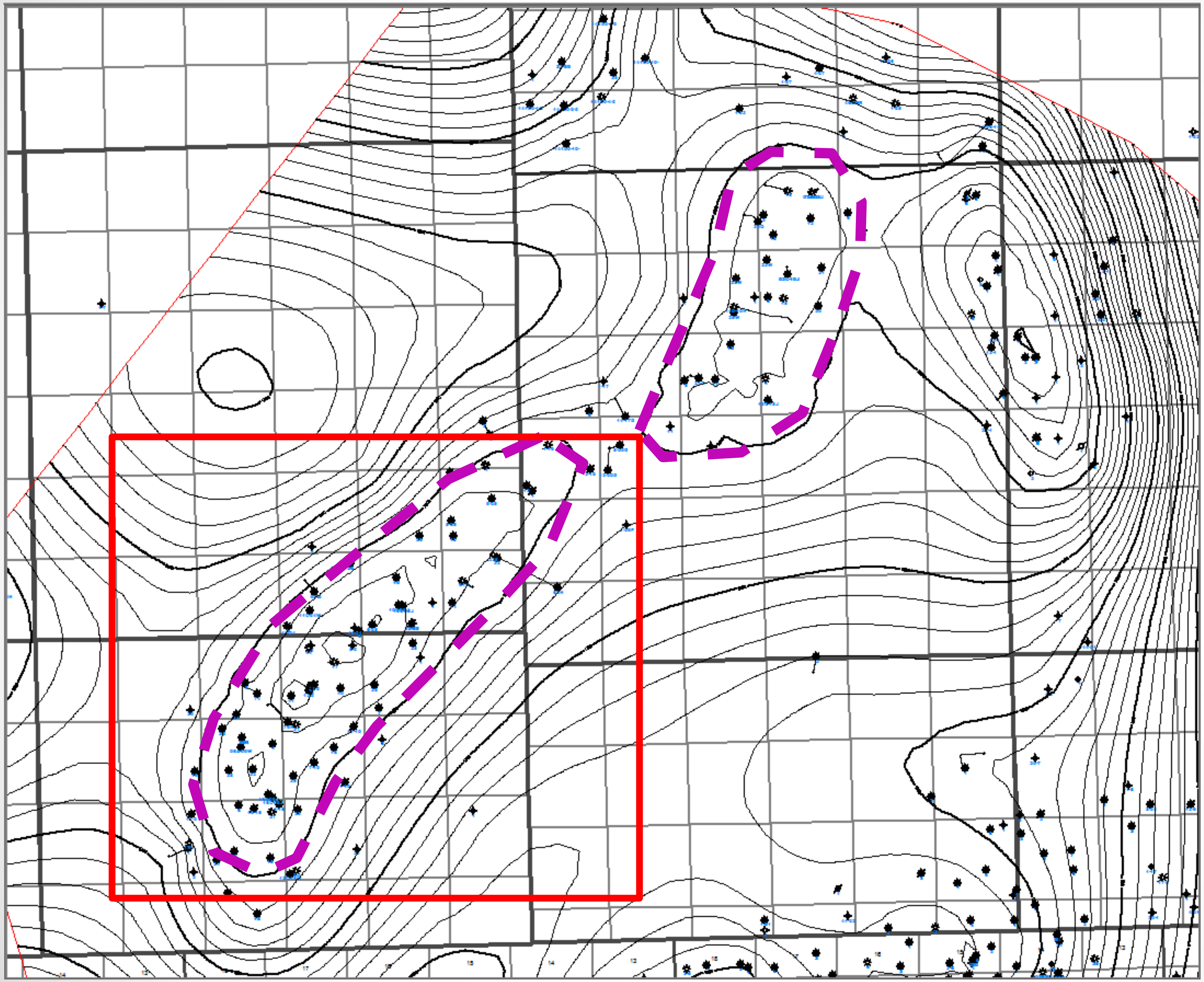
Google Earth, 2016

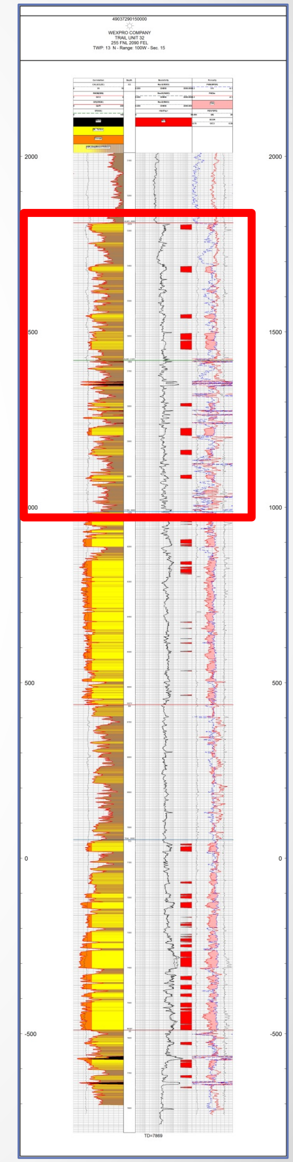
Regional Mesaverde Stratigraphy



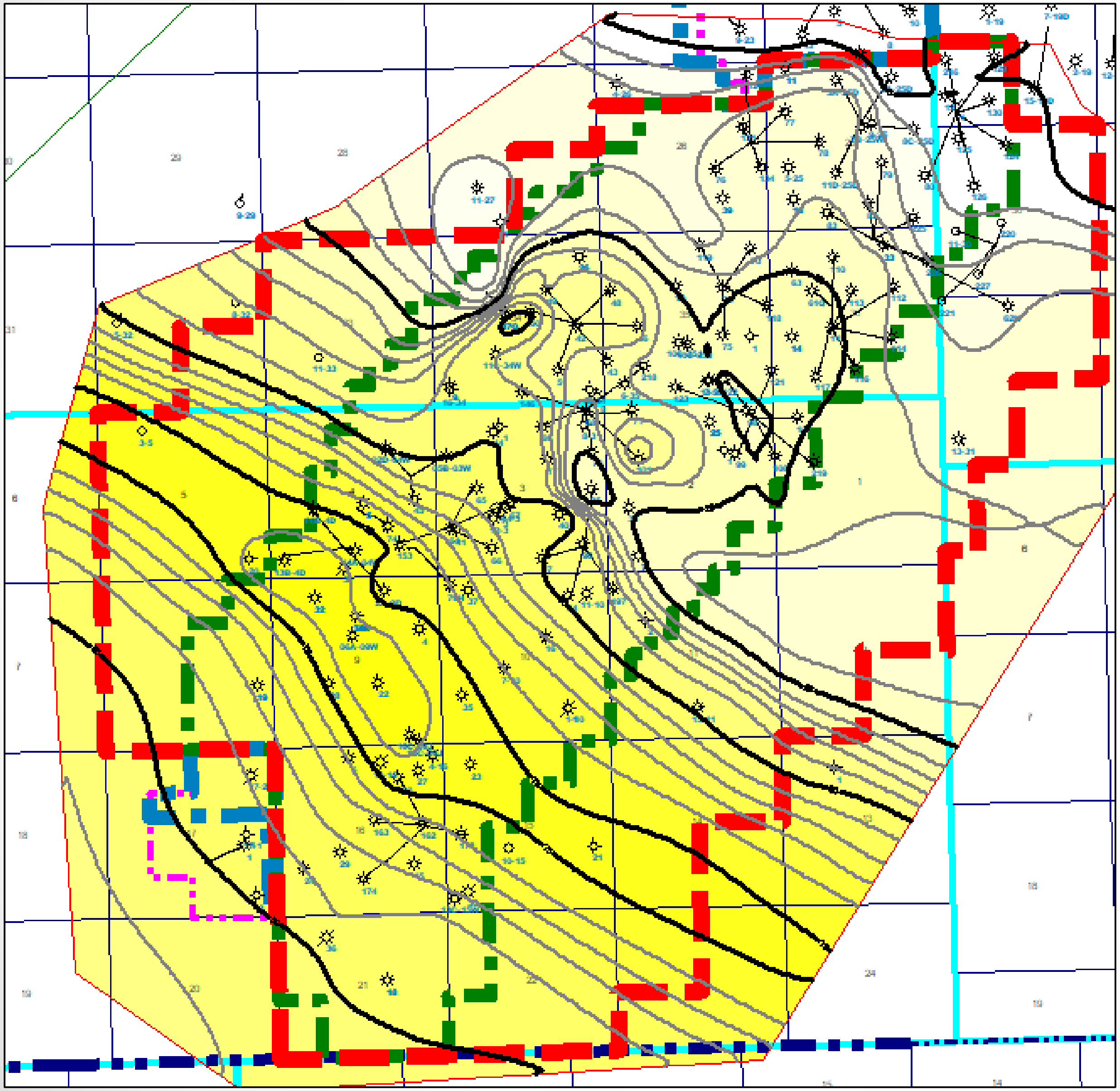
Modified from Johnson, R.C., et al. 2005

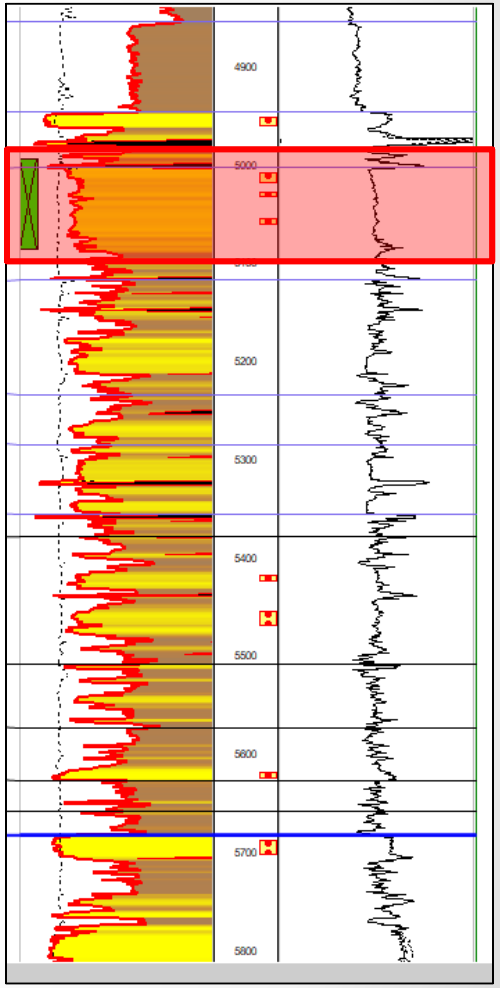
Almond Structure Map



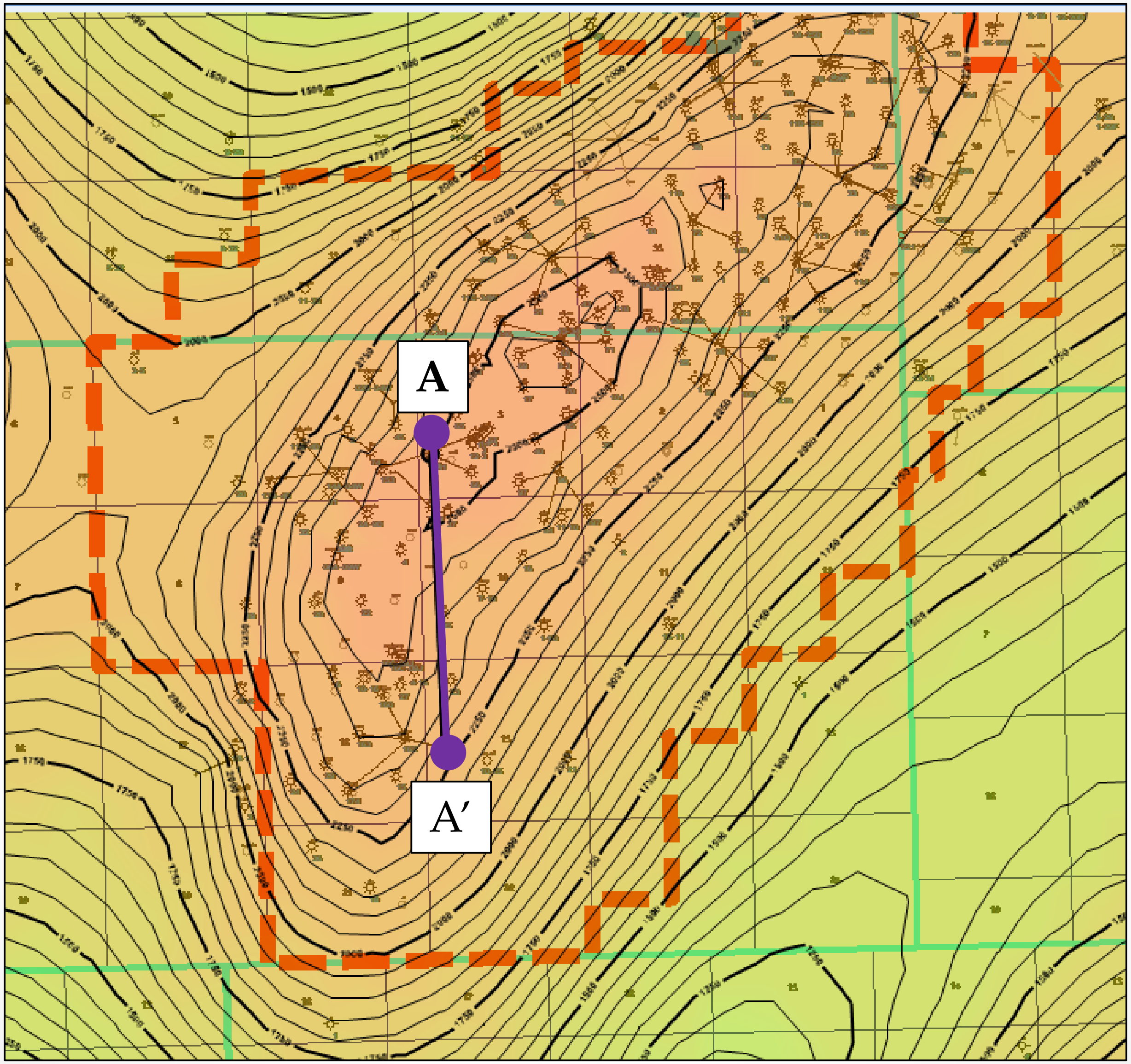


Almond Parasequence Sand Map



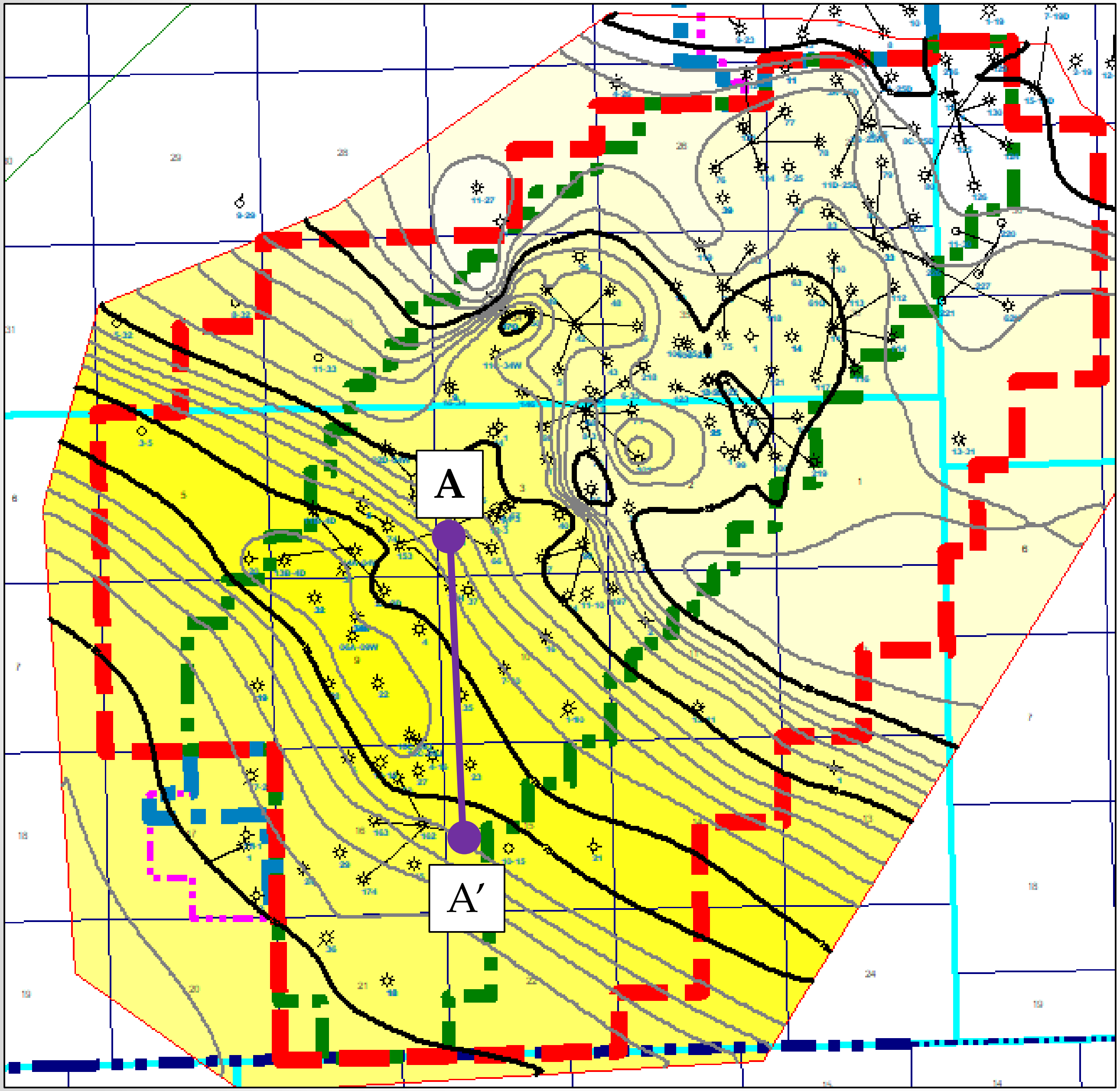


Cored well locations



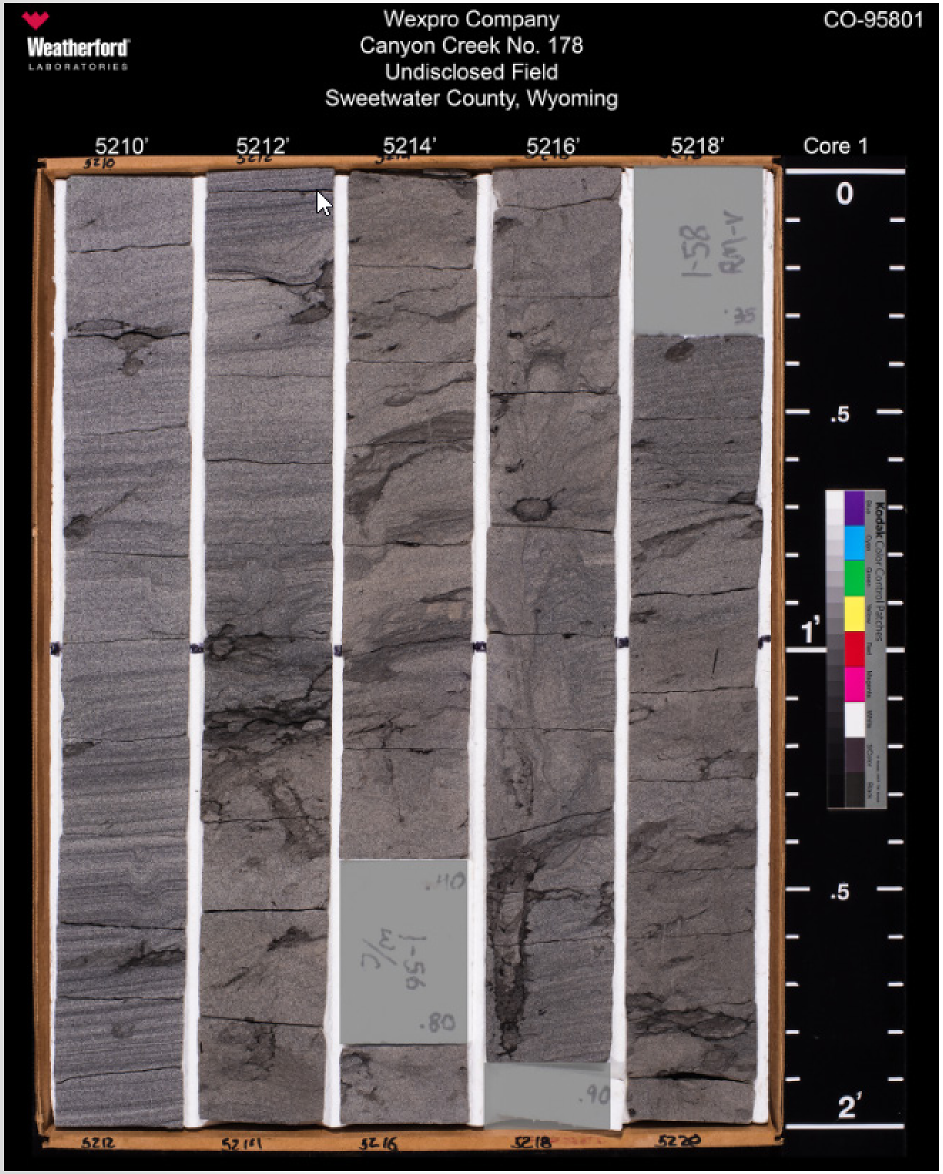
There is 200′ of structural relief between both cores

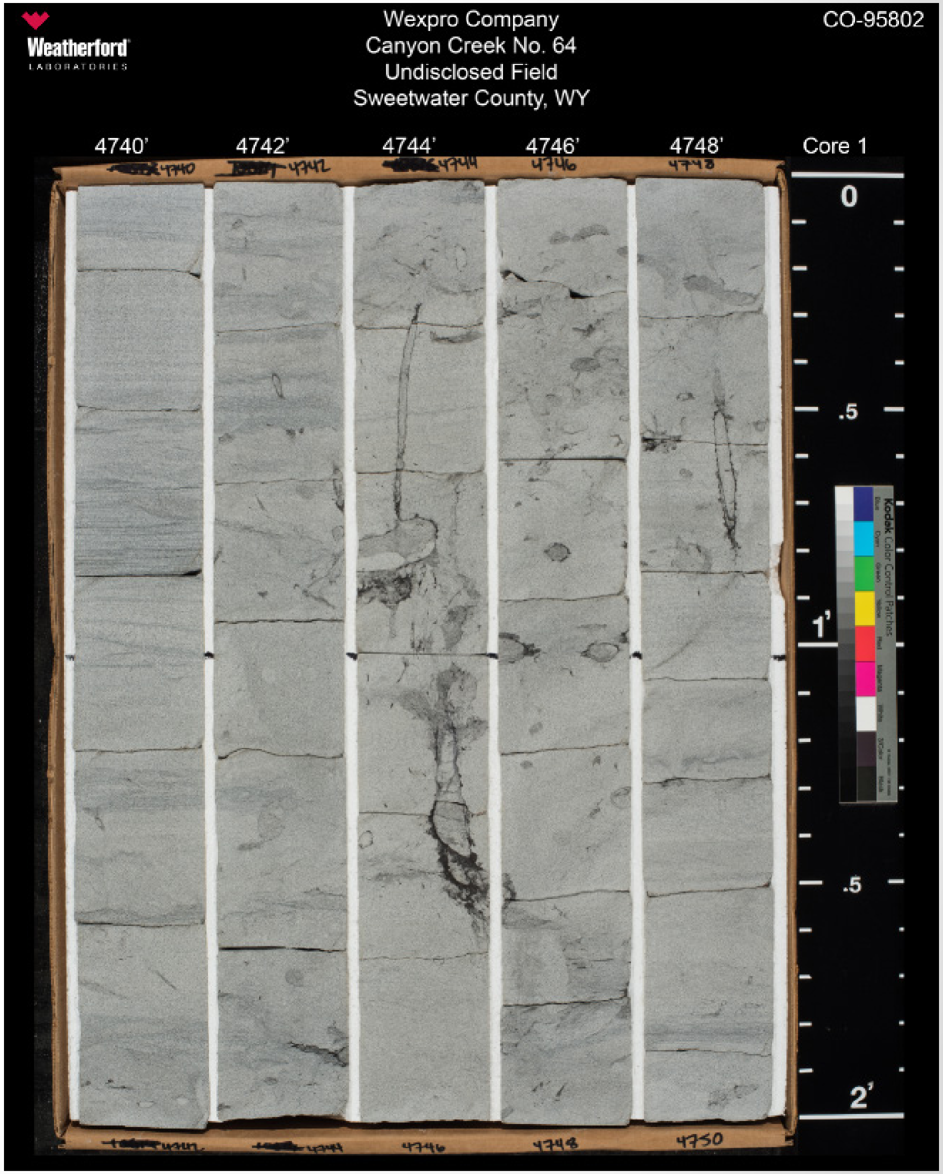
Cored well locations



- Does productivity decline because the rock is too tight? (Quartz overgrowth?)
- Does productivity decline because water saturation is too high? (permeability jail?)
- Is there some other controlling factor?

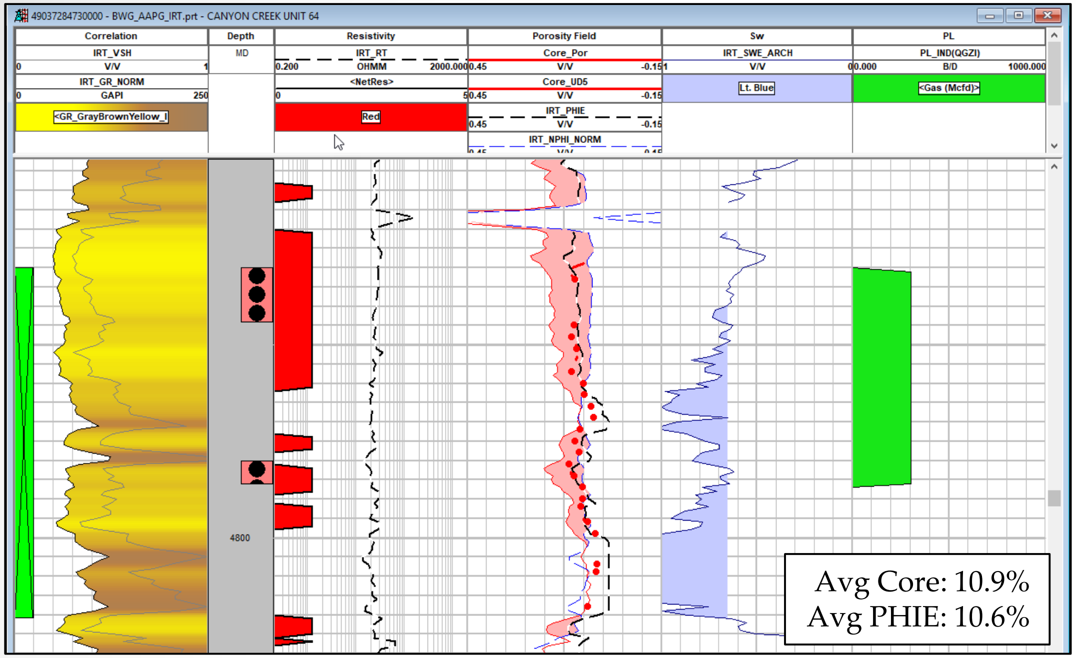
Core Photos


Weatherford
LABORATORIES
Wexpro Company
Canyon Creek No. 178
Undisclosed Field
Sweetwater County, Wyoming
CO-95801
5210'
5212'
5214'
5216'
5218'
Core 1
0
.5
1'
.5
2'
Kodak Color Control Patches

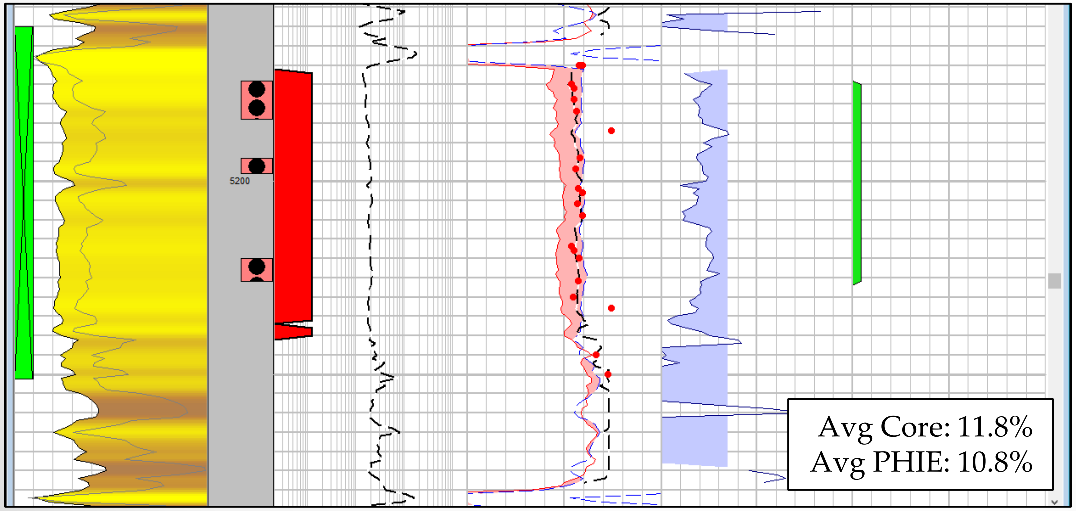

Weatherford
LABORATORIES
Wexpro Company
Canyon Creek No. 64
Undisclosed Field
Sweetwater County, WY
CO-95802
4740'
4742'
4744'
4746'
4748'
Core 1
0
.5
1'
.5
2'
Kodak Color Control Patches

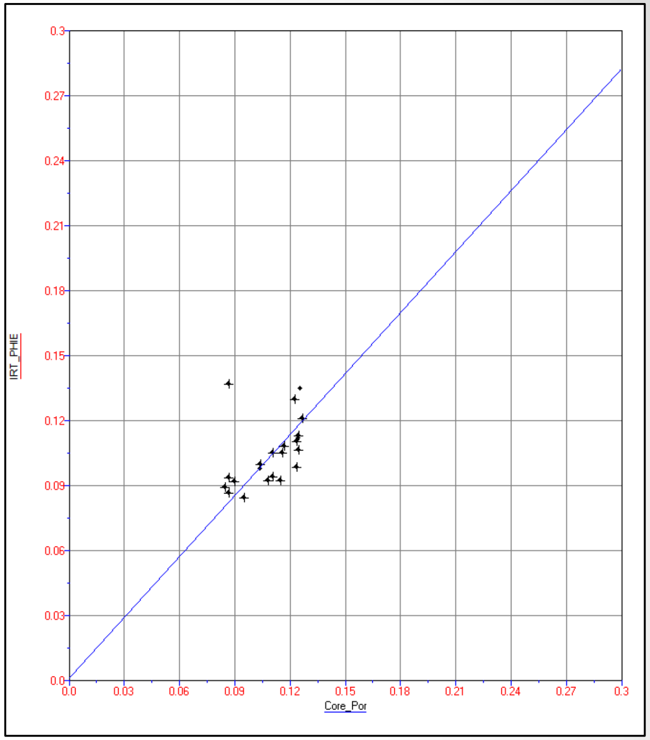
Core porosity comparison

CC 64 - Updip



CC 178 - Downdip

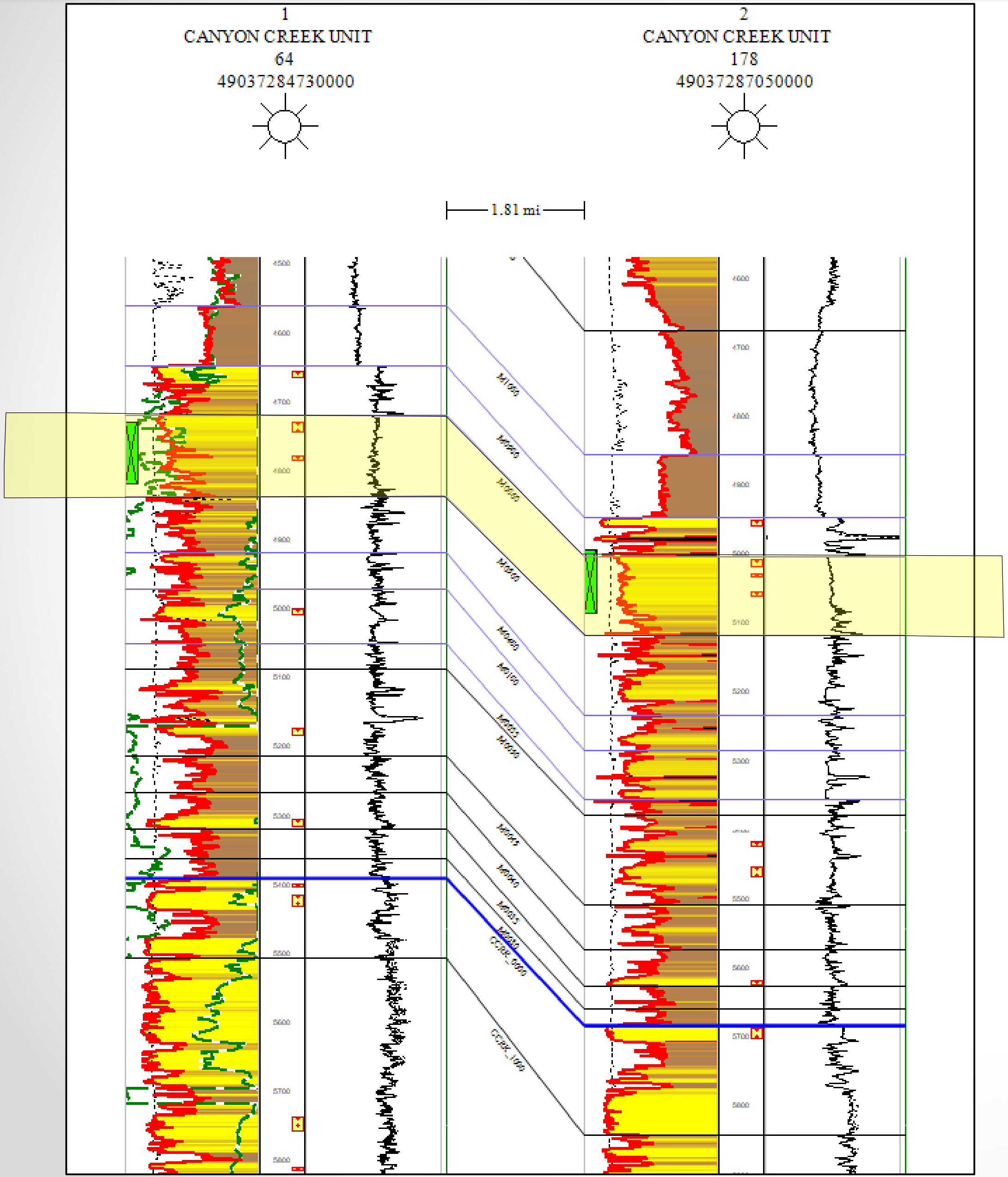




Effective Porosity

Core Porosity

Cored well petrophysics



	CC 64	CC 178
NetRes (ft)	64	68
NetPay (ft)	27	1
Avg Sw log (%)	68	79
PL Rate (mcfd)	300	44

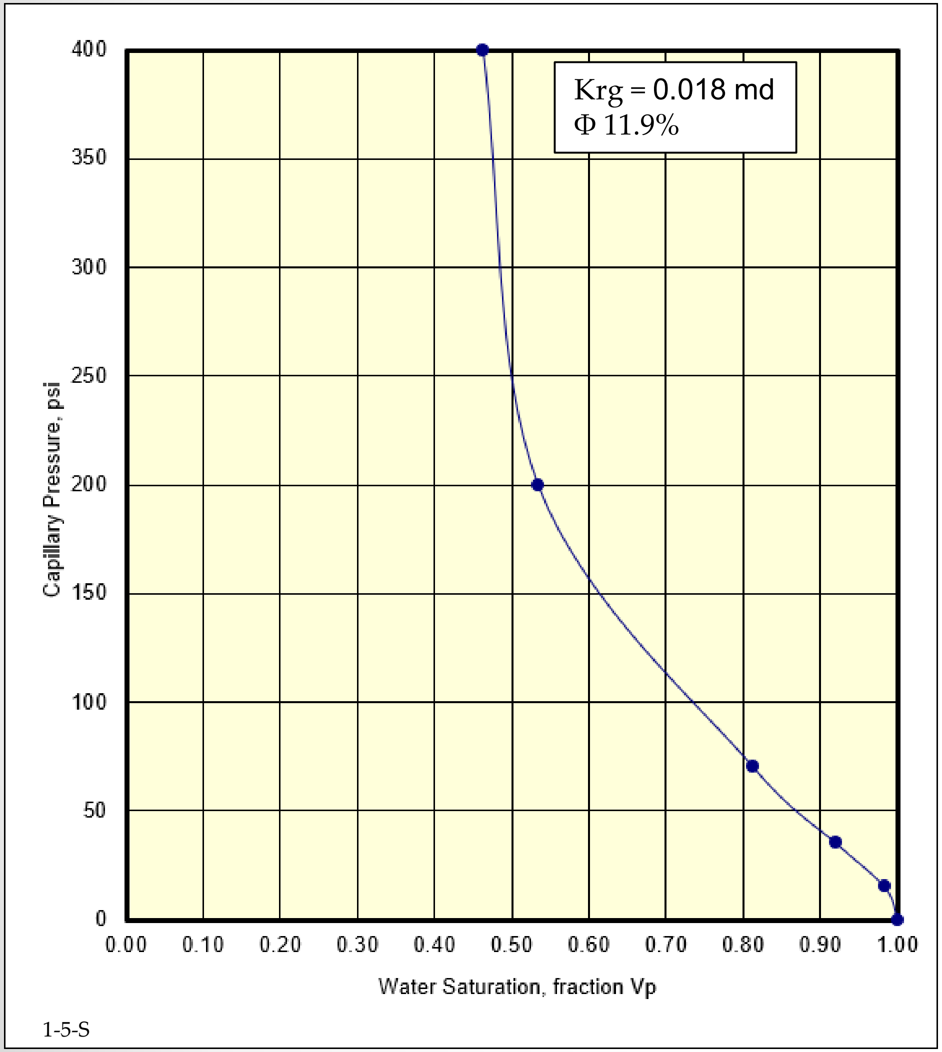
Initial results

- We might pat ourselves on the back for being clever enough to
  - Build a PHIE model that matches core porosity
  - Calculate an Archie Sw that matches observed production behavior
- We might conclude that the reservoir, as water saturation increases, progresses to permeability jail
- If we stopped here we'd miss a big part of the story...
- Dean Stark and capillary pressure data point to a more complex story:

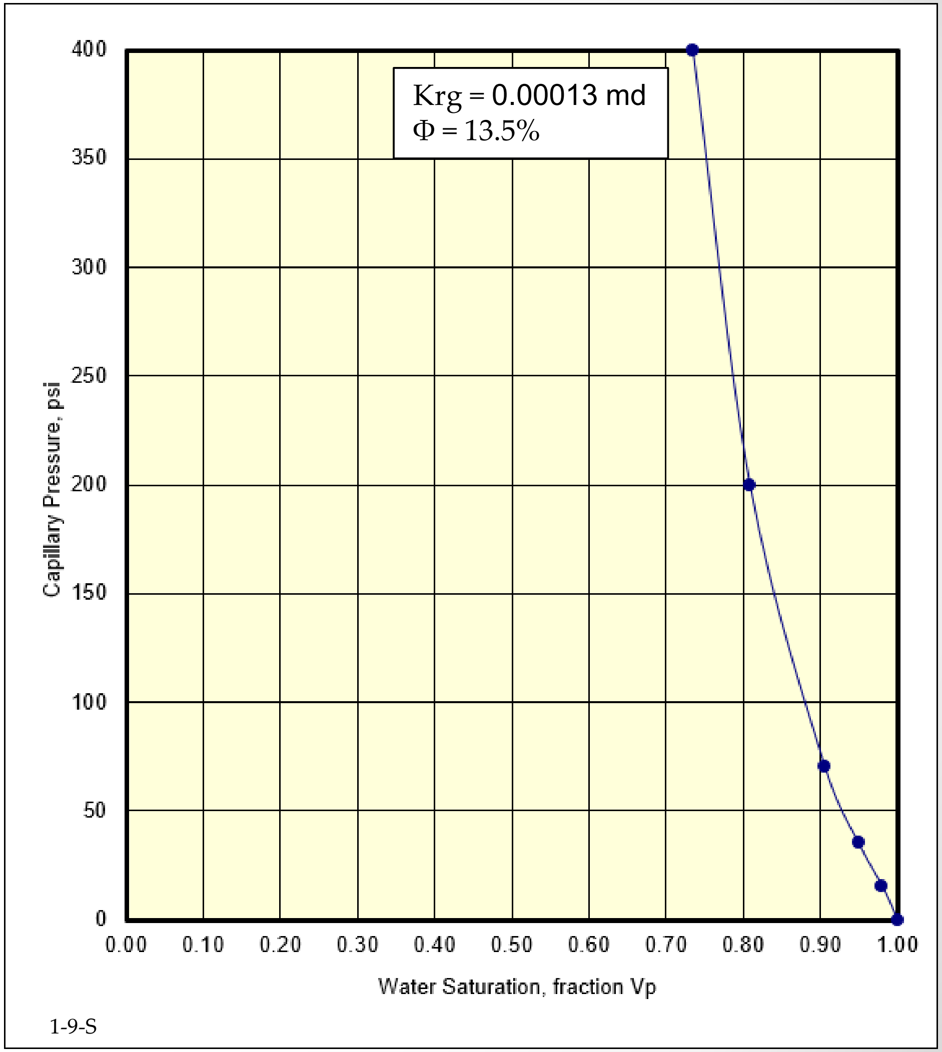
	CC 64	CC 178
NetRes (ft)	64	68
NetPay (ft)	27	1
Avg Sw log (%)	68	79
Avg Sw DS (%)	**57**	**55**
PL Rate (mcfd)	300	44

Cap Pressure Curves – High Porosity

CC 64

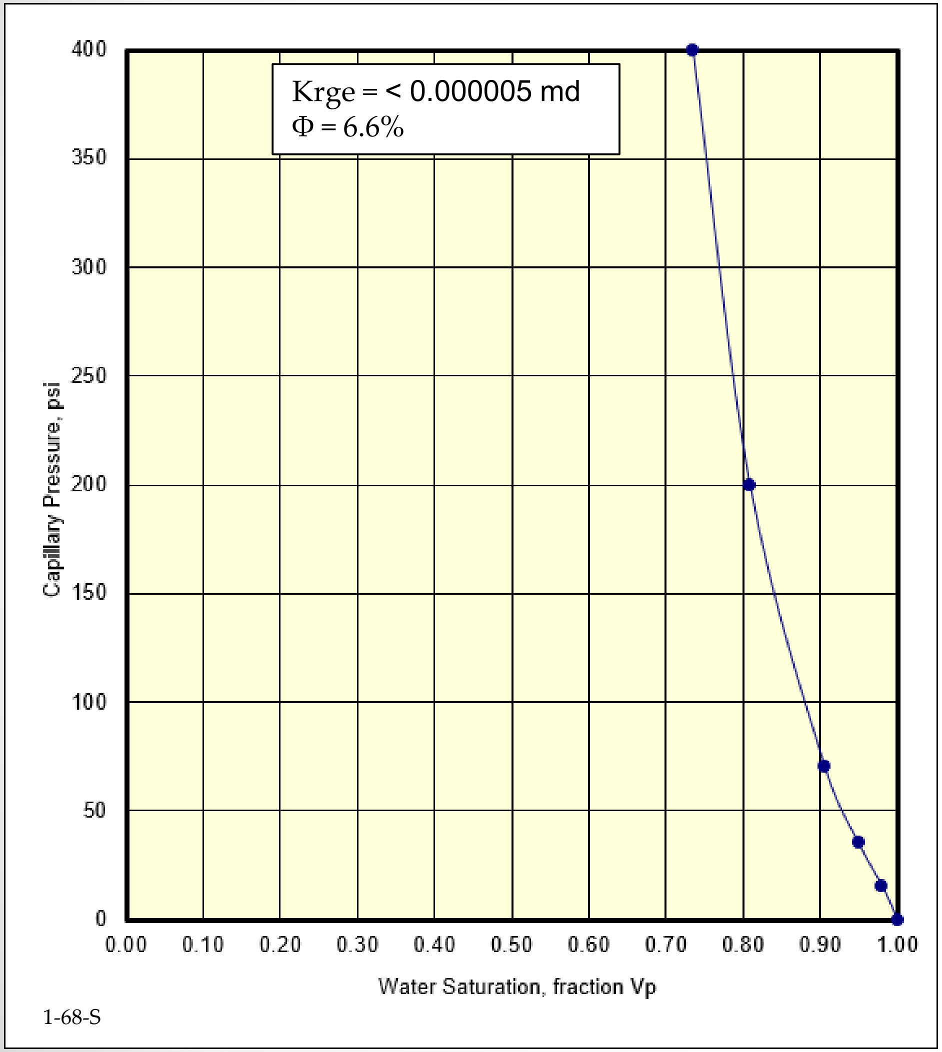


CC 178

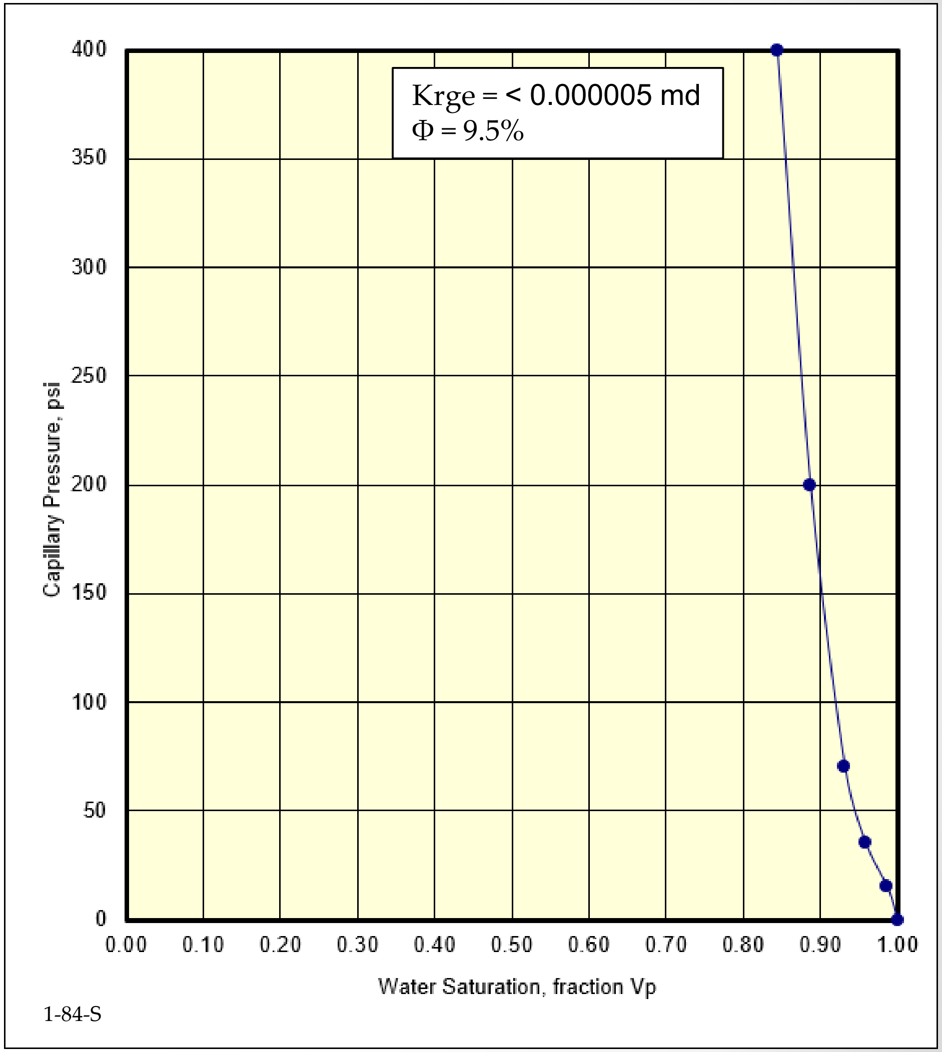


Cap Pressure Curves – Low Porosity

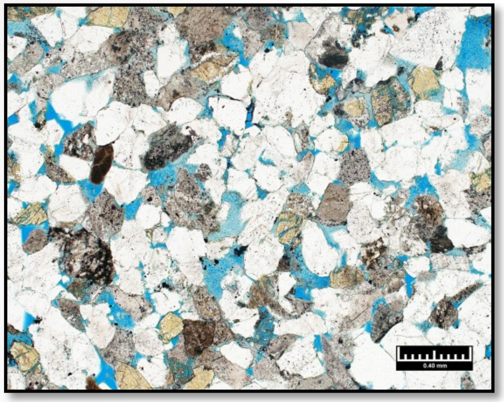
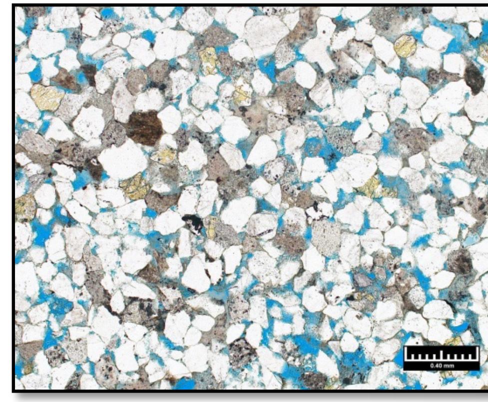
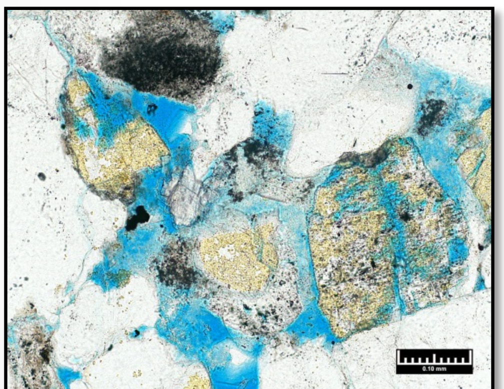
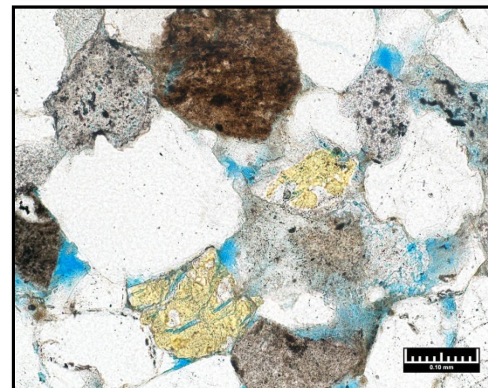
CC 64



CC 178



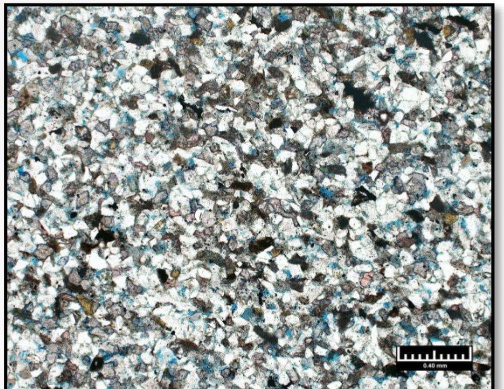
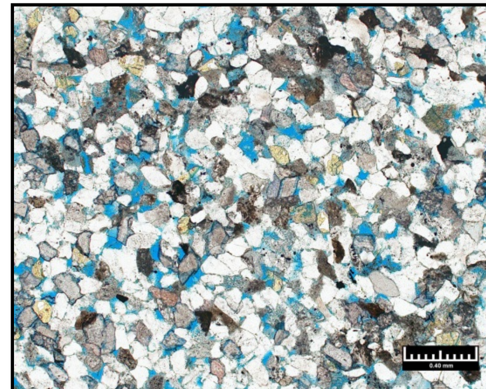
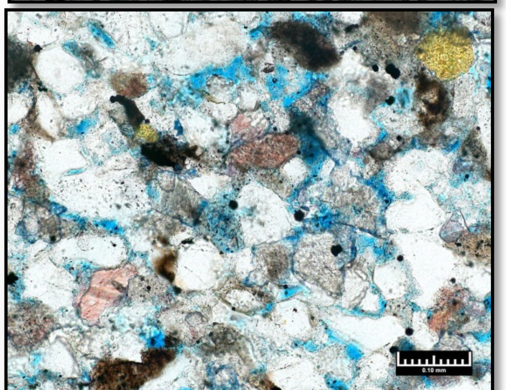
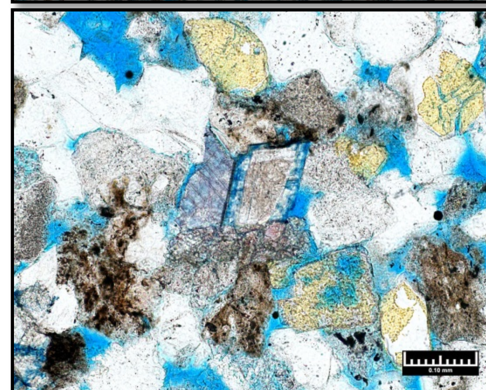
High Porosity Thin Sections

	CC 64	CC 178
50X		
200X		

Secondary grain dissolution pores > primary intergranular pores, micropores within altered/partially leached grains and between authigenic clay crystals; few primary and secondary pores are partitioned by authigenic fibrous illite

Primary intergranular pores > secondary grain dissolution pores > micropores within partially leached grains and between authigenic clay crystals; many primary and secondary pores are partitioned by authigenic illite

Low Porosity Thin Sections

	CC 64	CC 178
50X		
200X		

Secondary grain dissolution pores > primary intergranular pores > micropores associated with altered/partially leached grains and authigenic clays; some primary and secondary pores are partitioned by fibrous illite

Primary intergranular pores > secondary grain dissolution pores > micropores within partially leached grains and between authigenic clay crystals; some primary and secondary pores are partitioned by fibrous authigenic illite

Pore Filling Illite

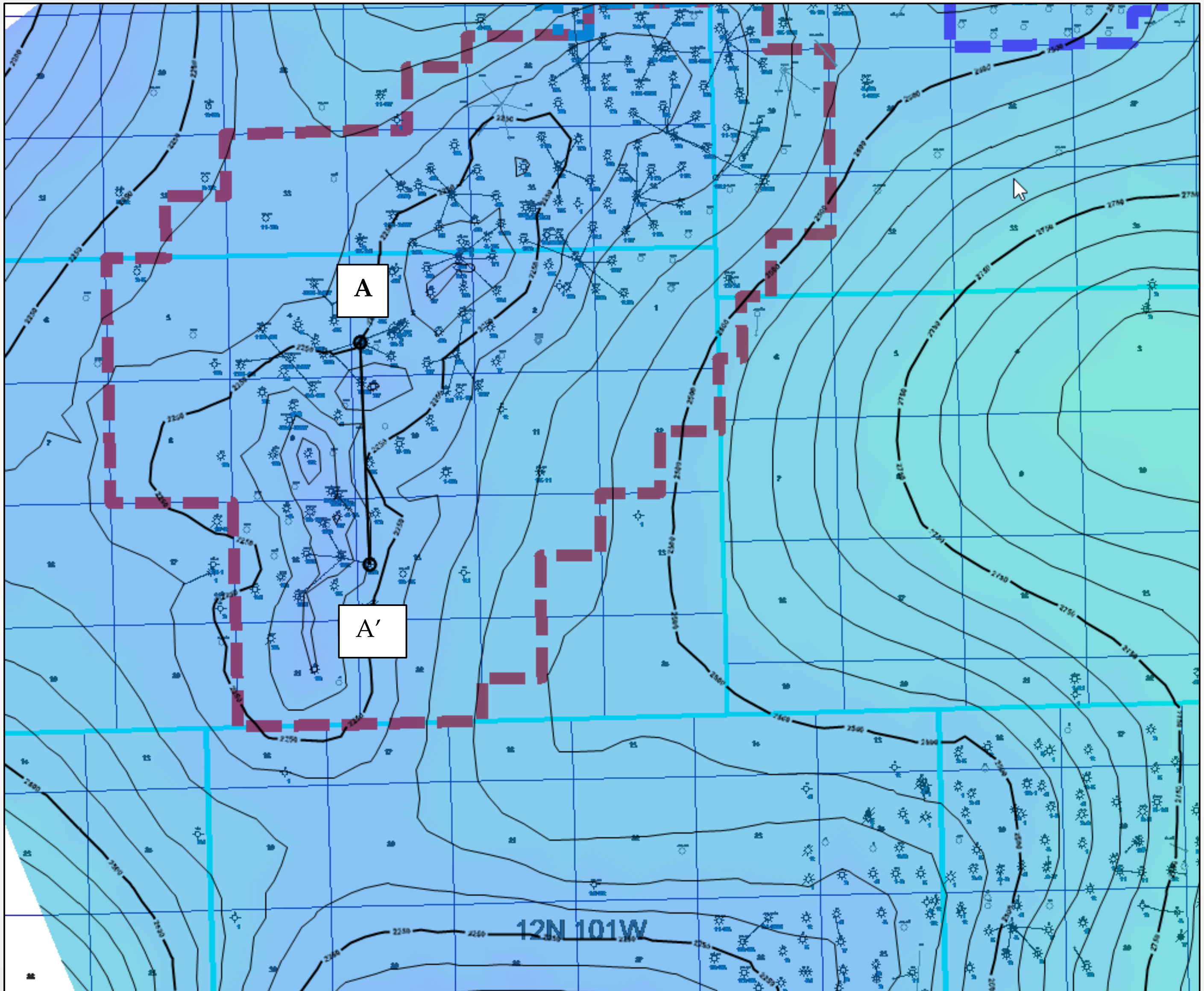
- Fibrous (pore-filling) illite has the following properties:
  - High surface area to volume ratio
  - Pore-bridging texture
  - Significant microporosity
- Pore filling illite is known to have the following effects on reservoir quality:
  - Mobilizes upon production
  - Plugs/clogs/bridges pore throats
  - Reduces permeability
  - Increases irreducible water saturation
  - Increases flow path tortuosity
  - More detrimental, due to fiber morphology, than quartz, calcite or other cements
  - Detrimental effects increase with decreasing porosity and permeability

Lander & Bonnell, 2010

Paragenetic Sequence

- Pyrite replacement (minor)
- Siderite replacement of siliciclastic grains (mostly mudstone fragments)
- Authigenic grain-coating clay (minor)
- **Quartz overgrowth (abundant)**
- Ferroan calcite cement (minor)
- **Grain replacement by authigenic clay (abundant)**
- **Authigenic pore-filling kaolinite (abundant)**
- **Calcite (abundant)**
- **Ferroan Dolomite (abundant)**
- **Authigenic pore-filling illite (abundant)**
- Titanium oxide minerals (minor)

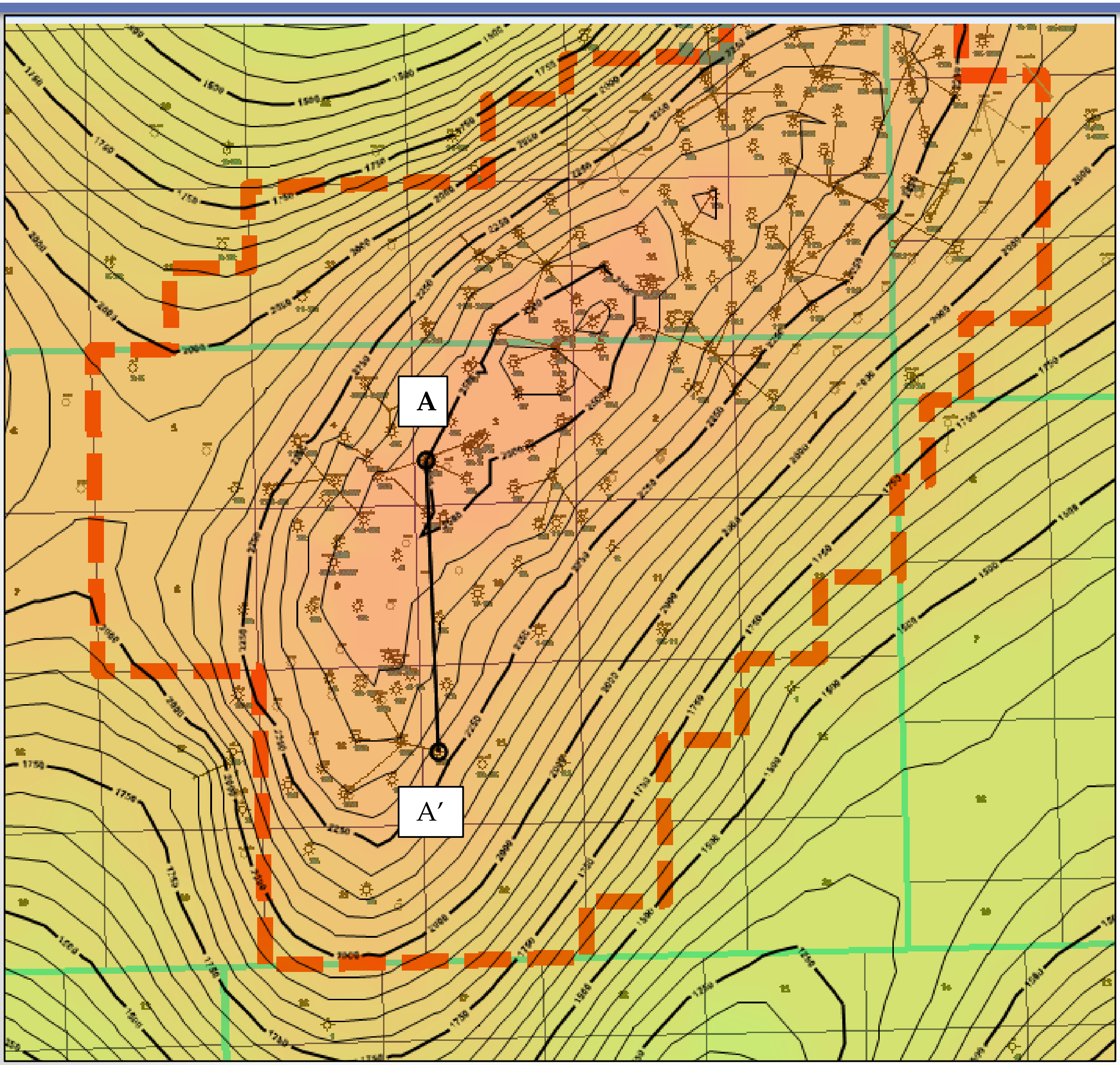
Paleostructure at ~55 Ma



When charge occurred at ~55 Ma both cores were in a similar paleostructural position

Lynds, 2016; Tobin et al, 2010

Current Structure



- At present there is 200′ of structural relief between both cores
- Updip core has experienced very little adjustment
- Downdip well likely experienced hydrocarbon remigration leading to imbibition of downdip water
- Water chemistry change could have induced the precipitation of pore-filling fibrous illite

Shanley & Cluff, 2015

Conclusions

- The presence or absence of fibrous illite in the pore space of our reservoir appears to be the most likely determinant of reservoir productivity
- Capillary pressure, thin section, and paragenetic sequence work provided the most helpful insight into the reservoir controls on production
- Routine core analysis, by itself was insufficient in determining reservoir controls
- The presence of a fraction of the reservoir without fibrous illite allows for economic production
- Structural evolution of the accumulation and its relation to petroleum and diagenesis may be a mechanism to explain both the similarities and differences in reservoir productivity
- Structural history mapping may provide a useful tool in predicting reservoir quality distribution in other fields with post-charge structural modification

References

- Google earth V 7.1.2.2041. (October 7, 2013). Sweetwater County, Wyoming.
  40° 59' 42.35" N, 108° 32' 23.69"W, Eye alt 33.49 miles.
  DigitalGlobe 2011. Image USDA Farm Service Agency. Imagery Date July 4th, 2009.
  http://www.earth.google.com [August 30th, 2016].
- Hendricks, M.L., 1994, Ravinement surface control on hydrocarbon accumulation in transgressive systems tracts: Almond Formation, Green River Basin, Wyoming, Unconformity Controls Symposium, Rocky Mountain Association of Geologists.
- Johnson, Ronald C., Thomas M. Finn, and Laura NR Roberts. "The Mesaverde total petroleum system, southwestern Wyoming province." *Petroleum systems and geologic assessment of oil and gas in the southwestern Wyoming province, Wyoming, Colorado, and Utah: US Geological Survey Digital Data Series DDS-69-D* 38 (2005).
- Lander, Robert H., and Linda M. Bonnell. "A model for fibrous illite nucleation and growth in sandstones." *AAPG bulletin* 94.8 (2010): 1161-1187.
- Lynds, R. M., and D. T. Lichtner. "Stratigraphy and hydrocarbon potential of the Fort Union and Lance." (2016).
- Shanley, Keith W., and Robert M. Cluff. "The evolution of pore-scale fluid-saturation in low-permeability sandstone reservoirs." *Aapg Bulletin* 99.10 (2015): 1957-1990.
- Tobin, Rick C., et al. "Reservoir quality modeling of tight-gas sands in Wamsutter field: Integration of diagenesis, petroleum systems, and production data." *AAPG bulletin* 94.8 (2010): 1229-1266.