Using Pore System Characterization to Subdivide the Burgeoning Uteland Butte Play, Green River Formation, Uinta Basin, Utah*

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*Adapted from oral presentation given at 2019 AAPG Rocky Mountain Section Meeting, Cheyenne, Wyoming, September 15-18, 2019

Abstract

Over 100 horizontal wells have been drilled in the large and growing Uteland Butte play in the past decade, with decidedly variable results. The best wells cum north of 300K barrels in the first 12 months of production, with conservative EUR's well above a million barrels per well. Conversely, the poorest Uteland Butte wells IP less than 10K in the first year and will never pay out their drilling costs. Pore pressure, oil viscosity, well length and frac size are recognized as important controls on well productivity, but the variable reservoir types within the Uteland Butte play is perhaps less understood. Defining each sub-play by its pore system, there exists four distinct sub-plays within the Uintah Basin; 1) A proximal play dominated by siliciclastic and carbonate grainstone pores, mostly normally pressured and charged by migrated hydrocarbons. This play has an average maturity of 0.5-0.7 VRo and produces highly viscous black wax with very low GOR's. To date, these wells have not been successful. 2) An intercrystalline-pore dominated play, with dolomites acting as the best reservoirs and at normal pressure or slightly above charged by mostly migrated hydrocarbons. This play was the first to be drilled horizontally because the dolomites are the most conventional targets. The Uteland Butte is quite thick in this fairway, consisting of over 130' carbonates and black shales, but only a fraction are high-porosity dolomites. This play has an average VRo of 0.6 to 0.8 and produces a black wax with low GOR's. 3) A mixed intercrystalline-organic porosity play, with significant overpressure and largely self-charged or with very short migration of hydrocarbons. This sub-play has the thickest gross section, but much less net dolomitic reservoirs. However, high TOC carbonates and shales contribute significant production. Maturities in this play vary from 0.8 to 1.0 VRo and produces a yellow to grey wax with moderate GOR's 4) an organic porosity dominated play, highly overpressured and completely self-sourced. Relatively little carbonate exists in this fairway and almost no reservoir-quality dolomites. Productive reservoir consists of organic porosity largely contained in bitumen mats that are expelled at lower maturities, then continue to thermally degrade with higher maturity, converting to zones of interconnected organic porosity. Maturities range from 1.0 to 1.2 VRo and produces a bright yellow wax with relatively high GOR's. By recognizing the important differences these pore systems exert on best development practices and then accurately mapping them across the basin, operators, interest owners and regulatory agencies can better plan operations.

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References Cited

Boden, T., and B.T. Tripp, 2012, Gilsonite Veins of the Uinta Basin, Utah: Special Study 141, Utah Geological Survey, ISBN 978-155791-856-7

Brinkerhoff, A.R., and K. Woolf, 2018, Characteristics of Sandy Hyperpycnite Deposits on the Shallow, Southern Margin of Eocene Lake Uinta, the Green River Formation of Northeastern Utah: Search and Discovery Article #51495, http://www.searchanddiscovery.com/pdfz/documents/2018/51495brinkerhoff/ndx brinkerhoff.pdf.html

Chaparro, F.R., H.G. Machel, and M.D. Vanden Berg, 2019, Dolomitization in the Uteland Butte Member of the Eocene Green River Formation, Uinta Basin, Utah: Utah Geological Survey Open-File Report; In Press

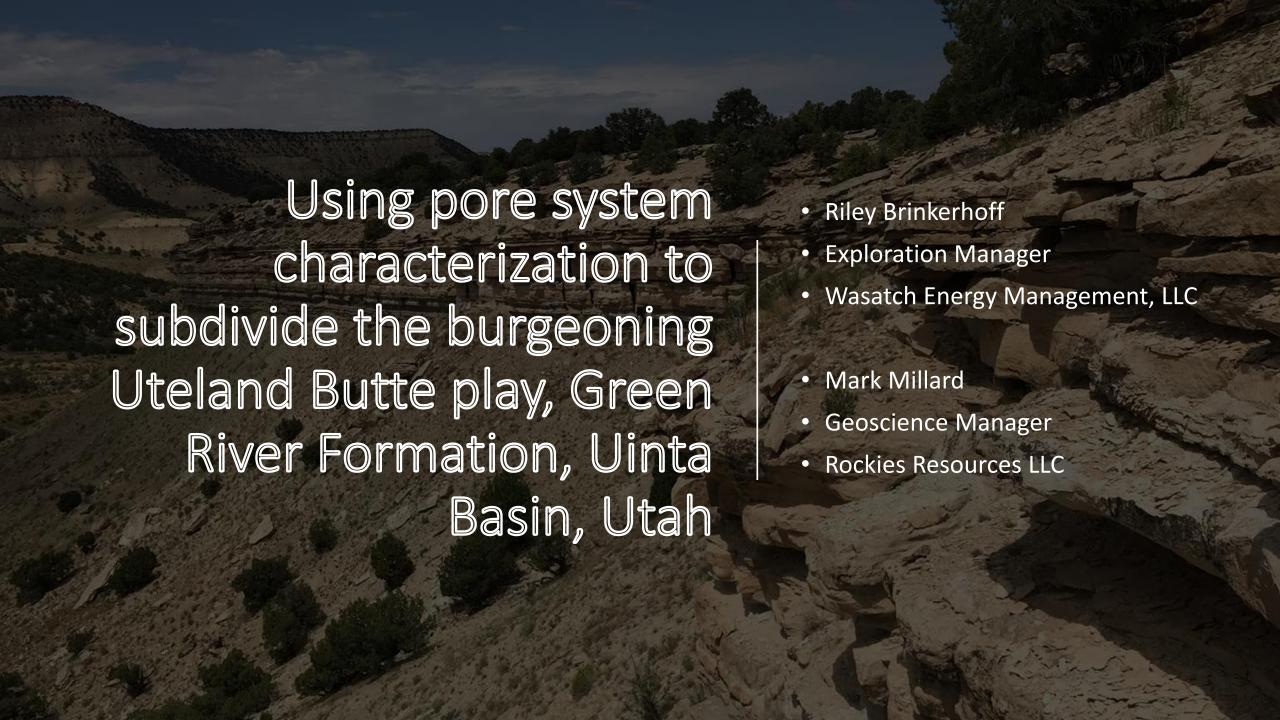
Eldridge, G.H., 1901, The asphalt and bituminous rock deposits of the United States, in Walcott, C.D., director: U.S. Geological Survey Twenty-second Annual Report of the United States Geological Survey to the Secretary of the Interior, pt. 1, p. 209–364.

Logan, S.K., J.F. Sarg, and M.D. Vanden Berg, 2016, Lithofacies, deposition, early diagenesis, and porosity of the Uteland Butte member, Green River Formation, eastern Uinta Basin, Utah and Colorado: Utah Geological Survey Open File Report 652, 32 p., Online, ugspub.nr.utah.gov/publications/open-file-reports/ofr-652.pdf

Morgan, D.M., and R.W. Stimpson, 2016, Characterization and Horizontal-Drilling Potential of Oolitic and Ostracodal Limestone Reservoirs in the Eocene Green River Formation, Northeastern Uinta Basin, Utah: Utah Geological Survey Open-File Report

Ruble, E.T., M.D. Lewan, and R.P Philip, 2001, New insights on the Green River petroleum system in the Uinta basin from hydrous pyrolysis experiments, AAPG Bulletin, v. 85/8, p. 1333–1371.

Vanden Berg, M.D., R.E. Wood, S.M. Carney, and C.D. Morgan, 2014, Geological characterization of the Uteland Butte member of the Eocene Green River Formation—an emerging unconventional carbonate tight oil play in the Uinta Basin, Utah [abs.]: Rocky Mountain Section AAPG Annual Meeting, Denver, Colorado.



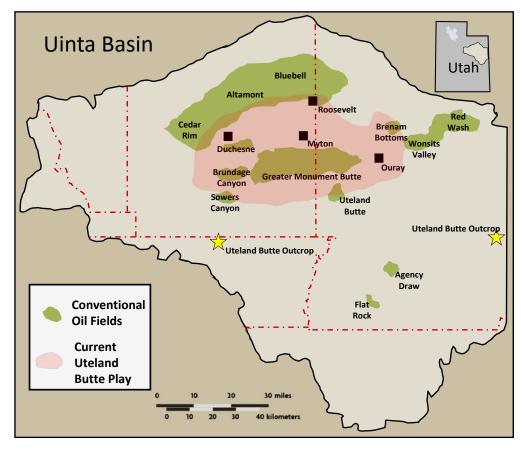


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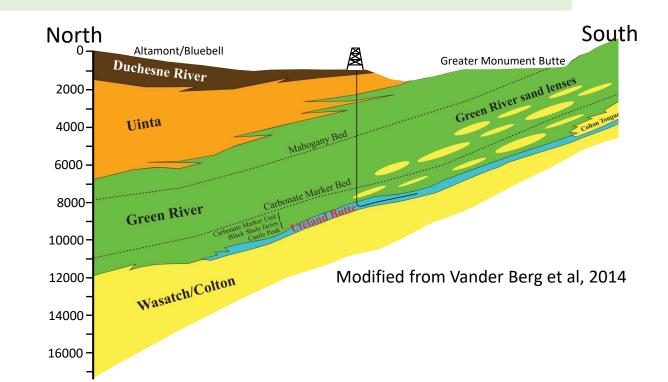


Study Location



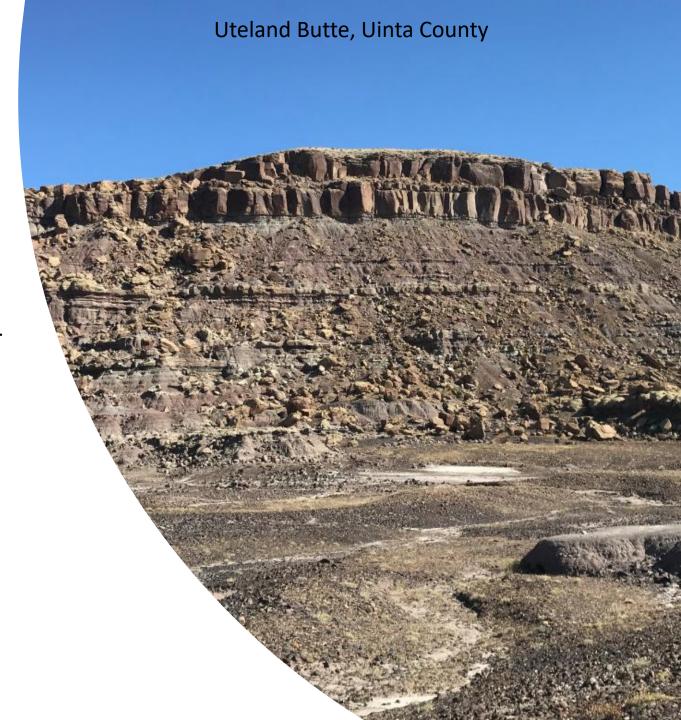
Modified from Brinkerhoff & Woolf, 2018

- Study area extends over 3300 square miles
- 2200 vertical logs
- 17 cores
- Production from 500 vertical and horizontal wells analyzed



Uteland Butte Member Introduction

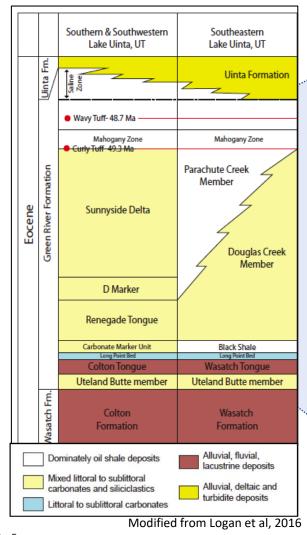
- First identified as "Basal Tongue of the Green River Formation" by Bradley in 1931
- Informally named the Uteland Butte Limestone by Osmond in 1992
- Vertically targeted for decades, first horizontals in 2010
- At 144 horizontals (as of summer 2019)
 - Most commonly targeted interval in the Uinta Basin
- Production results vary widely

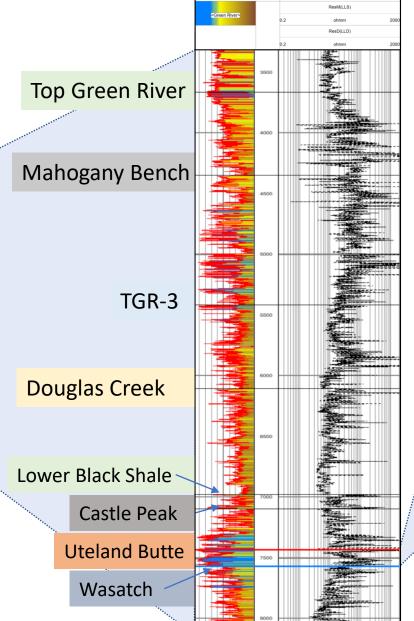


Uteland Butte's Place in the Green River Formation

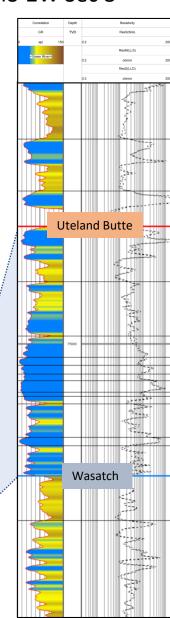
The Uteland Butte is located at the base of the Green River Formation







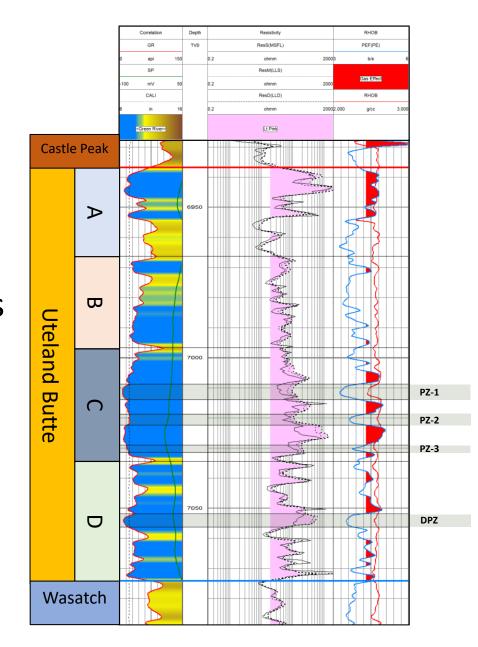
Williams 14-8-4-2 4S-2W Sec 8



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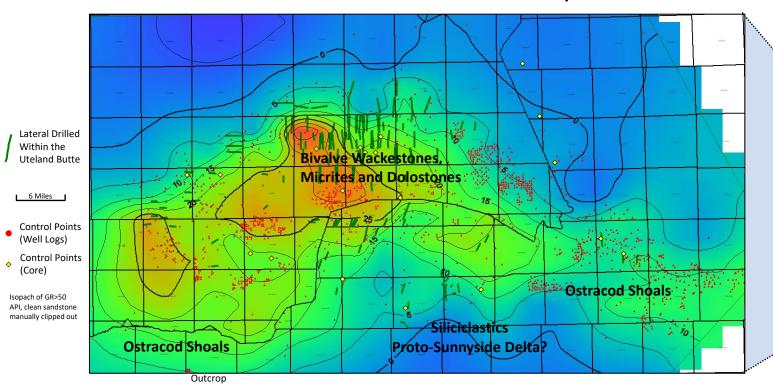
Uteland Butte Stratigraphy

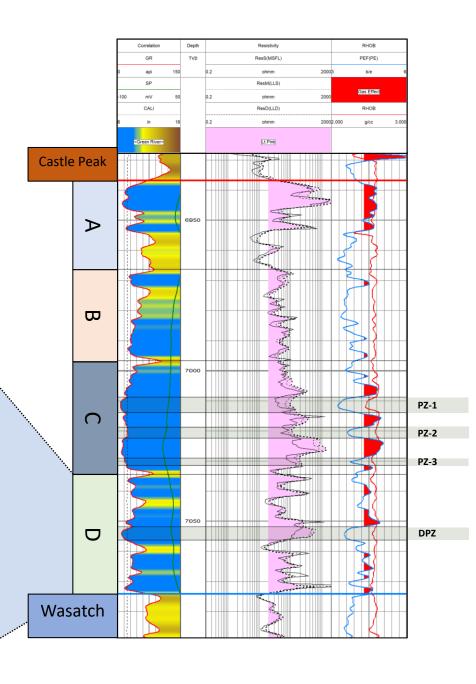
- Represents ~1 MM years of lacustrine deposition (53 to 52 Ma), Smith 2007
- Composed of a succession of interbedded limestone, dolostone, organic-rich calcareous mudstone, siltstone, and some sandstone
- Conformably bounded at the base by the Wasatch/Colton Formation and the top by the Castle Peak Member



D Bench Carbonate Isopach

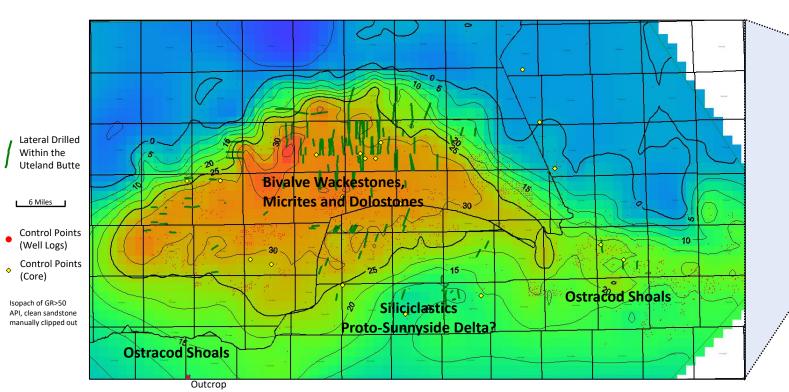
- Initial transgression of Uteland Butte carbonates across the Basin
 - High faunal diversity
- Contains extensive dolostone, the DPZ

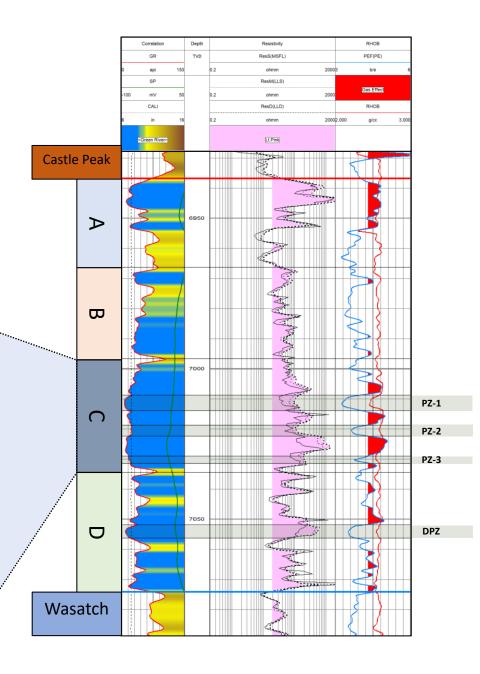




C Bench Carbonate Isopach

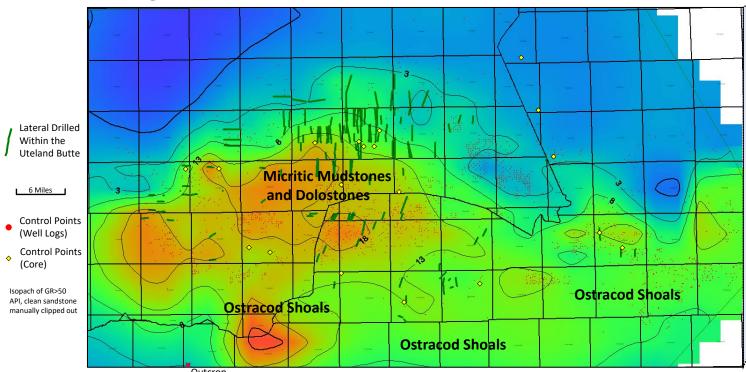
- This interval represents the thickest and most extensive carbonates of the Uteland Butte
 - Likely representing the widest extent of Lake Uinta during Uteland Butte time
 - Richest of the four zones in bivalves and gastropods
- Contains three important dolostones, the PZ-1, PZ-2, and PZ-3

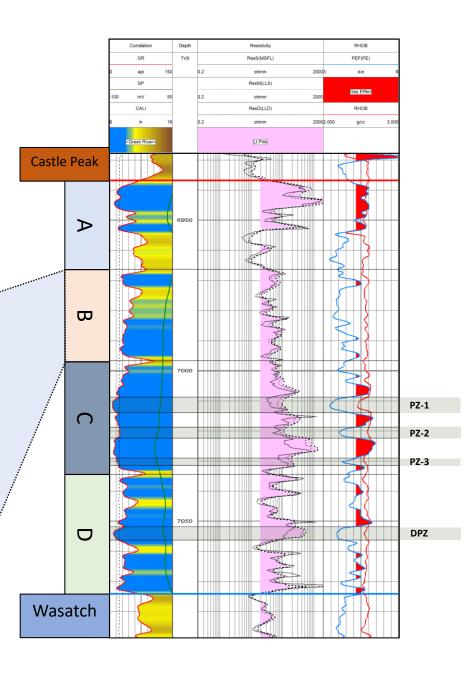




B Bench Carbonate Isopach

- During B Bench time clastics prograde into the lake from the north, while disconnected ostracod shoals dominate the southern margin
 - Bivalves and gastropods become less common
- Minor dolostones in the center of the lake and more high TOC shales

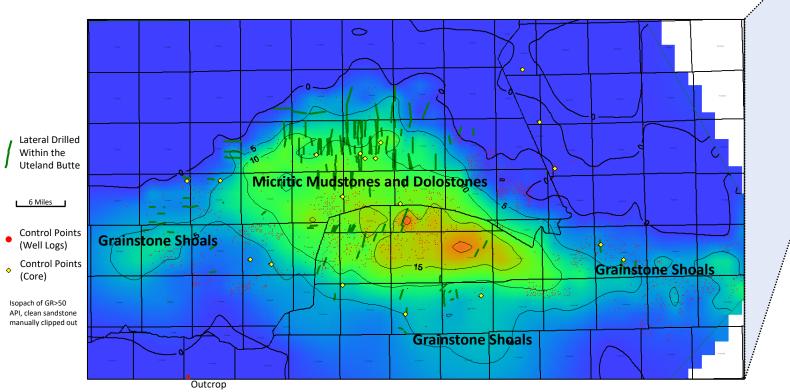


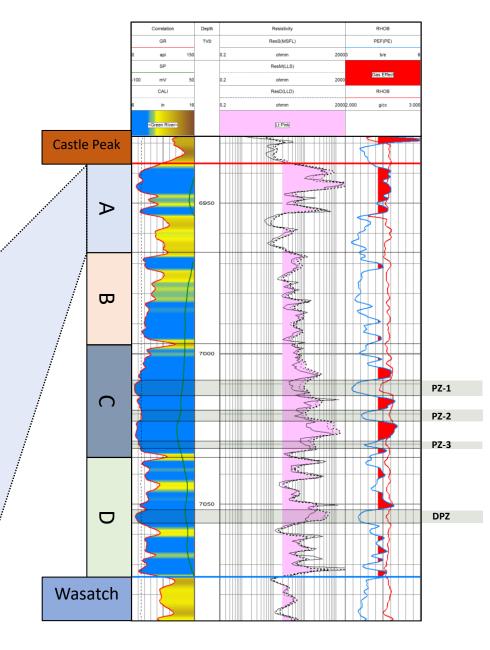


A Bench Carbonate Isopach

• At the end of Uteland Butte time, the lake shrinks to the center of the basin

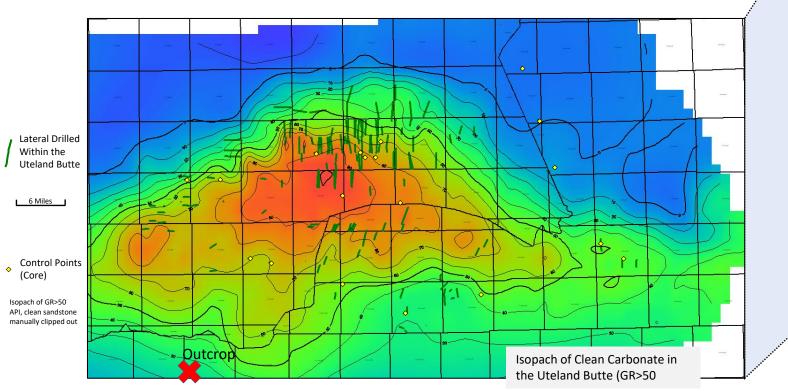
• Few bivalves, more restricted lake

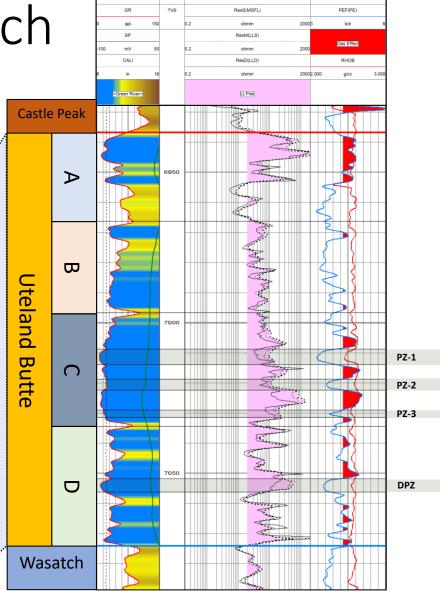




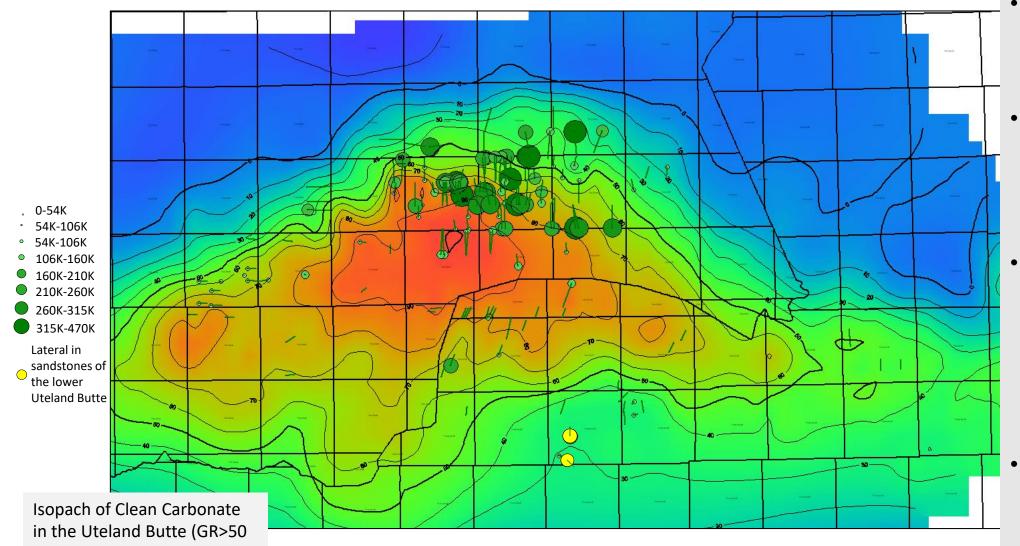
Uteland Butte Carbonate Isopach

 Sum of clean carbonates in the Uteland Butte neatly show the approximate extents of the Lake



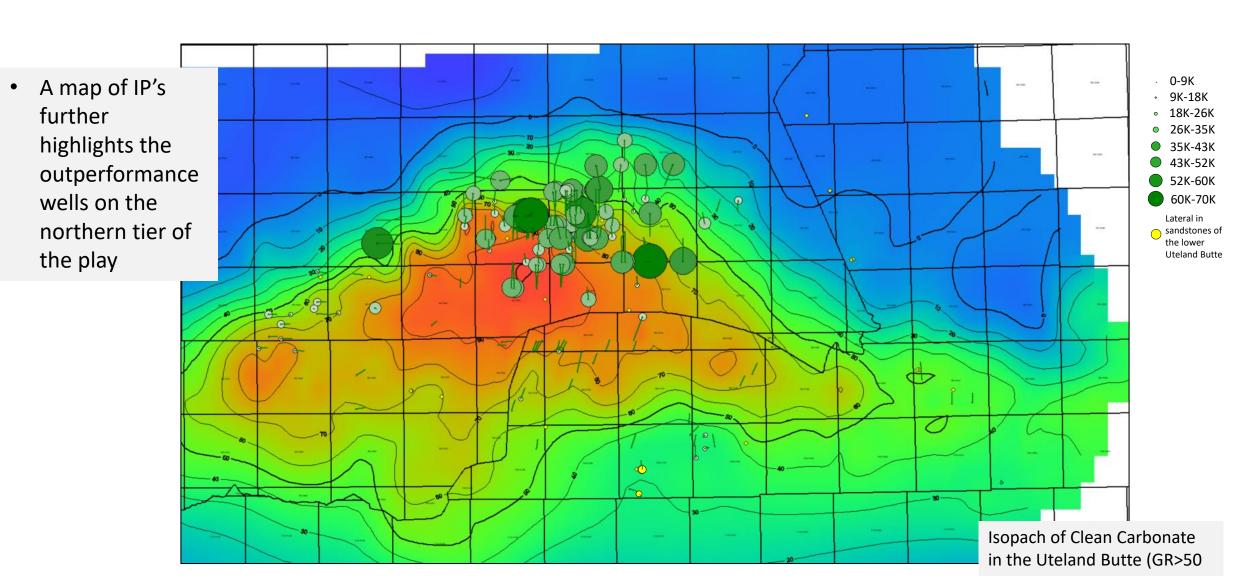


Uteland Butte Cumulative Production



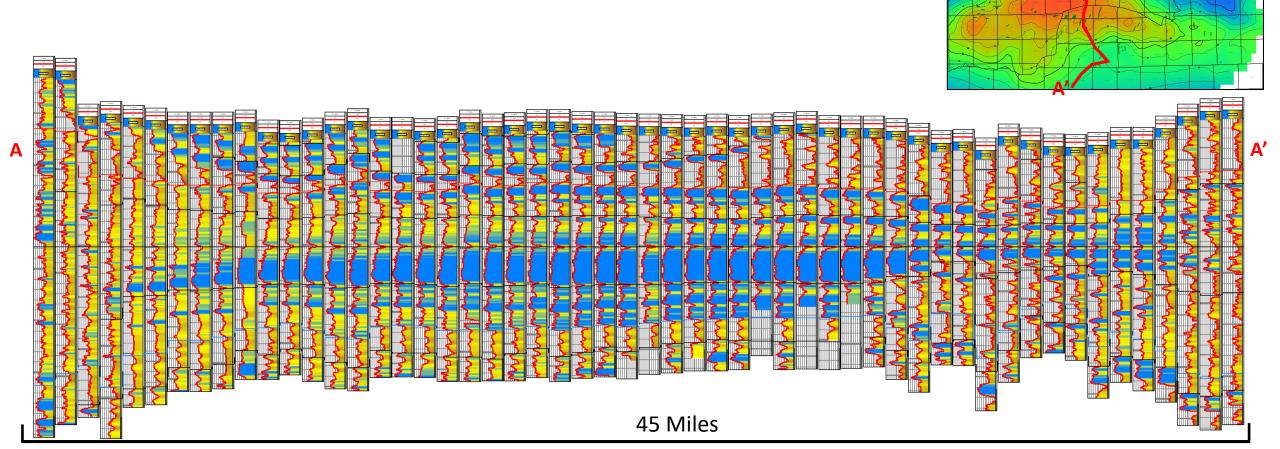
- Longest laterals with the biggest fracs produce the most oil
- Time is an important factor that makes older wells appear better than they are
- Important differences by area
 - In general, production improves to the north
- What are the geologic controls on production?

Uteland Butte Initial Production (Highest Monthly Total)

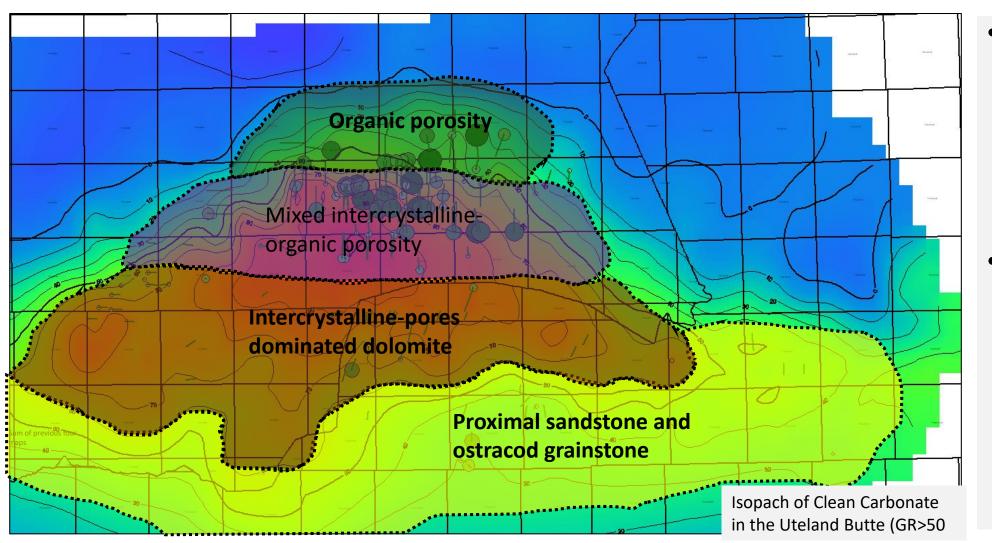


Uteland Butte Lithologies Across the Basin

Thickest carbonates in the center of the basin



Subdividing the Uteland Butte Play Based on Pore Type



- Identifying the dominant poretype by area highlights which reservoirs are being effectively exploited
- Conversely, it also shows where opportunities exist to use better engineering techniques to exploit these potential reserves

Proximal Sandstone and Ostracod Grainstone Sub-Play

- Reservoirs mostly present in the form of nearshore bars and deltas
- Normally pressured and charged by hydrocarbons that have migrated out of the deeper basin
 - Average maturity of 0.5-0.7 VRo



Proximal ostracodal shoals in Hells Hole Canyon, Uinta County, Utah

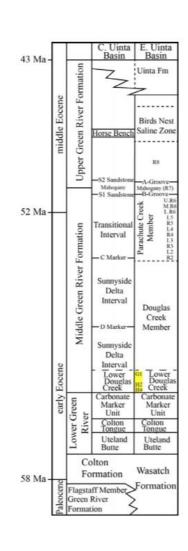


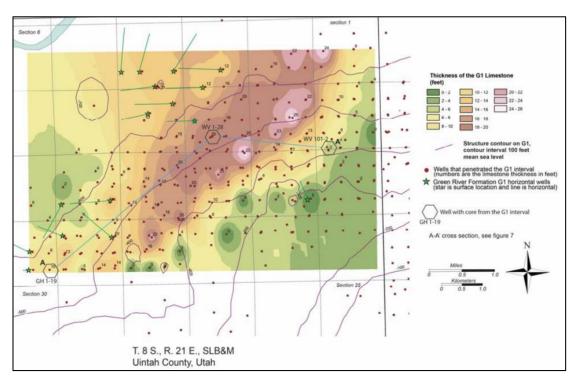
Distal ostracodal shoals pinching out into bivalve wackestone in Hells Hole Canyon, Uinta County, Utah

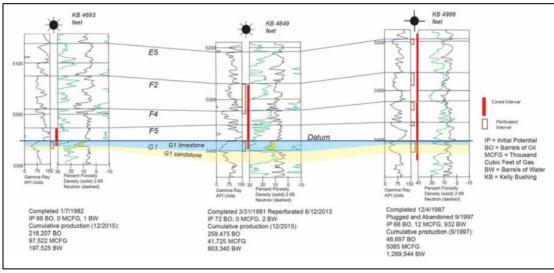
- Produces highly viscous black wax with very low GOR's
- To date, wells drilled in this sub-play have not been economically successful.

G1 Shoal Production: Chasing an Analogue

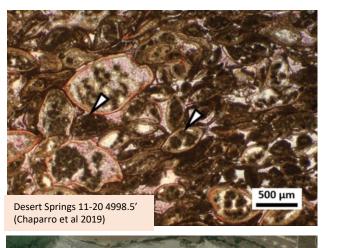
- The G1 shoal is a highly productive oolitic and ostracodal limestone reservoir at the base of the Douglas Creek Member
- Discovered in 1962, this field has made 52MM bbls of oil
- Mostly exploited in vertical wells (some have produced 500,000+ bbls oil)
- Beginning in 2007, it has been targeted by 35 horizontal wells







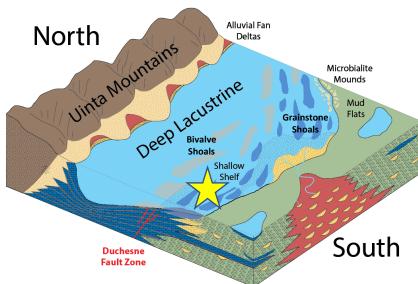
Morgan and Stimpson, 2016

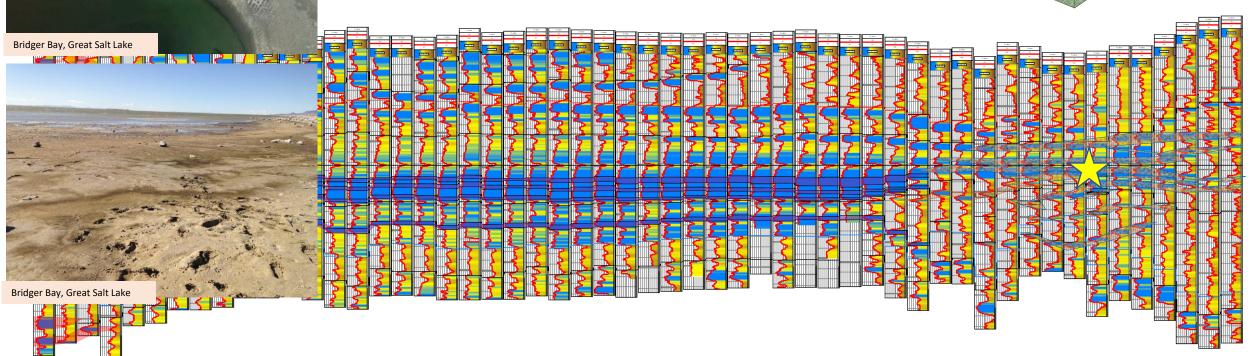


Grainstone Reservoirs

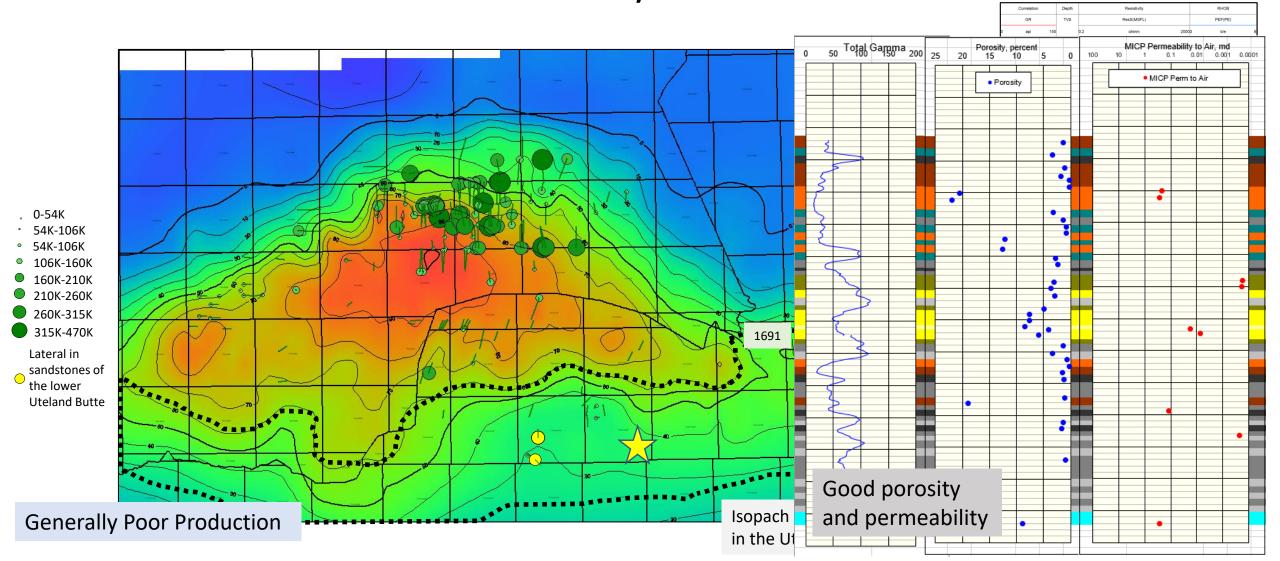
- Ostracod and ooid grainstone shoals
- Laterally extensive along southern flank of the Basin
- First Uteland Butte interval tested horizontally

Uteland Butte Depositional Model



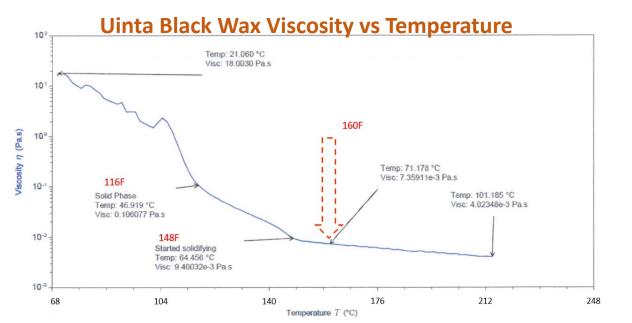


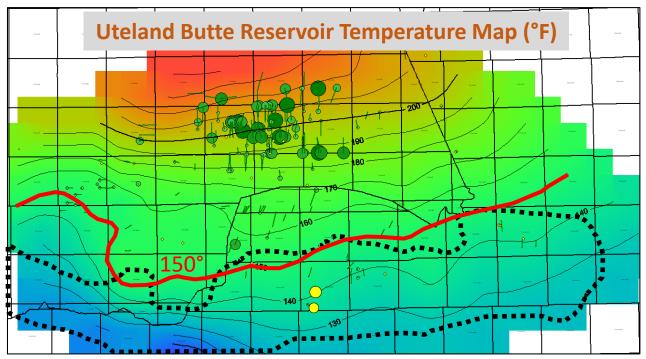
Proximal Ostracod/Ooid Grainstones and Sandstones Make Pretty Good Reservoirs



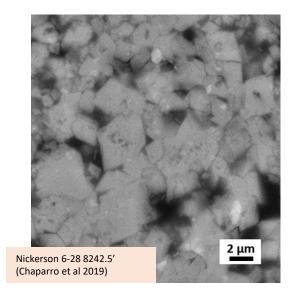
Proximal Ostracod/Ooid Grainstones and Sandstones Make Pretty Good Reservoirs

- Note that the ostracod/sandstone reservoirs lie in a region of the basin that is mostly under 150° F
- The force necessary to push black wax though the reservoir goes up by an order of magnitude from 150° to 120°



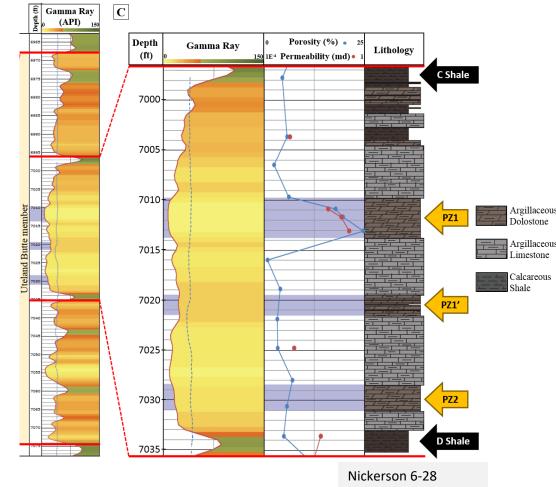


To produce at economic rates, either higher reservoir pressure or much better permeability is necessary

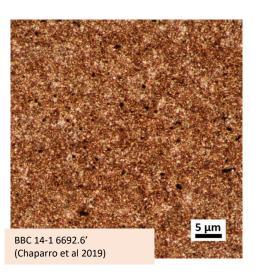


Intercrystalline-Pore Dominated Sub-Play

- Thin, high porosity dolomites and lower porosity bivalve packstones
- Normally pressured, or slightly above
 - Mostly charged by migrated hydrocarbons
- Drilled early in the horizontal play, with the dolomite beds being identified as the highest quality targets
- 130' thick interval consisting of carbonates and black shales with only a fraction being highporosity dolomites
- Average VRo of 0.6 to 0.8
- Produces a black wax with low GOR's.



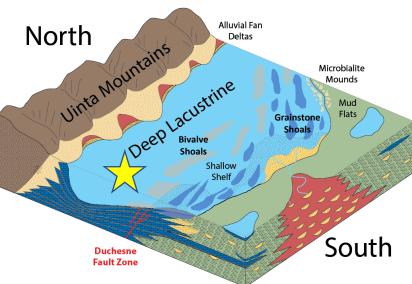
(Chaparro et al 2019)

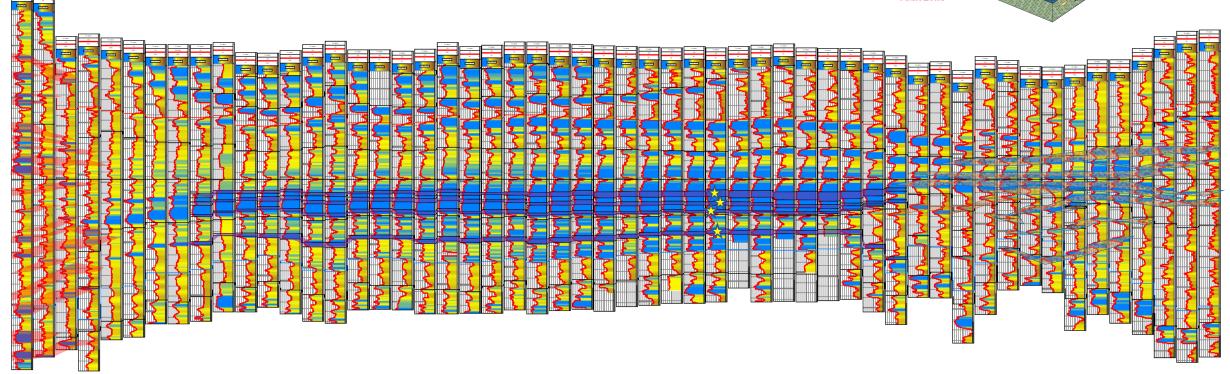


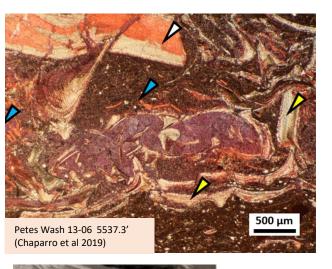
Dolostone Reservoirs

- Layers of dolomites 1'-8' with up to 30% porosity but only a max of 0.1 mD permeability
- Laterally continuous throughout the central portion of the Uteland Butte Play
- The dolomites have higher TOC values than the shoulder beds

Uteland Butte Depositional Model



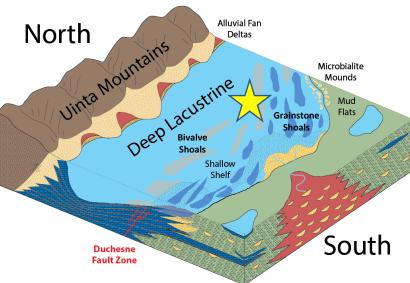


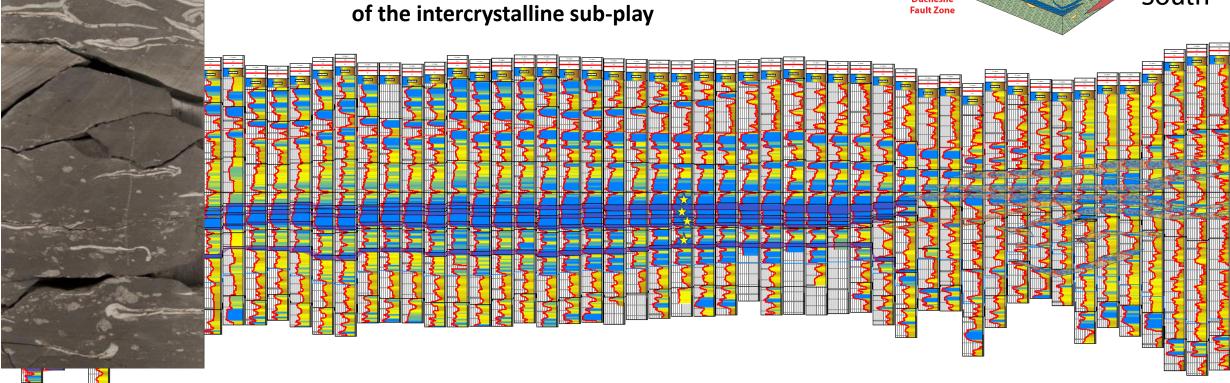


Bivalve Wackestones

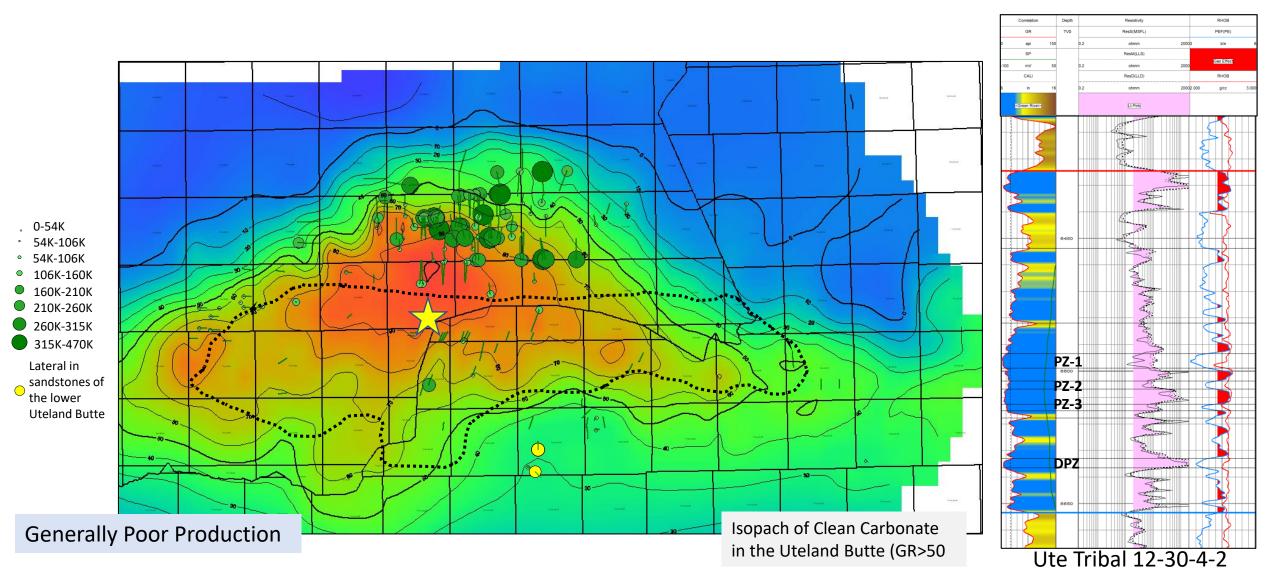
- Extensive in the sublittoral lake
- Interbedded with the dolostones
- Higher clay, lower porosity (~4%), much lower permeability (~0.001 mD) and lower TOC (~1-3%) than the adjacent dolostones
- Not included as an effective reservoir in most of the intercrystalline sub-play

Uteland Butte Depositional Model



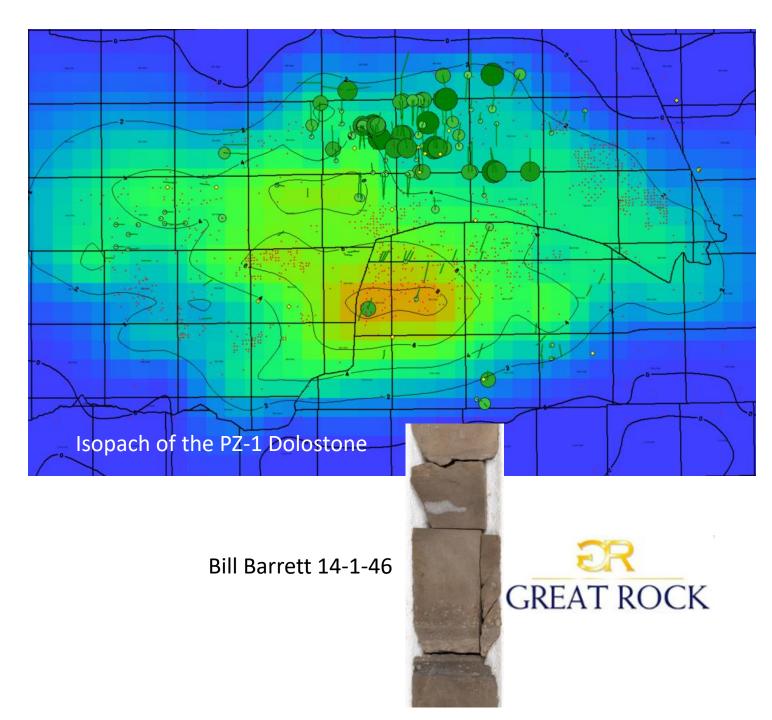


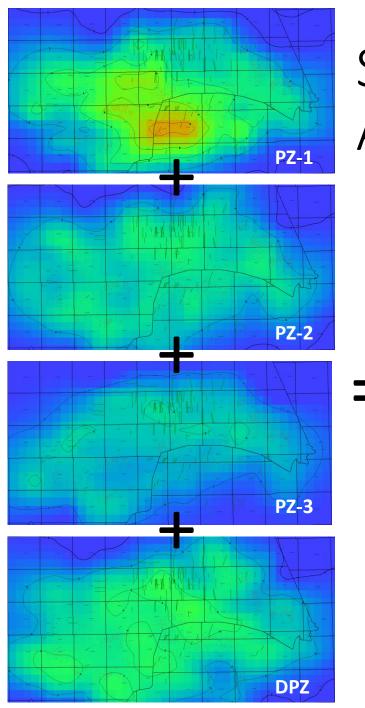
Tested Early, Generally Disappointing Results



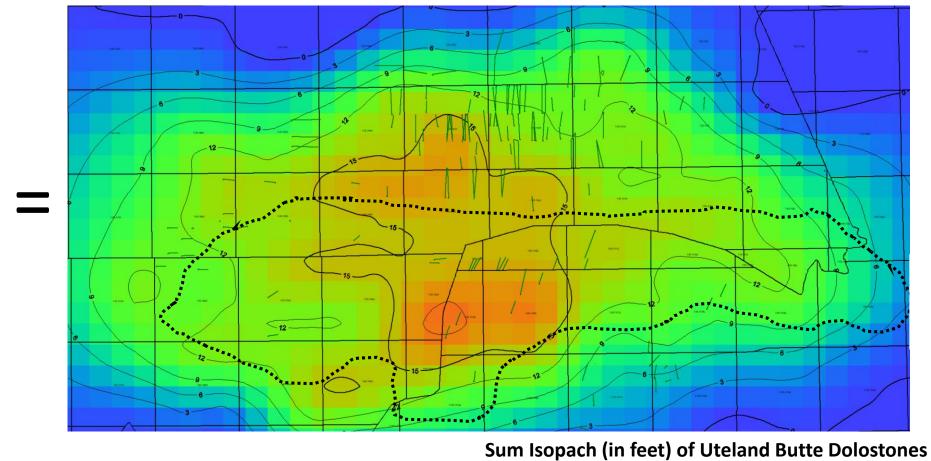
PZ-1 Dolostone

- Early in the play history, the PZ-1 was recognized as the thickest of the dolostones
- Newfield drilled a 15 horizontals, often attempting to keep the lateral within the PZ-1
- Short laterals, small frac volumes and limited reservoirs kept these wells from being large producers



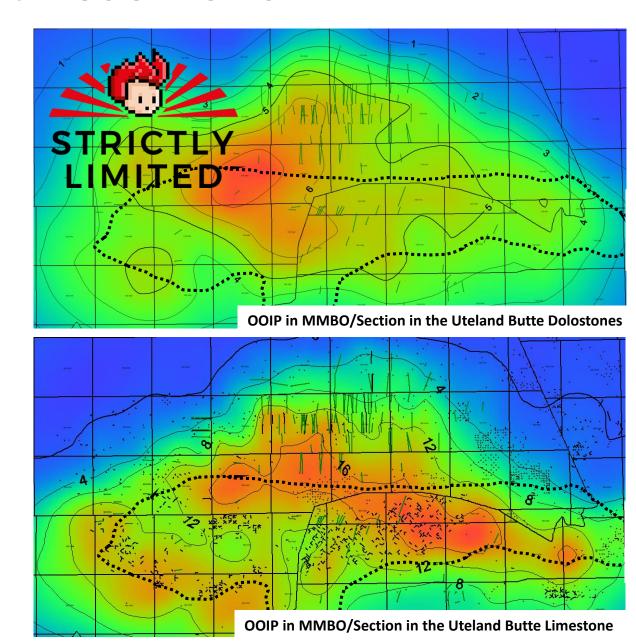


Summed Together, the Dolostones Are Still Rather Thin



Limited Oil in Place in Best Reservoirs

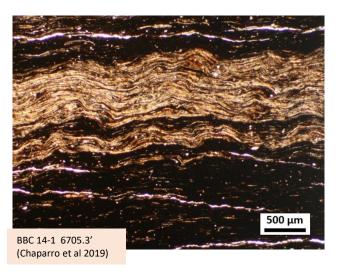
- Within the dolostones, 5-6 MMBO per section is really all that could be expected
- Given the typical recovery rates in unconventional plays of less than 5% of OOIP, well results can be expected to be disappointing
- To improve results, operators would need to increase the targeted inplace volumes by finding a way to make adjacent lithologies contribute
 - Frac strategies
 - Landing zones
 - Sweetspot targeting



Organic porosity

- Highly overpressured and completely self-sourced
- Relatively little carbonate
 - Almost no reservoir-quality dolomites
- Productive reservoirs consist of organic porosity largely contained in bitumen mats that were expelled at low maturities, then continue to thermally degrade at higher maturities, converting to zones of interconnected organic porosity
- 1.0 to 1.2 VRo
- Bright yellow wax
- Relatively high GOR's.

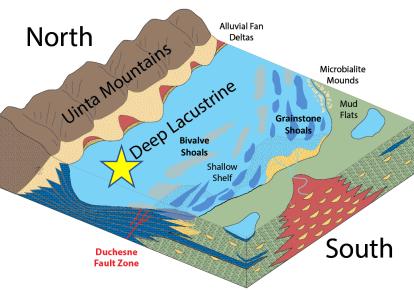


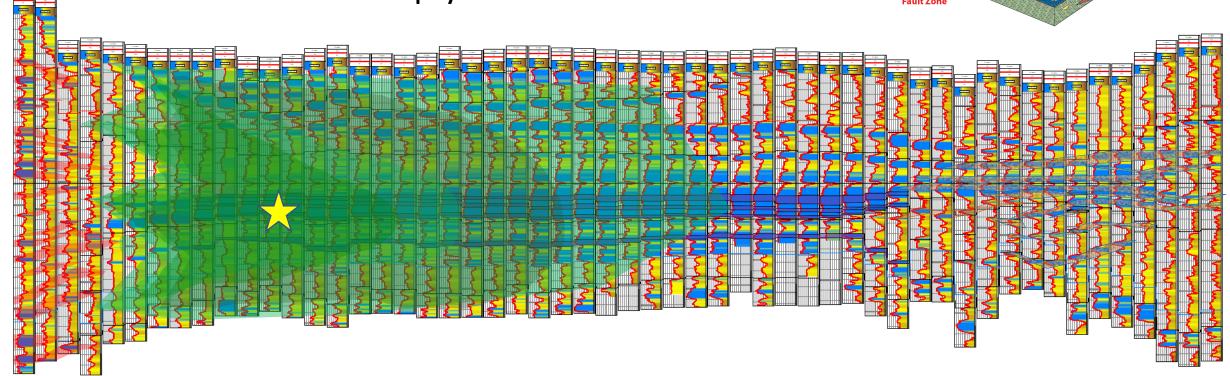


Organic Porosity Reservoirs

- Tied to TOC richness and maturity rather than lithology
- Extensive reservoir type in basin center
- Most productive reservoir in the Uteland Butte play

Uteland Butte Depositional Model



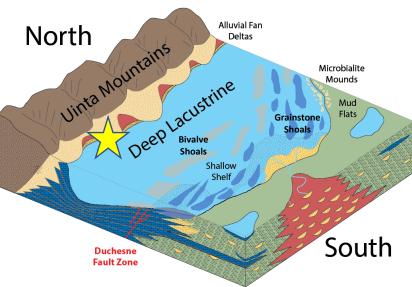


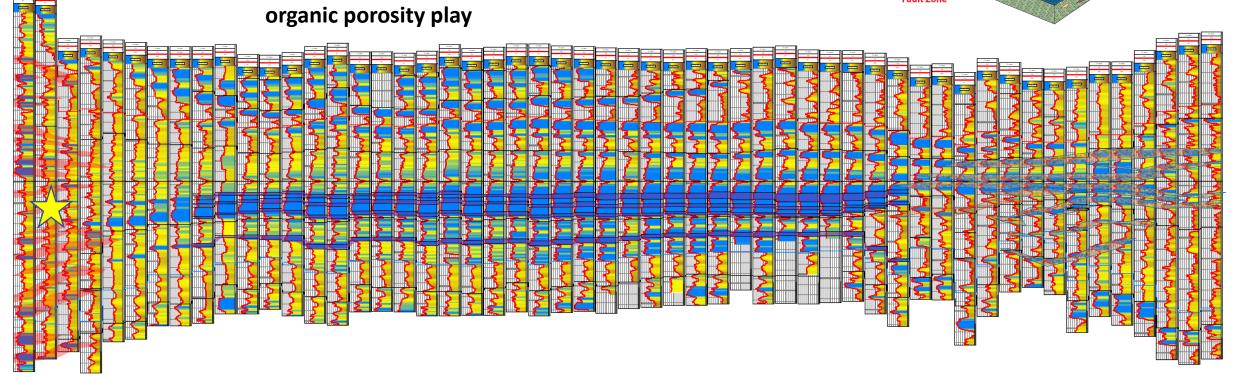


Wasatch Wash

- Relatively course clastic turbidites and gilbertian deltas coming off the rising Uinta Mountains
- Rapid sedimentation tied with faster subsidence lead to a thickening section
- The associated turbid water column poison the carbonate system and dilute TOC
- Not an active play-marks the northern edge of the organic porosity play

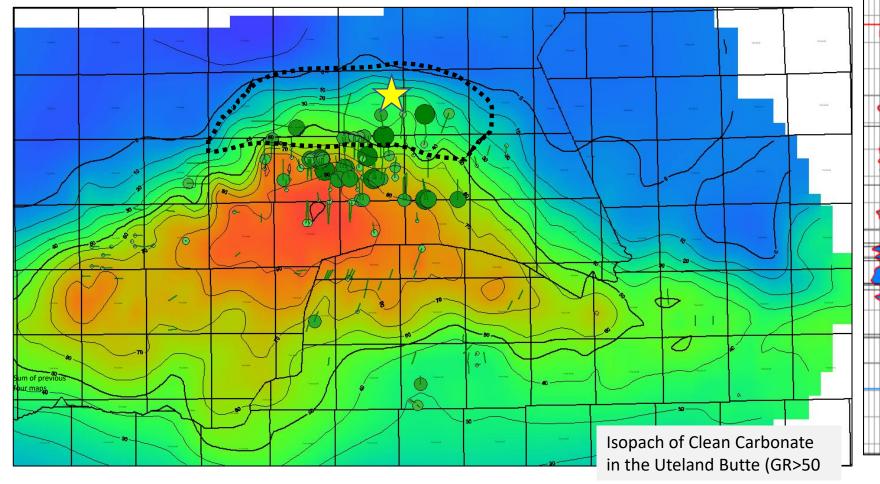
Uteland Butte Depositional Model

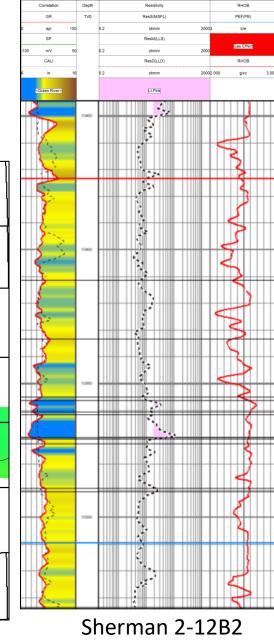




Very Strong Results Associated With An Area of Low Carbonate Percentage

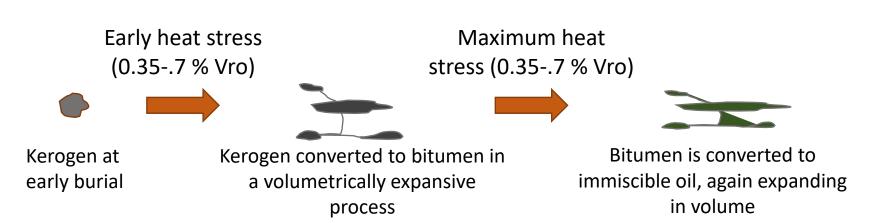
0-54K
54K-106K
54K-106K
106K-160K
160K-210K
210K-260K
260K-315K
315K-470K
Lateral in sandstones of the lower Uteland Butte

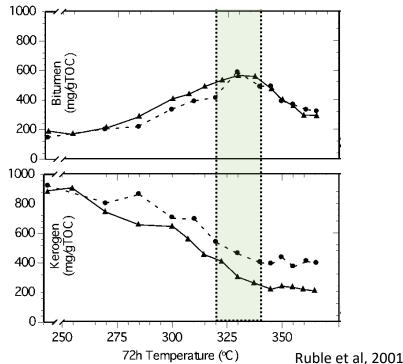




GRF's Two Part Maturation

- Work done by Tim Ruble and others (2001) demonstrated the complex evolution of organic phases yields during artificial maturation of Mahogany and Black Shale samples
- Kerogen fractional volumes fall with exposure to heat stress, but is not directly converted to oil and gas
- Rather, kerogen is converted to bitumen
- With greater heat stress, the bitumen is converted to oil





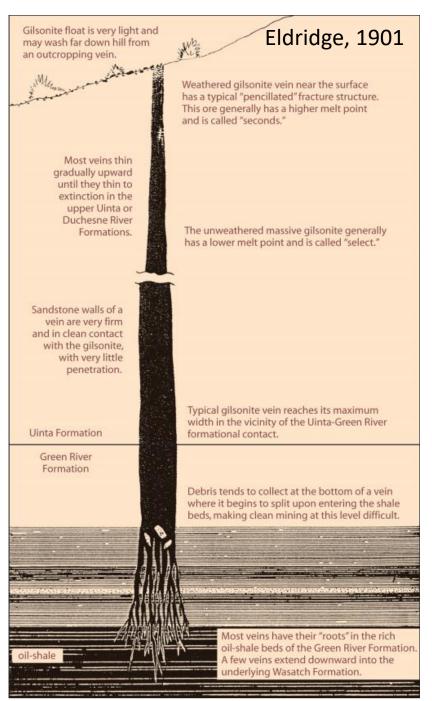
Many Examples of Bitumen Expulsion

 The most prominent example of relatively immature expulsion of bitumen would be the many gilsonite viens that often are sourced in the Mahogany Bed and intrude into adjacent rocks





Boden, 2012

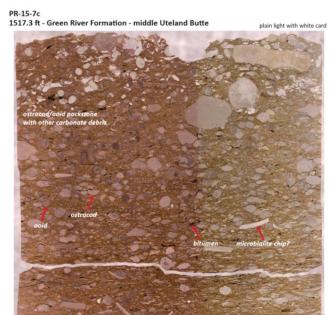


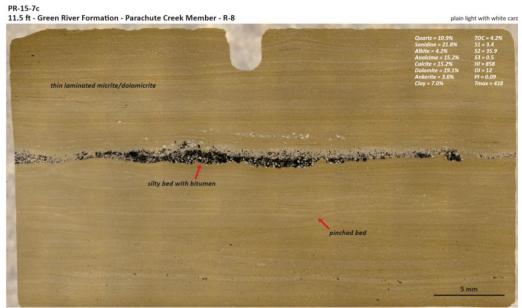
Examples of Green River Bitumen

- The thermal breakdown of kerogen to bitumen involves a significant volumetric expansion
- In early maturation within Green River sediments, bitumen is commonly forced into adjacent pores, vugs, fractures, and in some case with hydrofrac the rock





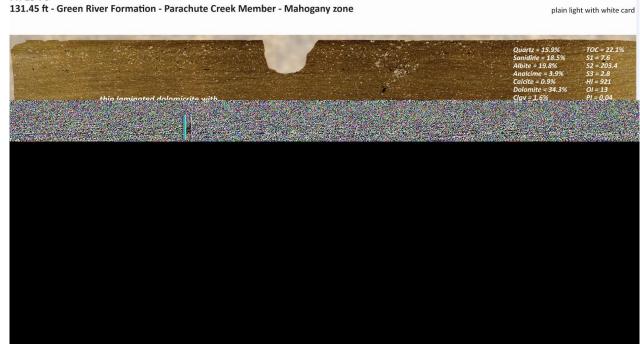




Examples of Green River Bitumen

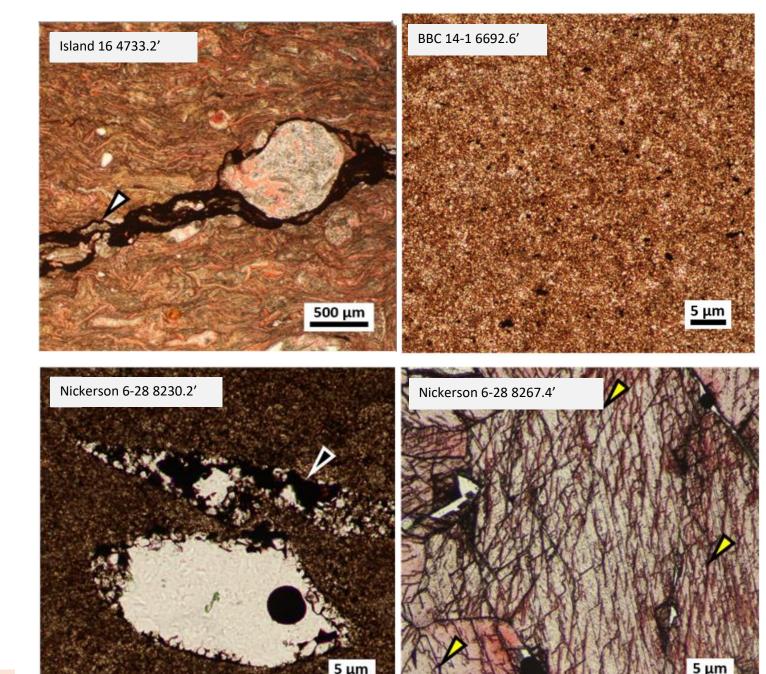
- The thermal breakdown of kerogen to bitumen involves a significant volumetric expansion
- In early maturation within Green River sediments, bitumen is commonly forced into adjacent pores, vugs, fractures, and in some case with hydrofrac the rock





Examples of Bitumen in the Uteland Butte

 Uteland Butte sediments show a similar trend, with bitumen invading intercrystalline porosity in the dolostones, fractures in the bivalve packstones and vugs in the mudstones

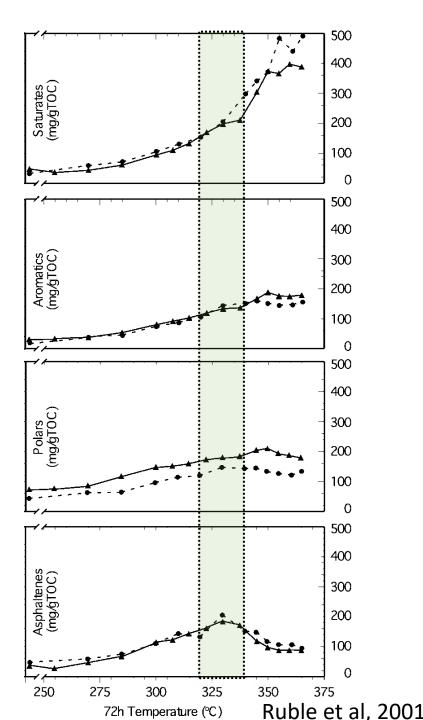


Connected Organic Porosity

- Ruble (1999), through analyzing hydrocarbon fractional yields, similarly shows asphaltenes dominating early generation
- The key takeaway is that the two-stage maturation process leads to large volumes of connected organic porosity – which is filled with oil



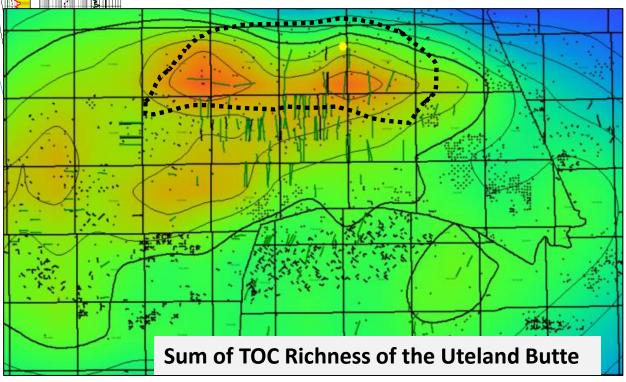
Uinta Basin oils from less mature to more mature



Modeling TOC

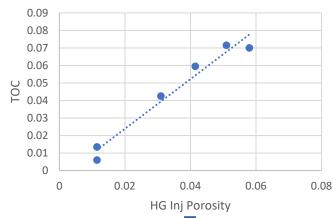
- There are a lot of core available in the Basin with TOC data
- Modifying a Schoker curve by empirically matching it to the TOC data leads to a pretty good match in the Uteland Butte

- TOC curve values can then be summed to give a TOC richness of the Uteland Butte
- Mapping this TOC richness shows the northern portion of the Uteland Butte play where the carbonate percentage falls is the area with the richest TOC



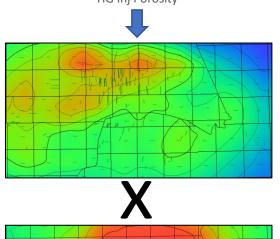
Calculating OOIP in Organic Porosity

Equation of MICP-Phi per TOC%



Map of Phi-TOC

Maturity Conversion Factor

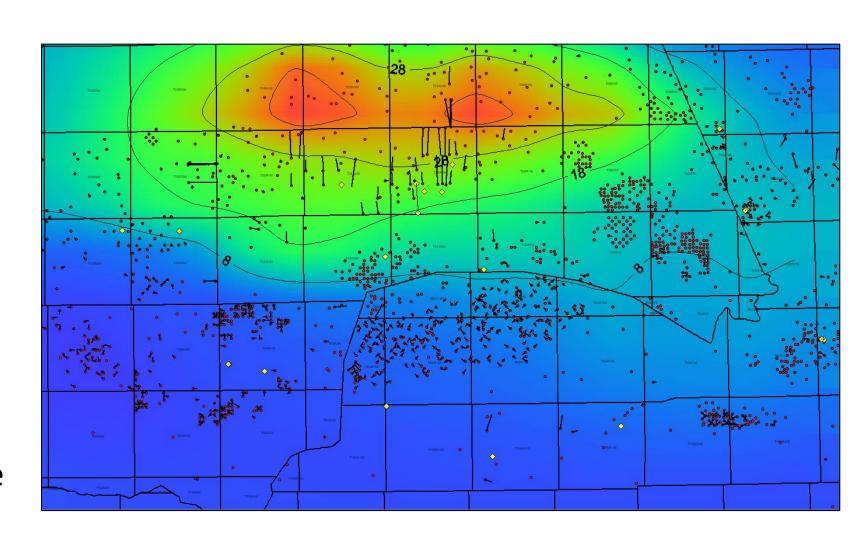


- Oil in place calculated using capillary pressure measurements cross-plotted against TOC in GRB rocks with no interparticle porosity
- Measurements at various levels of TOC richness at a set maturity allows us to calculate a TOC-Phi conversion equation
- Repeated at different maturities allows us to calculate a maturity conversion factor

TOC Hosted Oil in Place

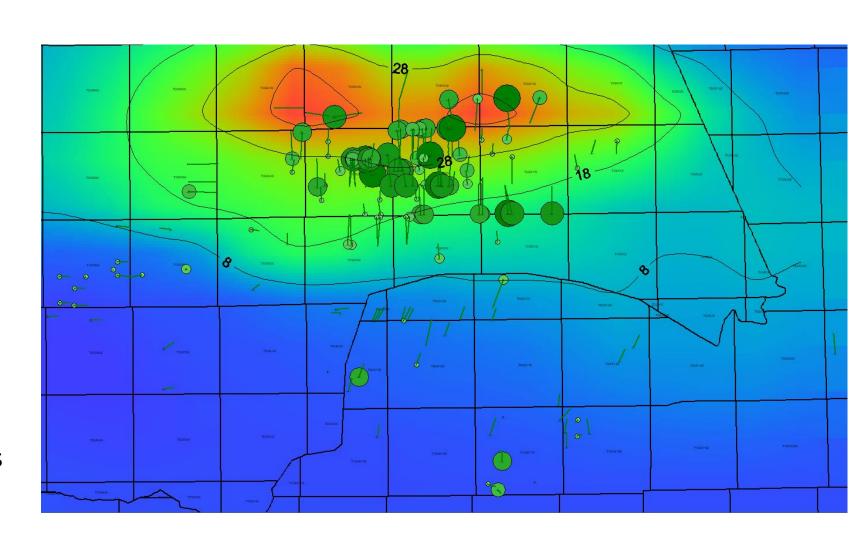
Uteland Butte TOC-Hosted Oil in Place

- Frac modeling suggests that at current designs operators are reaching the upper 30' of the Wasatch and the bottom 20' of the Castle Peak
 - Those intervals are included in this OOIP calculation
- OOIP volumes are quite large



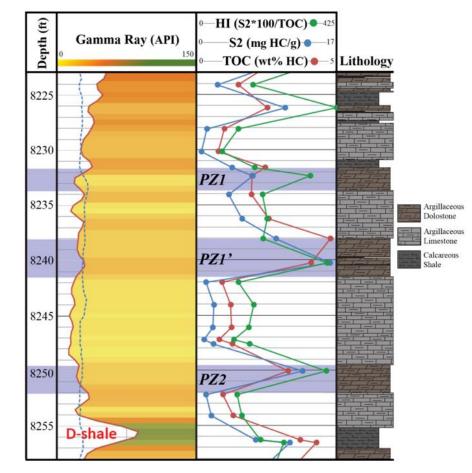
Uteland Butte TOC-Hosted Oil in Place

- Calculated organicporosity hosted oil volumes correlate well with measured reservoir pressures and production volumes
- Wells in the highest OOIP areas are aggressively choked back and appear smaller than they actually are
 - Axia puts EUR ranges of 1-2 MMBO on them



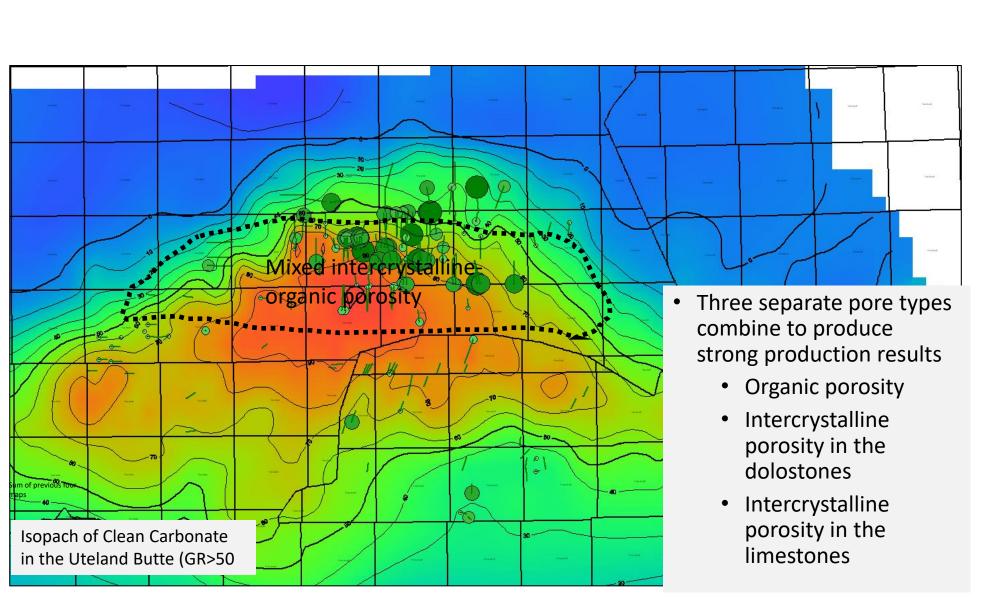
Mixed intercrystalline-organic porosity

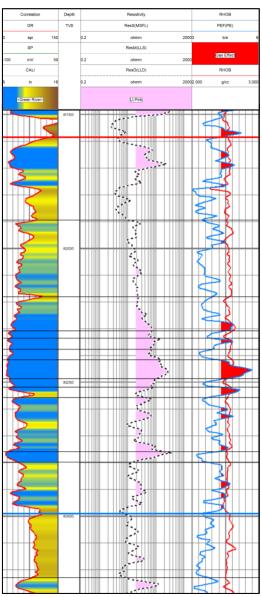
- Largely self-sourced
- Significantly overpressured
- Thickest gross section
 - Thin dolomite beds
 - Thick bivalve wackestone
 - Significant shales
- Organic porosity within argillaceous carbonates and shales contribute significant production
- 0.8 to 1.0 Vro
- Produces a yellow to gray wax with moderate GOR's.



TOC and S2 logs of Nickerson 6-28 Dolostones are highlighted in blue

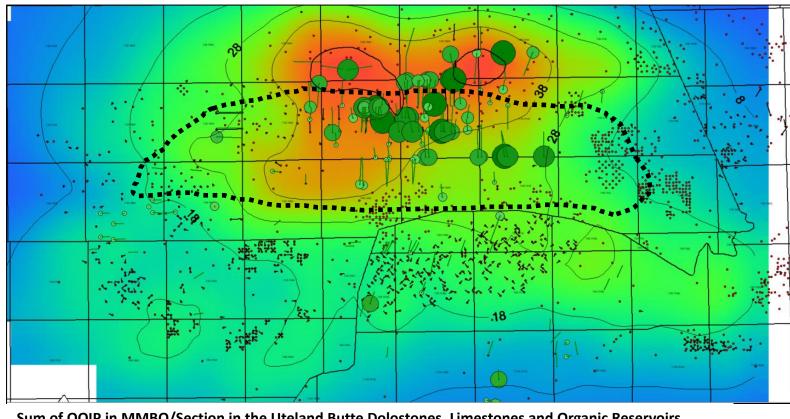
Strong Production Results in the Mixed Reservoirs





Organic Hosted OOIP in MMBO/Section in all Uteland **Butte Lithologies** OOIP in MMBO/Sectio n in the **Uteland Butte Dolostones** OOIP in MMBO/Sectio n in the **Uteland Butte** Limestone

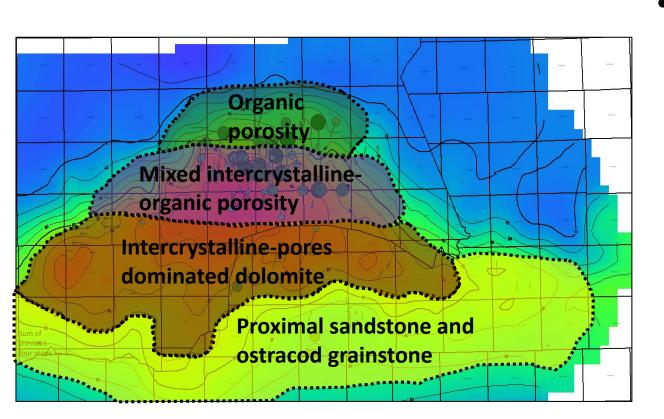
Sum of Organic and Crystalline Porosity



Sum of OOIP in MMBO/Section in the Uteland Butte Dolostones, Limestones and Organic Reservoirs

Conclusions

 Production results tie directly to the developed pore systems in the Uteland Butte



- A better understanding of these systems may lead to improved development practices
 - Particularly in the proximal and intercrystalline dominated areas, where large in-place volumes are not currently being developed

References

- Boden, T. & B.T. Tripp, 2012, Gilsonite Veins of the Uinta Basin, Utah, Special Study 141, Utah Geological Survey, ISBN 978-155791-856-7
- Brinkerhoff, A.R. & K. Woolf, 2018, Characteristics of Sandy Hyperpycnite Deposits on the Shallow, Southern Margin of Eocene Lake Uinta, the Green River Formation of Northeastern Utah, Adapted from oral presentation given at AAPG 2018 AAPG Annual Convention and Exhibition, Salt Lake City, Utah, May 20-23, 2018, http://www.searchanddiscovery.com/pdfz/documents/2018/51495brinkerhoff/ndx_brinkerhoff.pdf.html
- Chaparro, F.R., H.G. Machel, & M.D. Vanden Berg, 2019, Dolomitization in the Uteland Butte Member of the Eocene Green River Formation, Uinta Basin, Utah: Utah Geological Survey Open-File Report; *In Press*
- Eldridge, G.H., 1901, The asphalt and bituminous rock deposits of the United States, in Walcott, C.D., director: U.S. Geological Survey Twenty-second Annual Report of the United States Geological Survey to the Secretary of the Interior, pt. 1, p. 209–364.
- Logan, S.K., Sarg, J.F., and Vanden Berg, M.D., 2016, Lithofacies, deposition, early diagenesis, and porosity of the Uteland Butte member, Green River Formation, eastern Uinta Basin, Utah and Colorado: Utah Geological Survey Open File Report 652, 32 p., Online, ugspub.nr.utah.gov/publications/open_file_reports/ofr-652.pdf
- Morgan, D.M. & R.W. Stimpson, 2016, Characterization and Horizontal-Drilling Potential of Oolitic and Ostracodal Limestone Reservoirs in the Eocene Green River Formation, Northeastern Uinta Basin, Utah: Utah Geological Survey Open-File Report
- Ruble, E.T., M.D. Lewan, R.P Philip, 2001, New insights on the Green River petroleum system in the Uinta basin from hydrous pyrolysis experiments, AAPG Bulletin, v. 85, no. 8 (August 2001), pp. 1333–1371
- Vanden Berg, M.D., Wood, R.E., Carney, S.M, and Morgan C.D., 2014, Geological characterization of the Uteland Butte member of the Eocene Green River Formation—an emerging unconventional carbonate tight oil play in the Uinta Basin, Utah [abs.]: Rocky Mountain Section AAPG Annual Meeting, Denver, Colorado.