Lessons Learned from the KCC #503H Woodford Horizontal Well at Keystone South Field, Winkler County, TX*

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Search and Discovery Article #20254 (2014)
Posted June 30, 2014

*Adapted from oral presentation given at AAPG 2014 Southwest Section Annual Convention, Midland, Texas, May 11-14, 2014

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Abstract

The Devonian Woodford Shale is a prolific, world-class source rock in the Permian Basin. Vast amounts of oil and gas have been generated by the Woodford Shale, effectively sourcing nearly every potential reservoir from Early Ordovician through Late Permian. Like so many other source rocks on the heels of Barnett Shale success, the Woodford underwent intense scrutiny as a viable unconventional target. By the mid-2000's, operators yielded some marginally economic gas production in the deep Delaware Basin, while only a few uneconomic vertical oil producers existed throughout the Permian Basin.

Fueled by momentum from Bakken results, Whiting Petroleum Corporation set out to delineate the resource potential of the Woodford. Integration of the previous experiences of some co-authors, the gathering and analysis of geochemical data, and a revised subsurface characterization of Woodford stratigraphy, warranted a test at Whiting's existing acreage at Keystone South Field.

Whiting acquired over 300 feet of conventional core in the upper and middle Woodford, along with an advanced log suite in the vertical pilot hole. To avoid potential water blockage and clay swelling, a synthetic oil-based mud was utilized during the drilling of the lateral. The 3,137 ft horizontal leg consisted of five hydraulic fracture stages using sliding sleeves and an un-

cemented liner with swell-packers. Reservoir modeling was performed, primarily to understand potential contribution from a complex fracture network observed in core. Ultimately, the test was uneconomic.

Several key learnings were made from the test at Keystone South Field. Present-day maturity of the Woodford, at this location, has resulted in insufficient oil-in-place and a low viscosity product that cannot produce from a normally pressured reservoir. Synthetic oil-based mud is not necessary, nor did it add value or contribute to any success in this application. Lastly, insufficient lateral length and subsequently low number of stages, as well as poor execution of most hydraulic fracture stages, resulted in an insignificant stimulated rock volume and an uneconomic test.

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Presented at the SWS-AAPG Annual Meeting
Midland, TX
May 12, 2014

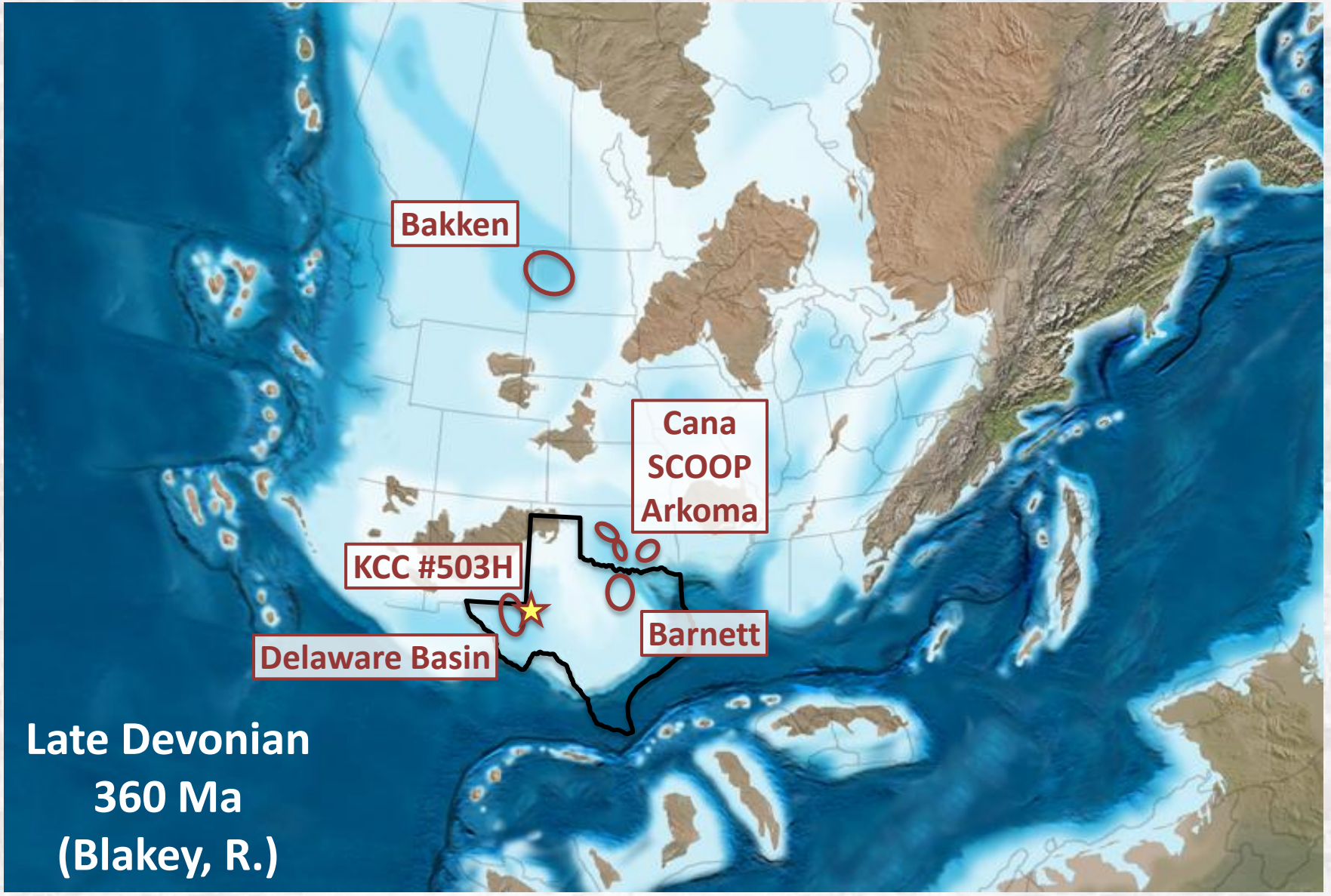
Outline

- History
- Regional Woodford Overview
- Whiting AOI
  - Central Basin Platform
  - Keystone South Field
- KCC #503H
  - Core
  - Well
- Learnings

History

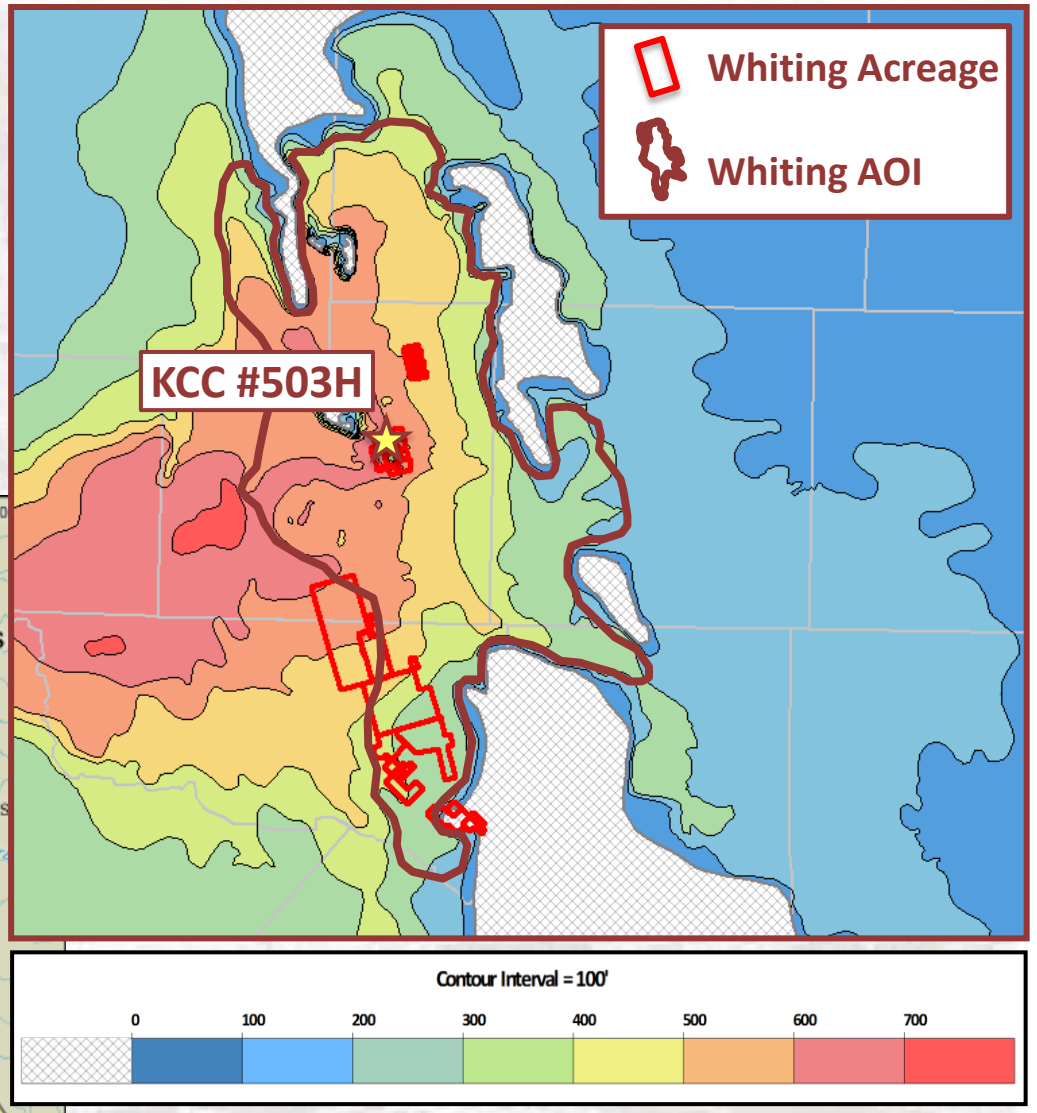
- **2003 –** Onset of horizontal drilling in the **Barnett**
- **2005 –** Delaware Basin **Woodford/Barnett** combo wells
- **2006-2007 – Whiting success in the Bakken**
- **2007-2008 –** Oklahoma Woodford plays emerge
- **2008 – Whiting Woodford data gathering**
- **2nd Qtr. 2009 – Drill and core KCC #503 pilot**
- **3rd Qtr. 2009 – Drill and complete KCC #503H**

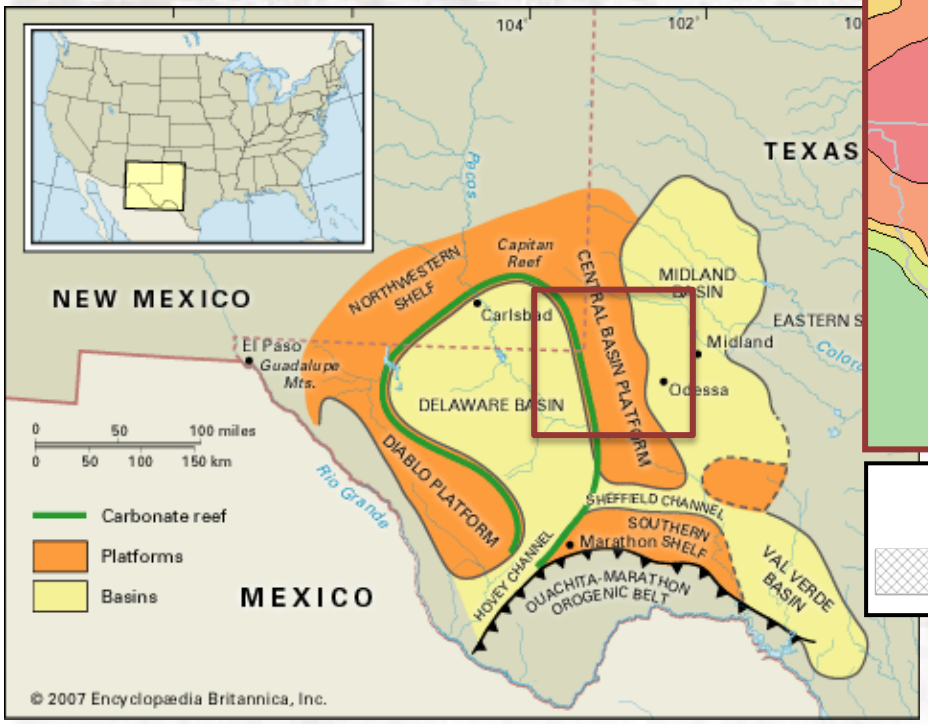
History


Bakken
Cana
SCOOP
Arkoma
KCC #503H
Barnett
Delaware Basin
Late Devonian
360 Ma
(Blakey, R.)

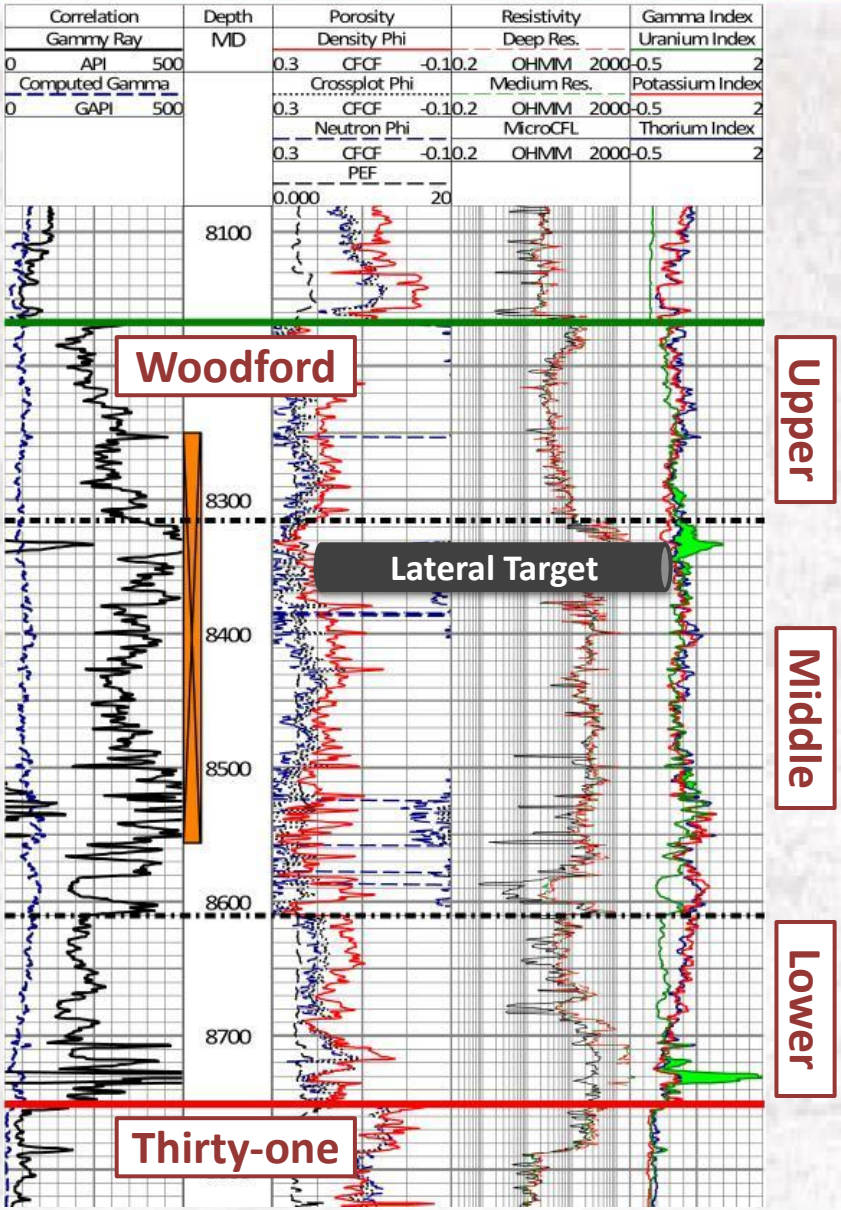
Regional Woodford Overview

- **Whiting area of interest determined by thick section of Woodford (>200') at "peak oil generation" (R_o ~0.6-1.0%)**





KCC #503H Type Log



System	Time (Ma)	Stage	Delaware Basin	Central Basin Platform
Permian	251	Ochoan	Dewey Lake	Dewey Lake
			Rustler	Rustler
			Salado	Salado
			Castile	
		Guadalupian	Lamar	Capitan: Tansill
			Bell Canyon	Capitan: Yates
				Capitan: Seven Rivers
			Cherry Canyon	Goat Seep: Queen
				Goat Seep: Grayburg
				Upper San Andres
			Brushy Canyon	
		Leonardian	Cutoff	Lower San Andres
				Holt
			Bone Spring	Glorieta
				Upper Clear Fork
				Middle Clear Fork
				Tubb
				Lower Clear Fork
				Wichita Albany
		Wofcampian	Wolfcamp	Wolfcamp
Pennsylvanian	302	Virgilian	Cisco	Cisco
		Missourian	Canyon	Canyon
		Desmoinesian	Strawn	Strawn
		Atokan	Atoka	Atoka
		Morrowan	Morrow	
Mississippian	323	Chesterian	Barnett	Barnett
		Meramecian	Mississippian	Mississippian
		Osagean		
		Kinderhookian		
Devonian	363	Famennian	Woodford	Woodford
		Frasnian		
		Givetian	Woodford (?)	Woodford (?)
		Eifelian		
		Emsian		
		Pragian	Thirty-one	Thirty-one
		Lochkovian		
Silurian	417	Pridolian	Wristen	Wristen
		Ludlovian		
		Wenlockian		
		Llandoverian		
Ordovician	443	Ashgillian	Fusselman	Fusselman
			Sylvan	Sylvan
		Caradocian	Montoya	Montoya
		Llandeilian	Simpson	Simpson
		Llanvirnian		
		Arenigian	Ellenburger	Ellenburger
		Tremadocian		

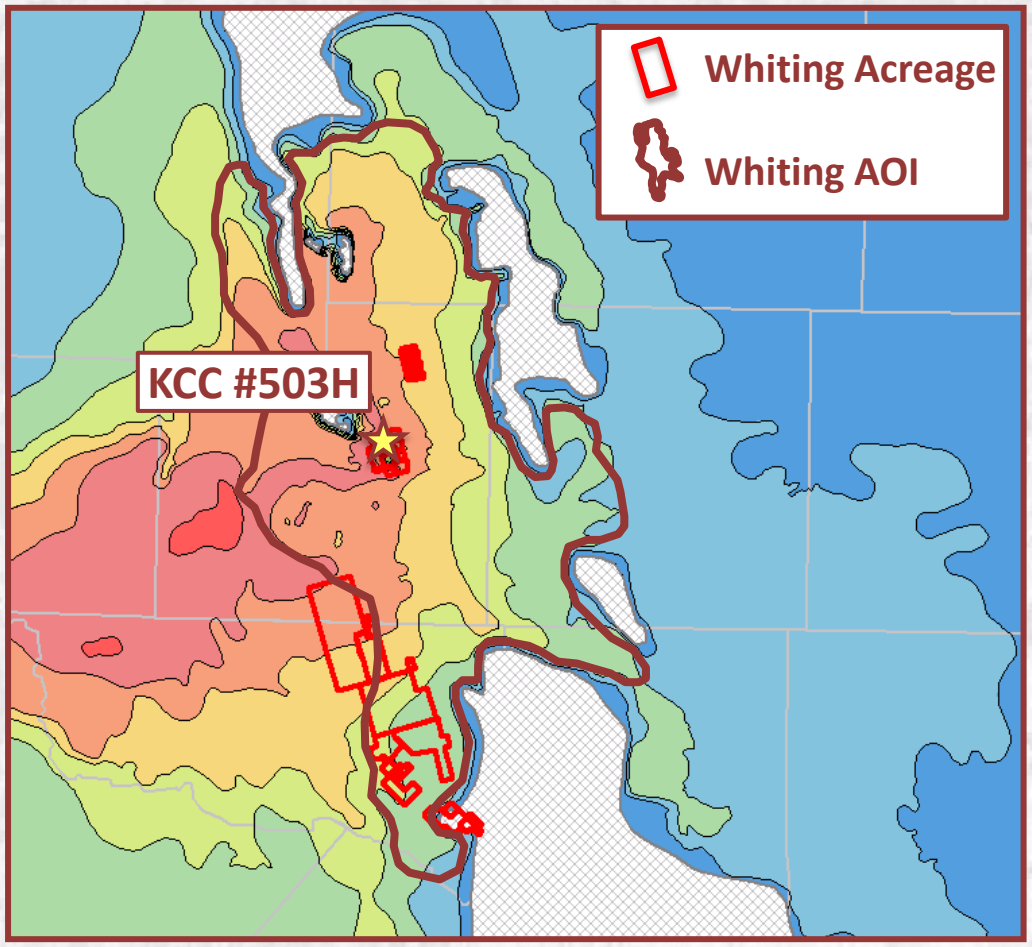
Modified from Dutton et al., 2005

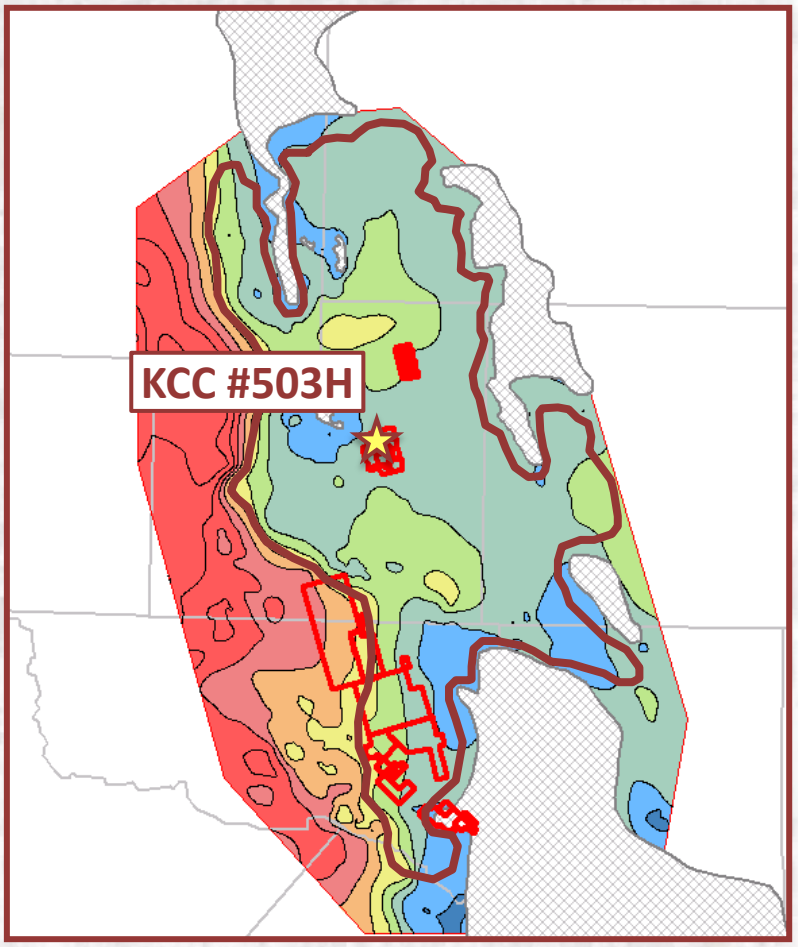
Whiting AOI Woodford Characteristics

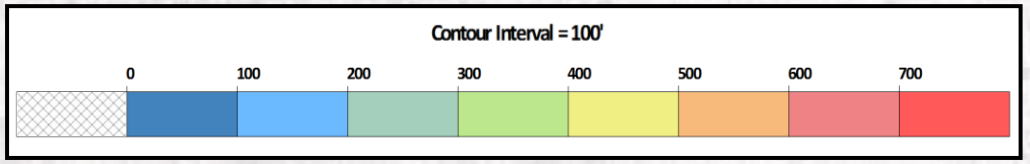
What we *knew!*

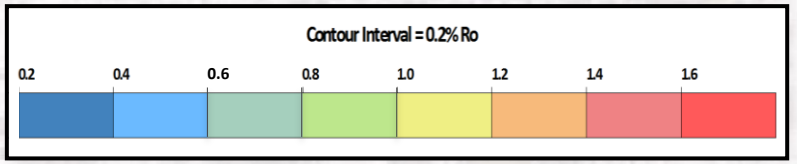
- > 500’ thick
- > 5% TOC common – up to 12% TOC or higher?
- Oil-prone type II kerogen
- ~0.6-0.8% R_o – Onset of oil generation
- 8,000-9,000’ vertical depth
- Existing vertical production in the area
  - Kermit Field – 3 miles west
  - Bedford Field – 20 miles north
  - Monahans Field – 18 miles south

Whiting AOI Woodford Characteristics

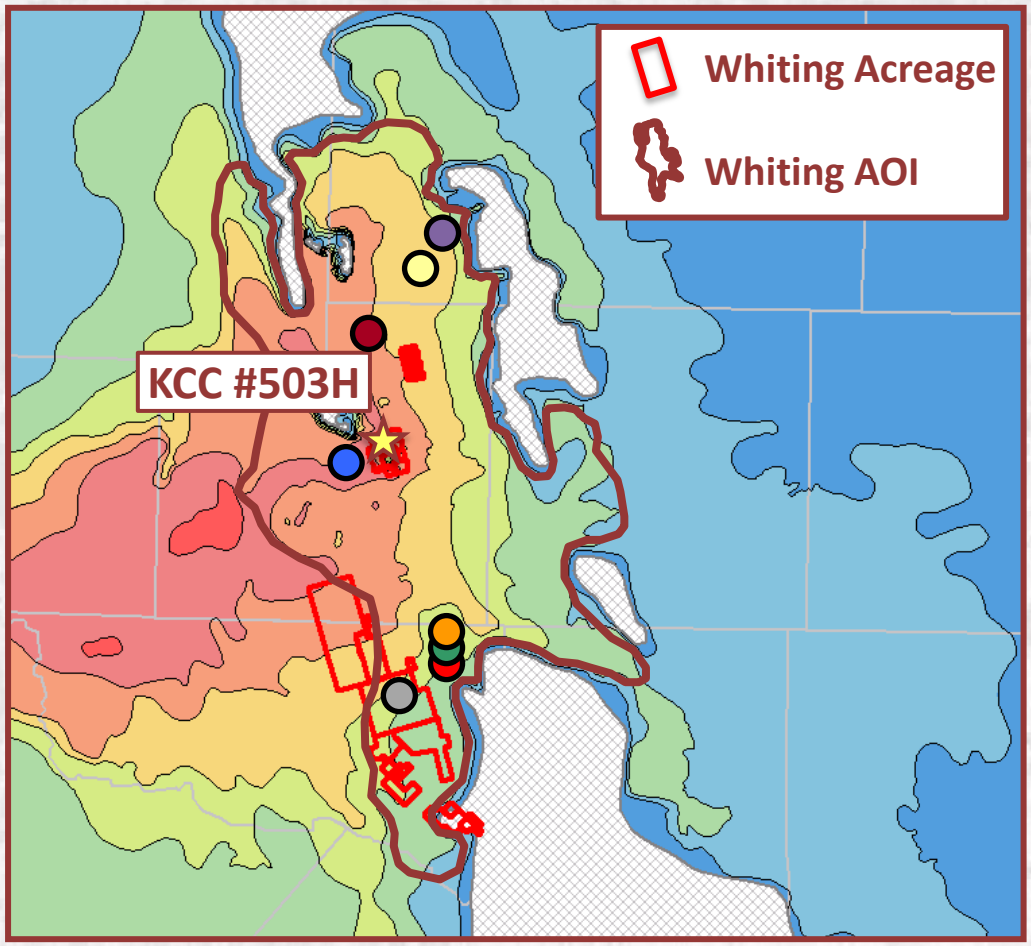


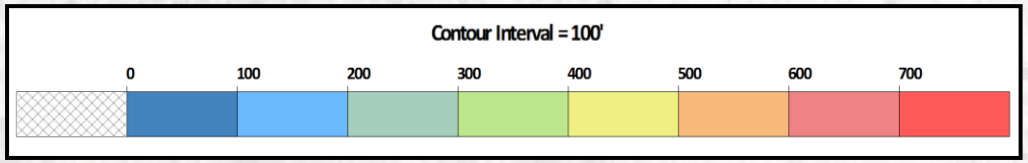






Area Woodford Producers





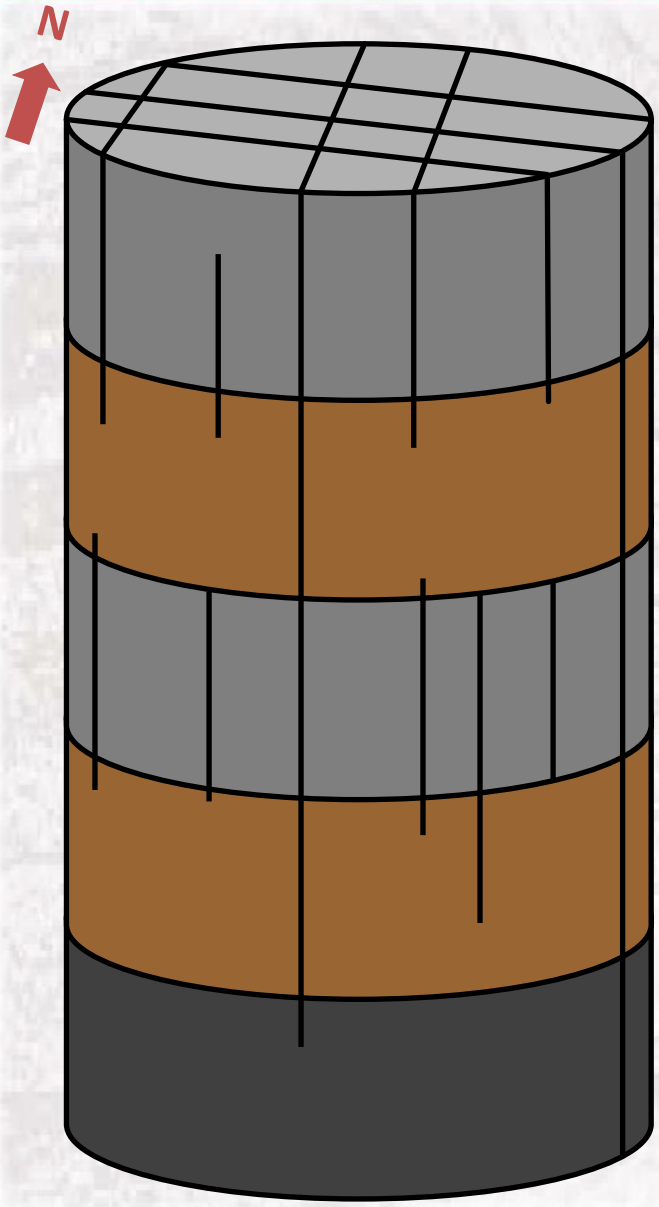
Well Name	EUR Oil	EUR Gas	EUR Wtr
University 12-32 #1 (5/08)	0	0	0
Ratliff & Bedford #13 (9/95)	27,000	47,000	18,500
Rube Evans 2 #1H (7/07)	55,000	65,000	0
Campbell Estates A #1 (5/01)	6,279	17,288	0
H.S.A. 3010 (6/07)	913	2,081	4,881
Sealy Smith #10 (3/97)	5,877	104,880	3,076
Sealy Smith #59 (12/97)	6,856	125,219	4,041
Sealy Smith #83 (6/95)	1,482	35,589	10,796

Keystone S. Woodford Characteristics

Early observations from core

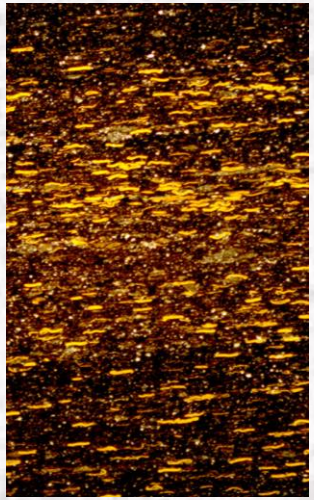
- Complex *oil-stained* fracture network
- Excellent TOC – up to over 14%!
- Excellent source rock characteristics from RockEval
- Average 0.7% R_o – low-level conversion

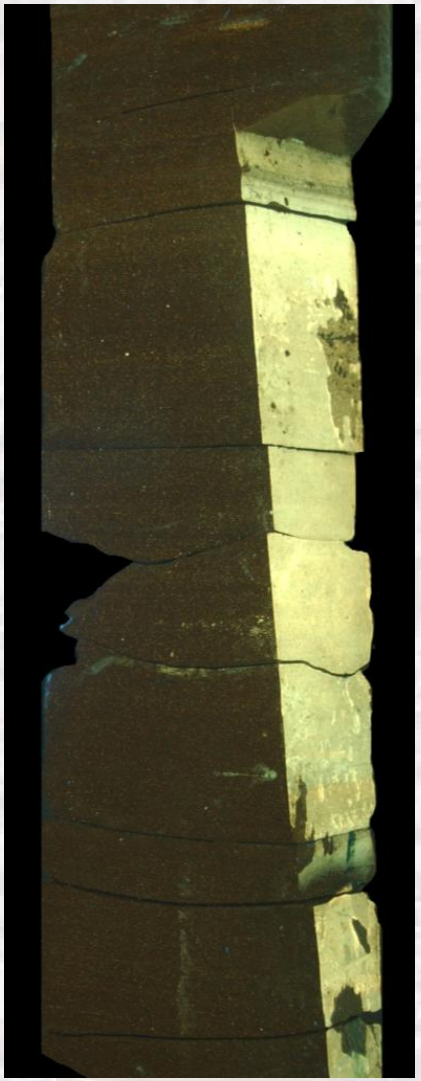
Fracture Network



- E-W drilling induced fracture throughout core
- NW-SE through going fractures
- Bed-limited fractures with multiple orientations

- TOC/tasmanites mudstone
- Quartzitic or dolomitic silt
- Clay-rich mudstone

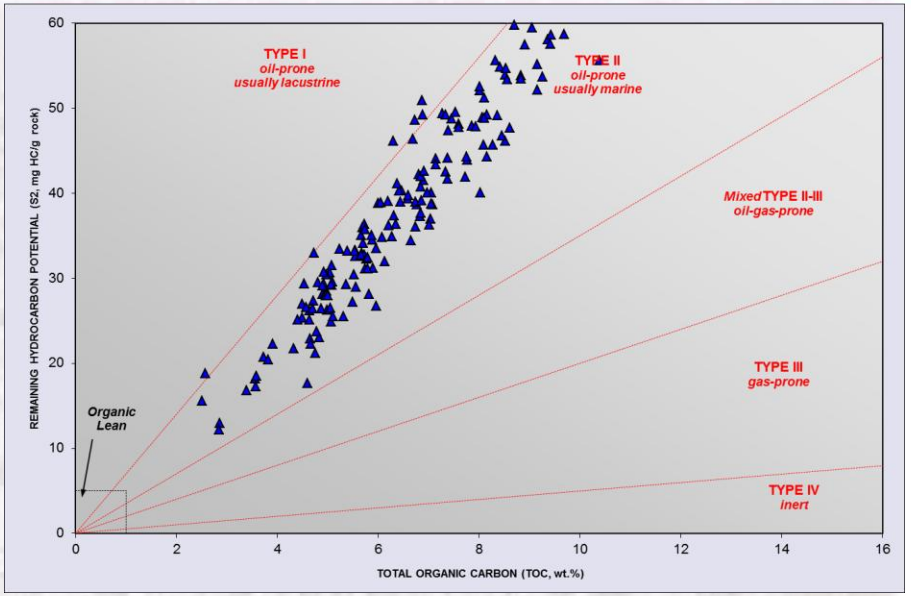


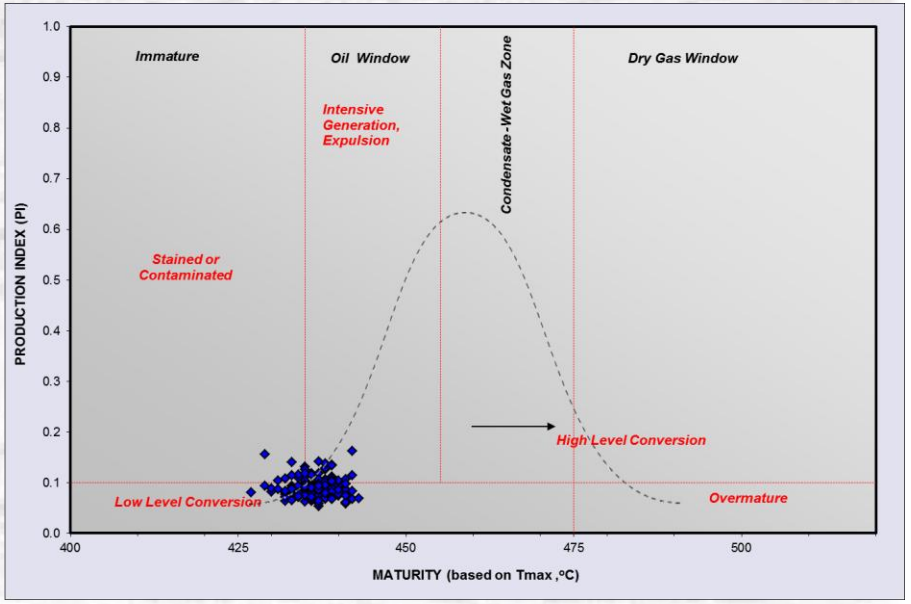


Left: 100x photomicrograph of tasmanites-rich mudstone; Middle: close-up view of partially cemented bed-limited fracture sets; Right: UV close-up showing partially cemented, oil-stained through going fracture in tasmanites and organic-rich interbeds.

Pyrolysis Data

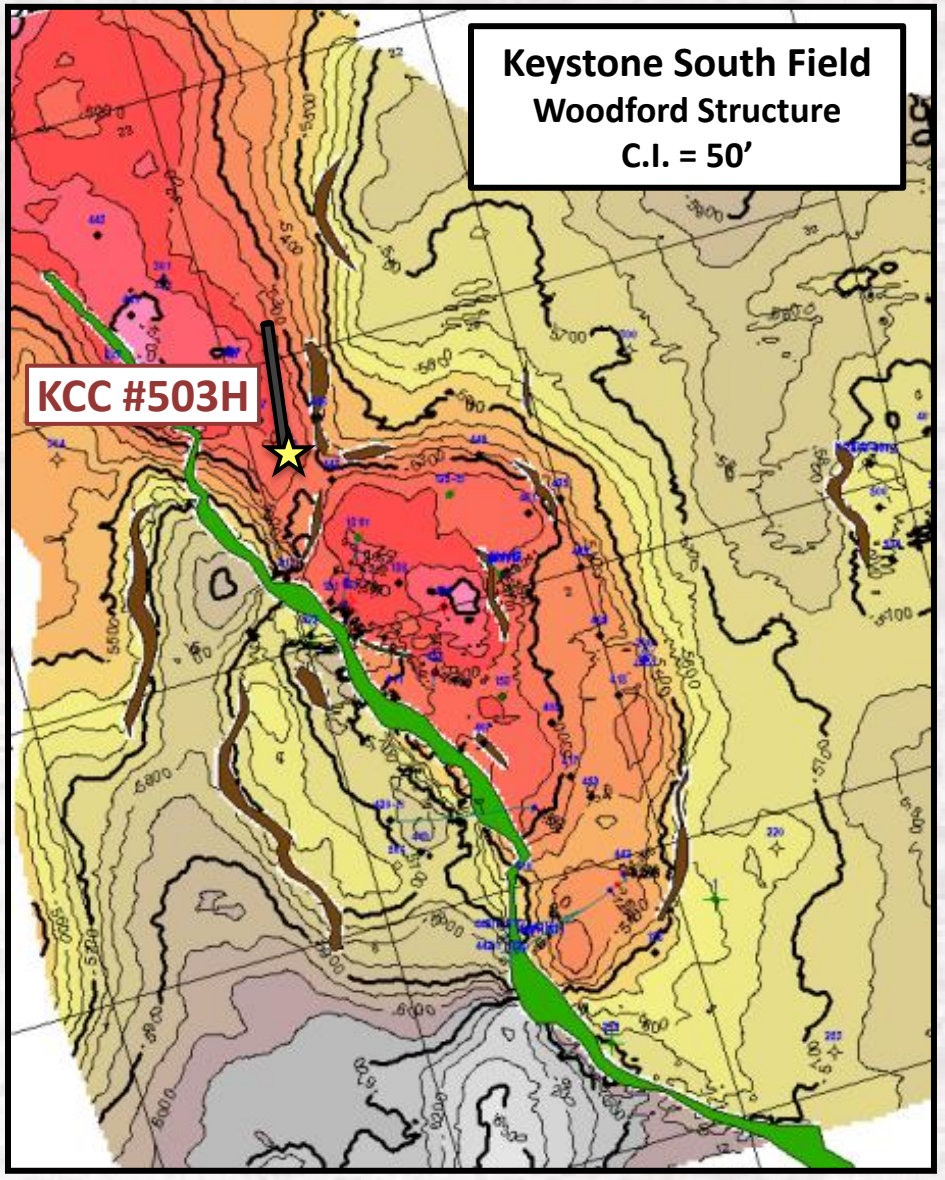
Leco	RE			Tmax	HI	OI	S2/S3	S1/TOC *100	PI
TOC	S1	S2	S3	(°C)					
14.07	6.45	74.34	0.69	432	528	5	107.7	46	0.08
13.46	6.41	89.47	3.12	439	665	23	28.7	48	0.07
13.42	6.56	94.08	3.68	433	701	27	25.6	49	0.07
13.08	6.09	82.82	5.47	438	633	42	15.1	47	0.07
12.40	5.83	81.31	3.39	439	656	27	24.0	47	0.07
12.12	5.15	84.12	2.03	441	694	17	41.4	43	0.06
11.25	5.56	65.20	5.87	434	580	52	11.1	49	0.08
10.74	5.48	67.28	1.27	437	627	12	53.0	51	0.08
10.55	5.66	64.86	1.14	434	615	11	56.9	54	0.08
10.39	5.06	55.63	2.86	436	535	27	19.5	49	0.08
10.09	4.70	60.97	7.28	437	604	72	8.4	47	0.07
9.87	4.81	61.01	2.68	438	618	27	22.8	49	0.07
9.76	5.11	60.54	0.70	436	621	7	86.5	52	0.08
9.69	4.43	58.69	0.79	436	606	8	74.3	46	0.07
9.61	5.05	61.24	0.79	433	637	8	77.5	53	0.08
9.49	3.79	67.40	0.88	437	710	9	76.6	40	0.05
9.43	4.52	58.64	1.04	434	622	11	56.4	48	0.07
9.42	4.32	57.58	3.55	439	611	38	16.2	46	0.07
9.36	4.73	58.07	2.73	436	620	29	21.3	50	0.08
9.26	4.13	53.73	2.88	433	580	31	18.7	45	0.07
9.16	5.06	55.14	0.75	441	602	8	73.5	55	0.08
9.15	4.72	52.14	4.17	433	570	46	12.5	52	0.08
9.05	5.27	59.50	0.72	438	658	8	82.6	58	0.08



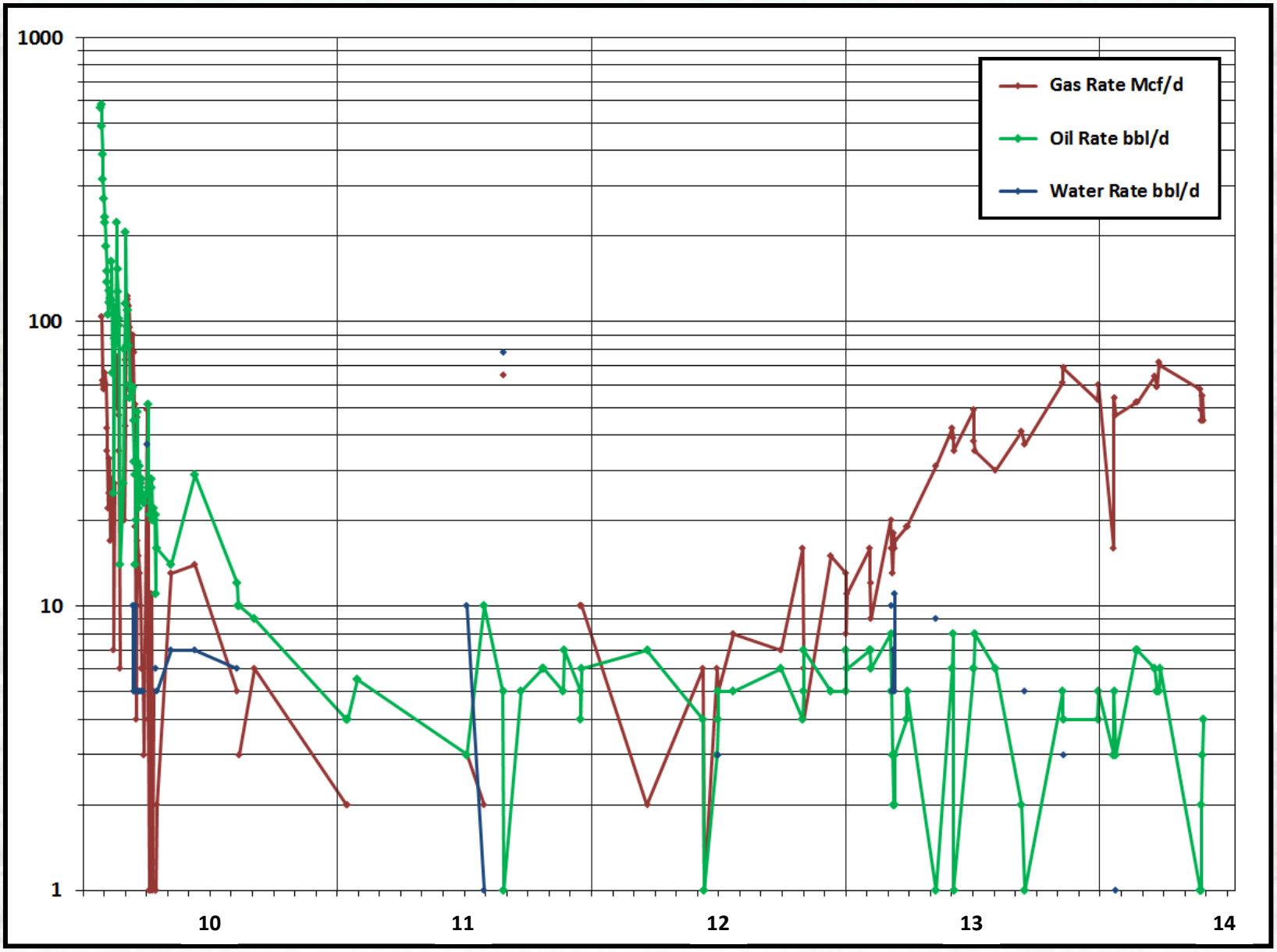


KCC #503 Lateral Design

- Maximize fracture storage potential
  - Parallel to N-S fault trend
  - Perpendicular to Sh_{max}
- Test away from structural crest to prove larger play potential
- Target upper-middle Woodford
  - High TOC
  - Lower clay
  - Abundant fractures
  - Apparent clay-rich frac barrier in lower-middle Woodford to prevent growth into “wet” Devonian
- Drilled with oil-based mud to ensure hole quality and reduce clay-swelling
- Un-cemented sliding sleeves with swell-packers
  - 3,137’ lateral length
  - 5 stages
  - 1,500 bbls/stage w/ diesel



Results


1000
100
10
1
10
11
12
13
14
Gas Rate Mcf/d
Oil Rate bbl/d
Water Rate bbl/d

Results

- Seamless drilling of the lateral resulting in excellent hole quality
- Poor frac execution
  - 2 out of 5 stages screened out
  - Cautiously pumped stage 5 to avoid additional screen out
- Cumulative production = 7,800 BO & 28,000 MCF
  - Currently producing ~7 BOPD

Learnings

What we *know now!*

- R_o ~0.7% is *too* immature
- Normally pressured reservoir
- Fracture network alone is *not* enough storage
- 41 API product – viscosity *too* high
- Unsure of the necessity of oil-based drilling mud
- Insufficient stimulated rock volume
- Unnecessary sliding-sleeve completion