

PS Analysis of a Long Cane Creek Horizontal: New Insight into an Unconventional Tight Oil Resource Play, Paradox Basin, Utah*

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Abstract

A recent 5,600-ft Cane Creek horizontal well drilled by Whiting Oil & Gas provides new insight into the Cane Creek tight oil resource play in the northwestern Paradox Basin. The Threemile #43-18H well was drilled in early 2009, approximately 20 miles southeast of the Long Canyon, Bartlett Flat, and Big Flat producing fields. Sidewall cores from the vertical pilot hole showed good reservoir storage potential in dolomitic siltstone intervals with porosities of 8 to 13 percent, permeabilities between 10 and 50 microdarcies, and 20 to 35 percent water saturation. Interbedded mature source rocks sampled from this and the nearby Gibson Dome #1 well indicate a range of from nearly pure Type II kerogen to a mixture of Type II and Type III kerogen with up to 44 percent TOC.

Three hundred feet of salt overlying the Cane Creek and 80 plus feet of salt below provide the necessary top and bottom seals for the petroleum system and were viewed as potential hydraulic fracture barriers as well. Mud weights progressively increasing from 11.5 to 15 plus ppg were required during horizontal drilling, and a later DFIT analysis determined a formation pressure gradient of 0.938 psi/ft. Strong hydrocarbon shows during horizontal drilling included a steady flare up to 25 feet in length, oil over the shakers, and an overall 600 bbl pit gain. An uncemented liner with swell packers was run in the horizontal wellbore and the Cane Creek was hydraulically fracture stimulated over eleven 500-foot stages, each with 110,000 pounds of proppant and 2,000 bbls of gel. Although the Threemile #43-18H well is producing oil and gas, it also produces a significant NaCl brine cut, an indication that the stimulation propagated into a nearby water-bearing zone. Several candidates for over-pressured water sources of unknown volumetrics were observed through cored salt sections in the Gibson Dome #1 well. Observations point to technological solutions as a key to the success of the Cane Creek tight oil resource play.

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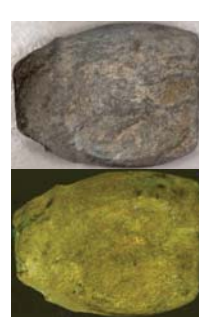
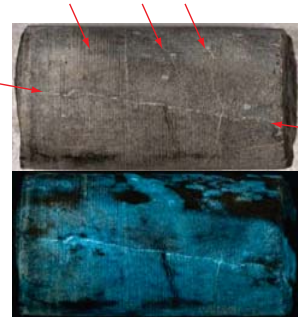
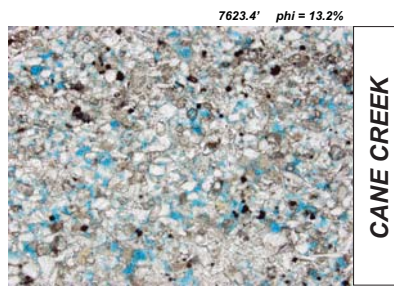
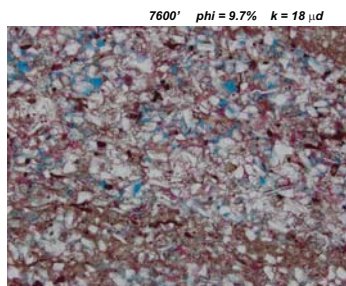
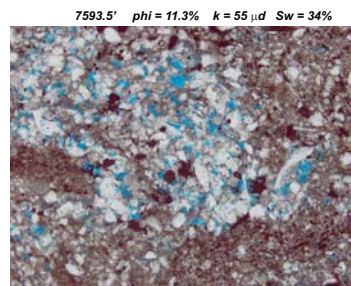
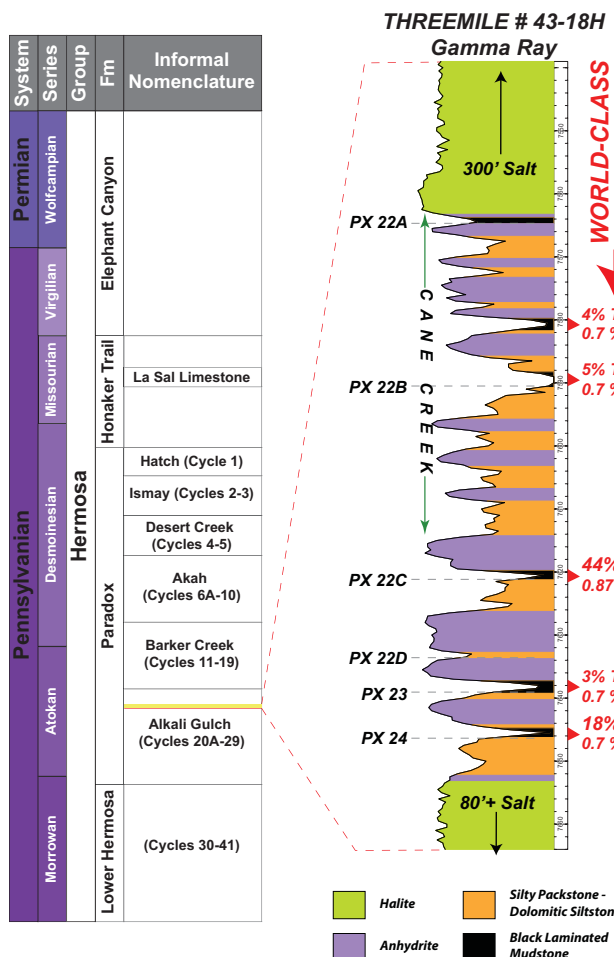


ABSTRACT

A recent 5,600-foot Cane Creek horizontal drilled by Whiting Oil & Gas provides new insight to the Cane Creek tight oil resource play in the northwestern Paradox Basin. The Threemile # 43-18H was drilled in early 2009 approximately 20 miles southeast of the Long Canyon, Bartlett Flat and Big Flat producing fields.

Sidewall cores from the vertical pilot showed good reservoir storage potential in dolomitic siltstone intervals with porosities of 8 to 13 percent, permeabilities between 10 and 50 microdarcies, and 20 to 35 percent water saturation. Analysis of interbedded mature source rocks sampled from this and a nearby well indicate a range from nearly pure Type II kerogen to a mixture of Type II and Type III kerogen with up to 44 percent TOC. Three hundred feet of salt overlying the Cane Creek and >80 feet of salt below provide the necessary top and bottom seals for the petroleum system and were viewed as potential hydraulic frac barriers as well. Mud weights progressively increasing from 11.5 to >15 ppg were required during drilling, and a later DFIT analysis determined a formation pressure gradient of 0.938 psi/ft. Hydrocarbon shows during drilling included a steady flare up to 25 feet in length, oil over the shakers, and an overall 600 bbl pit gain.

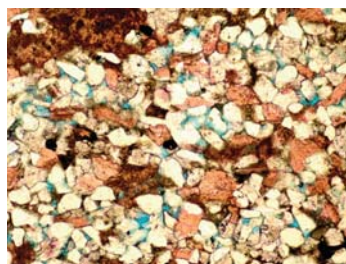
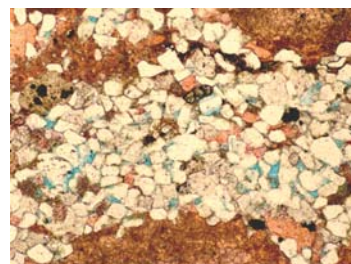
An uncemented liner with swell packers was run in the horizontal wellbore and the Cane Creek was frac stimulated over eleven 500-foot stages, each with approximately 110,000 pounds of proppant and 2,000 barrels of cross-link gel. Although the Threemile # 43-18H is producing oil and gas, it also produces a significant NaCl brine cut, an indication that the stimulation may have propagated into a nearby water-bearing zone. Several candidates for over-pressured water sources of unknown volumetrics were observed through salt sections in the continuously cored nearby Gibson Dome # 1 well. Observations from this core point to technological solutions as the key to success in the Cane Creek tight oil resource play.



7586' - dolomitic siltstone; 1" spaced subvertical fractures plus subhorizontal fracture; good blue-yellow UV fluorescence

7589' - dolomitic siltstone; 1/2" spaced subvertical fractures plus subhorizontal fracture with local extensional rhomboid gash; good blue-yellow UV fluorescence

7593.5' - dolomitic siltstone; even yellow fluorescence throughout



Side-by-side comparison of the Cane Creek with two similar & well-known tight oil resource reservoir rocks

CANE CREEK
Porosity 8-13 %
Permeability 10-50 μ d

BRAAFLAT # 11-11H, Sanish Field, Mountrail County, North Dakota



MIDDLE BAKKEN SS
Porosity 7%
Permeability 3-100 μ d

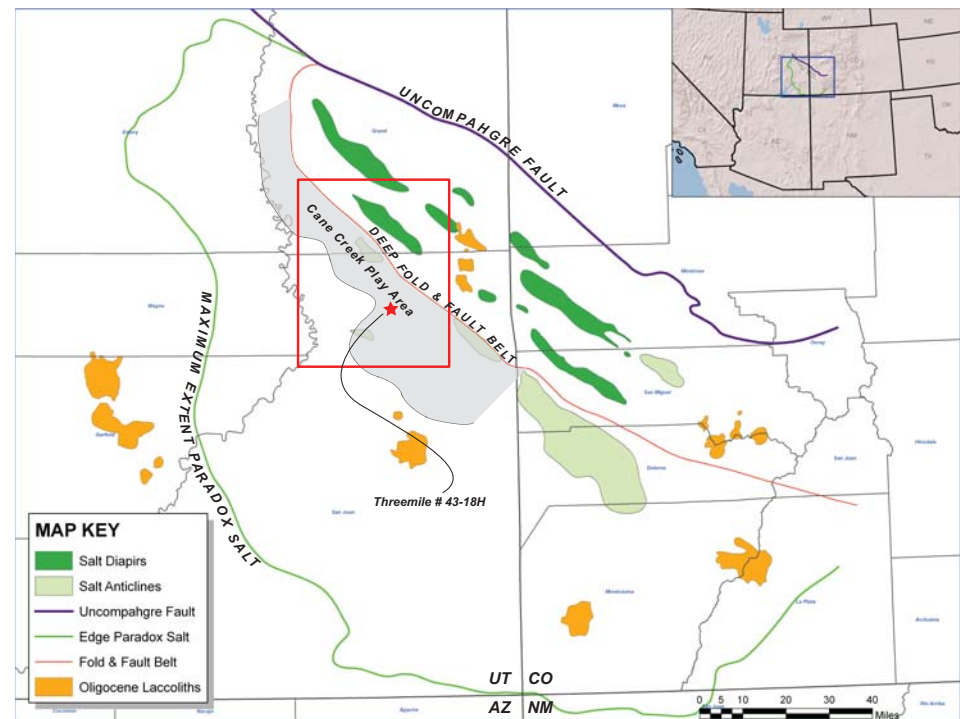
THREE FORKS DOL
Porosity 7.5%
Permeability 1-30 μ d



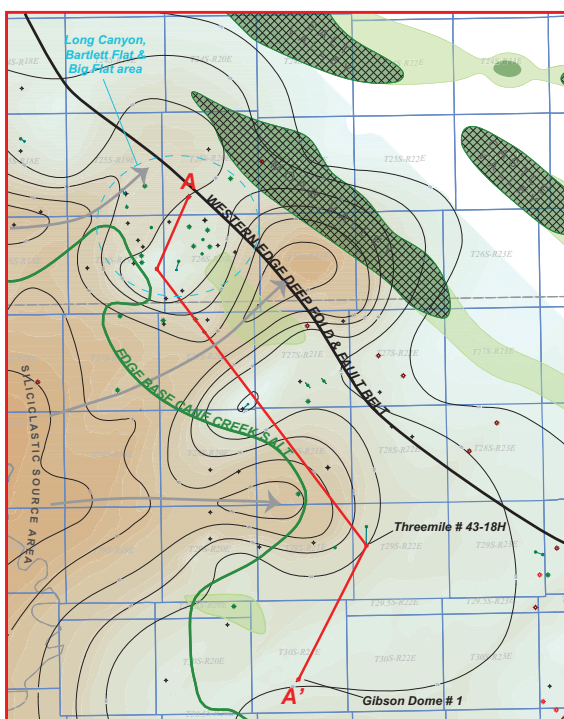
7611.5' - dolomitic siltstone; even yellow fluorescence throughout

7623.5' - dolomitic - calcareous siltstone; even yellow fluorescence throughout

MINERAL CONSTITUENTS	Core Depth (ft.)		
	7593.5	7600	7611.5
RELATIVE ABUNDANCE (%)			
Quartz	49	54	51
Plagioclase Feldspar	trc	trc	trc
K-Feldspar	3	4	3
Calcite	1	6	
Dolomite	32	8	34
Halite	5	1	1
Anhydrite		3	
Pyrite	1	1	1
Kaolinite	1	trc	
Chlorite	trc	1	1
Illite/Mica	6	15	6
Mixed-Layer Illite/Smectite	2	7	3
% Illite Layers in ML I/S	75-85%	70-80%	80-90%



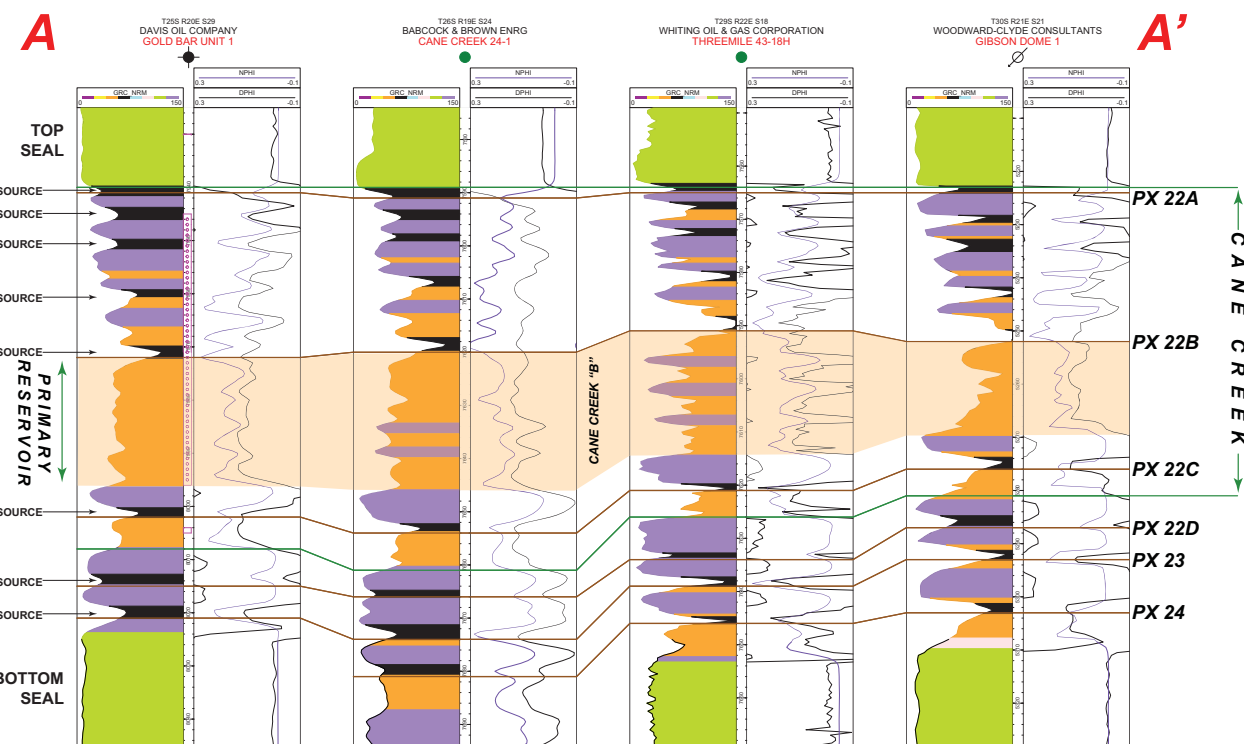
Map of Paradox Basin showing Cane Creek tight oil resource play area which extends for 75 miles or more in length and 10 - 20 miles in width. The western limit of the play area is defined by the maximum extent of sub-Cane Creek salt, and the eastern limit is the edge of the Deep Fold and Fault Belt. Location of Threemile # 43-18H shown for reference.



Map of gross isopach thickness (C.I. = 5') of the Cane Creek "B" reservoir interval. Siliciclastics were likely sourced from the west and thin to a feather edge in the NW and SE extents of the play area. Within the play area they range in thickness from 20 ft to >40 ft.

CANE CREEK PLAY AREA

- The Cane Creek tight oil resource play area occurs along a 75 mi long, 10-20 mi wide NW-SE swath in the northern Paradox Basin (Grand & San Juan counties, UT) adjacent to the Deep Fold and Fault Belt (DFFB)
- Western limit of play area defined by maximum extent of salt beneath the Cane Creek; This is the basal seal of the hydrocarbon accumulation and, together with the top halite seal, is responsible for the near lithostatic overpressure in the reservoir
- Eastern limit of play area defined by the western edge of the DFFB; This is a convenient limit, as the Cane Creek does occur in places within the DFFB, but in most areas it is either missing in the salt withdrawal minibasins or caught up in massive salt flowage in diapirs and anticlines
- The Cane Creek "B" (cycle 22B siliciclastic) reservoir is present everywhere, ranging in thickness from 20 to >40 ft; It thins considerably to the NW and SE
- The source is also present everywhere in the play area and is interbedded with reservoir siltstone



SOURCE

- World-class source rocks -- high TOC (up to 44%!!), pure Type II to mixed Type II-III kerogen, currently in the oil window
- Source rocks interbedded with reservoir siltstones

RESERVOIR

- Dolomitic siltstones and silty dolomitic packstones
- Porosities range from 8 to 13% and Permeabilities from 10 to 50 microdarcies
 - As good or better than the Middle Bakken or Threeforks
- Good, even blue to yellow UV fluorescence indicates good hydrocarbon saturation
 - Sw from 20-35% likely irreducible
- Closely-spaced (1/2 to 1 cm) subvertical and additional subhorizontal fractures noted in several sidewall core samples; indicates brittle, fracture-prone reservoir
- Mineralogically, there are very low proportions of problematic minerals; chlorite and kaolinite are 1% or less; illite is mostly detrital and the %smectite in mixed-layer illite/smectite is very low; pyrite is ~1%; salt is 5% or less

SEAL & TRAP

- Salt above and below the Cane Creek interval forms an excellent seal
- Low reservoir permeability results in pervasive reservoir saturation with little opportunity for regional lateral migration

DRILLING SUMMARY

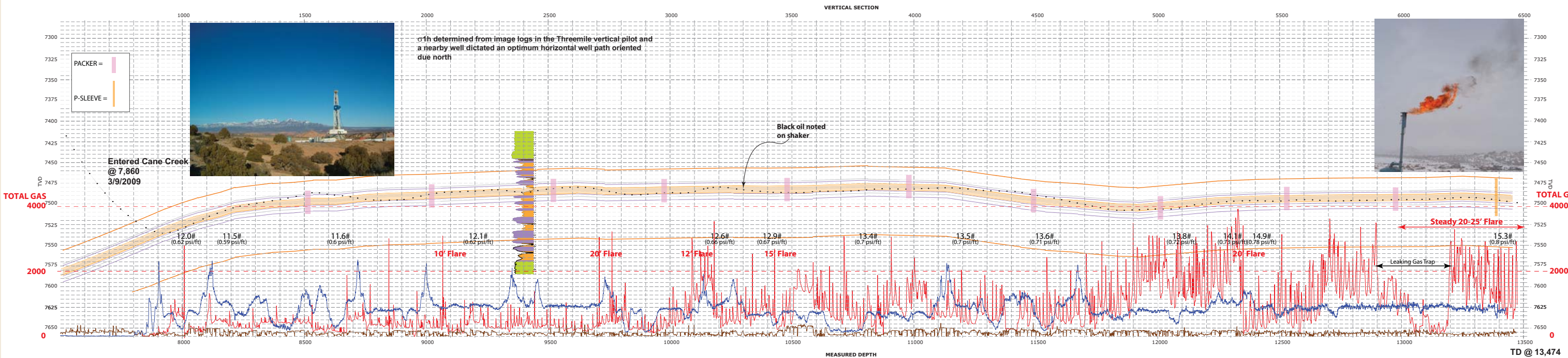
- 3D seismic absolutely critical for avoiding structurally complex areas and steering the horizontal
- Steered at top of Cane Creek "B" siltstone with black carbonaceous mudstone above and 2' anhydrite below as marker beds
- Stayed in 4' to 6' zone for 93% of horizontal
- Mud weight continually raised over length of horizontal from 11.5# (0.59 psi/ft) to 15.3# (0.8 psi/ft) to keep well from flowing
- Mud gas continually increased over length of horizontal; Oil over shakers @ 10,300'; Steady 20-25' flare and well attempting to flow during final 500' of drilling completed
- A pit gain of 600 Bbl was noted after drilling completed
- Horizontal TD'd @ 13,474' on 4/11/2009
 - 5,600' in Cane Creek
 - Longest Cane Creek horizontal drilled to date by 2x

WHENCE THE WATER?

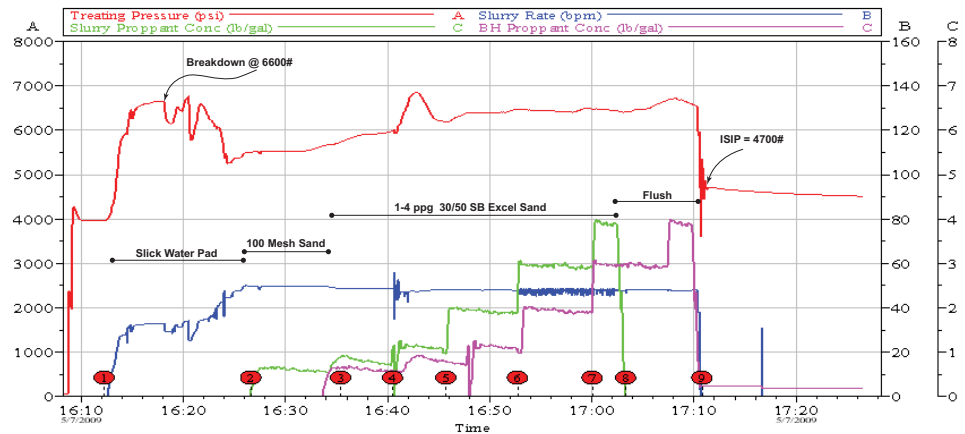
- Water accounts for 70 - 80% of produced liquids
 - VERY unusual** for Cane Creek producers which usually make < 10% water cut
- Is it possible that the Cane Creek matrix is wet?
 - Unlikely** -- Dean Stark extraction of sidewall core plugs suggested 25-35% Sw; even UV fluorescence points to HC saturation of the effective pore space
- Did the frac stimulation propagate through the basal salt into a wet zone below the Cane Creek?
 - Unlikely** -- A continuously cored interval from the nearby Gibson Dome #1 suggests that there is no interval in the Lower Hermosa capable of producing water and the large number of shales in the Lower Hermosa would be a major barrier to any frac that might propagate into the underlying Leadville LS
- The water appears to be on a linear decline (fracture drainage) and the oil on a hyperbolic decline (matrix drainage)
 - One possibility is that the water is coming from the microfracture network within the Cane Creek; however, observed fractures appear to be healed and not wet

WHAT ABOUT THE SALT?

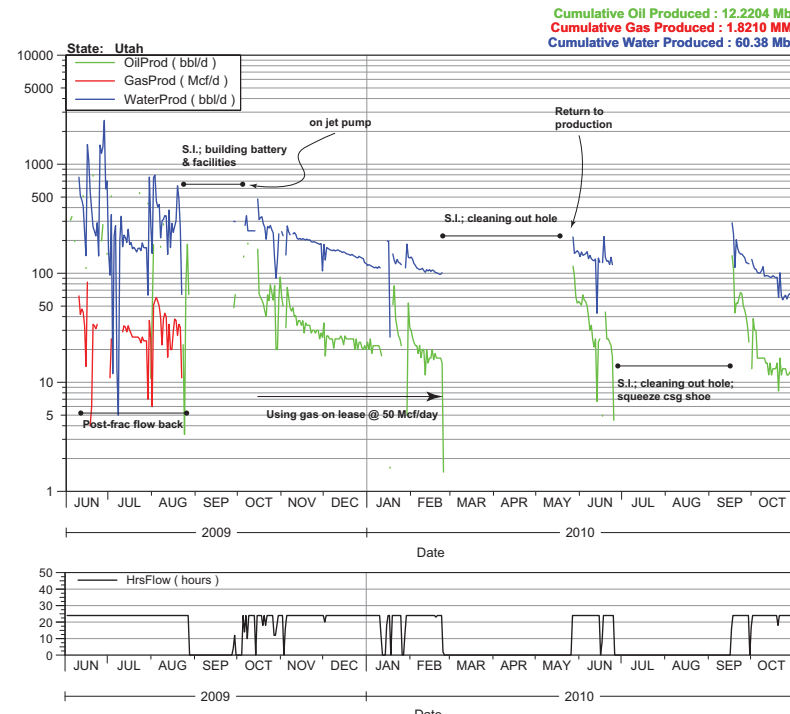
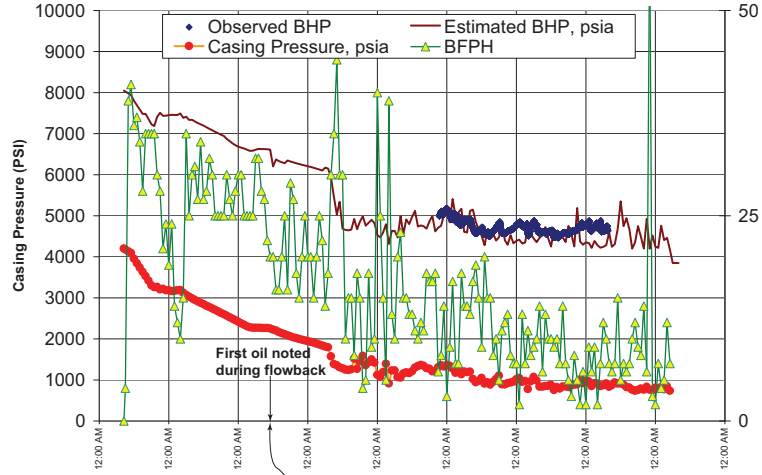
- Salt can be an excellent (perfect?) seal, but is it capable of producing large volumes of water? Is it a frac barrier, or will it frac?
- Numerous coarsely-crystalline, vuggy intervals in salt within 100' of the Cane Creek were observed in the Gibson Dome core; these would likely be over-pressured and capable of producing an unknown volume of water if connected to the production interval
 - Major through-going fractures? frac propagation? channels behind 7" casing?



STAGE 1 TREATING CHART



STAGE 1 FLOWBACK



Photographs of vugs in salt section immediately overlying the Cane Creek in the Gibson Dome #1 core.



TAKE AWAY POINTS / CONCLUSIONS

- The Cane Creek petroleum system has all of the hallmarks of a pervasive tight oil accumulation
 - The reservoir is over-pressured, naturally fractured, has low porosity & permeability, and is interbedded with world class oil-prone source rocks that are currently in the oil window
 - Salt seals above and below form the ideal container resulting in near lithostatic over-pressure in the reservoir; low permeability prevents long distance lateral migration of oil
- Excellent hydrocarbon shows while drilling the Threemile # 43-18H indicate a HC saturated reservoir
 - As horizontal length (k'h) increased, greater mud weight was required to hold back ever-increasing mud gas; well attempted to flow during final 500' of drilling and an overall 600 Bbl pit gain was noted post-drilling
- The Threemile # 43-18H was successfully frac stimulated over 11 stages using plug & perf method with approximately 110,000# sand and 2,000 Bbl cross-link gel per stage
- A significant NaCl water cut unusual for the Cane Creek is currently being produced along with oil and gas
 - Water production is on a linear decline and may indicate fracture-like drainage, while oil appears to be on a hyperbolic decline, indicating reservoir matrix drainage
- Salt 25-30' above the horizontal target is a possible source of brine
 - Numerous large, open vugs were observed in coarsely-crystalline salt in the nearby Gibson Dome #1 core; these are likely over-pressured and capable of producing an unknown volume of brine if connected to the production interval; if the halite is not a frac barrier, then they could have been contacted by the frac; if salt behaves as a frac barrier, then they could be connected via channels behind 7" casing or major fractures
- Future success of the Cane Creek tight oil resource play may involve a combination of long horizontals and a modified completion design; work on the Threemile # 43-18H to minimize water production is on-going

COMPLETION SUMMARY

- DFIT on Stage 1 indicated natural fractures and was critical in evaluating reservoir properties prior to full frac job
- Plug and perf stage frac method used because screen out potential existed with ball sleeve system
 - Hindsight indicates that ball sleeves would have been preferred as far as time and costs were concerned
- Used hybrid frac system with 100 mesh sand for leakoff control in pad ahead of cross-linked gelled water system with a 1-4 ppg 30/50 white sand followed by 30/50 SB-Excel resin-coated tail to control post job sand movement
- Surface microseismic and tracer in frac sand was utilized to evaluate frac job placement and formation stress orientation
- Cleanout of frac plugs was difficult in this long horizontal wellbore using coil tubing equipment and required the use of stick tubing and downhole motor
 - Some of this cost would have been avoided using the ball sleeve technology mentioned above

DFIT SUMMARY

- Pumped ~100 Bbls 7%KCl water @ 20 BPM, 4786#, surf ISIP = 4185#
- BH ISIP = 7575#; Fracture gradient = 1.01 psi/ft
- Pressure-dependent type leakoff was observed during shut-in
- Fissure opening pressure = 7303#
- Hydraulic fracture closure est = 7202#; Closure gradient = 0.96 psi/ft
 - G-time = 36 hours
- Horizontal pseudoradial flow was NOT observed during shut-in
 - Hence, only an Upper Limit for k'h could be obtained
 - k'h << 41.69 md-ft
- Pore pressure estimated to be ~7040# or 0.938 psi/ft after-closure pseudolinear flow analysis

PRODUCTION

- Salt control in downhole and surface equipment was a major factor in the design of the production system; Fresh water used as a diluent and a power fluid for the jet pumping system
- The cost of water disposal is 70% of the operating costs for the well; Identification and isolation of brine producing zones that could later precipitate salt as the brine cools moving uphole is of utmost importance
- Produced gas is used to power the surface injection pump engine and for fuel treating and oil sales tank heaters
- Oil sales are by truck haul over gravel roads for 20+ miles; market for crude is Farmington or Salt Lake City; Full field development would require surface pipeline and loading station near pavement due to cost and environmental impacts