Characterizing Outcrop Growth Faults, Slump Blocks, Mud Volcanoes and Other Sedimentary Deformation Features for use as Reservoir Analogues for Observed Features in Targeted Reservoirs in the Green River Formation, Uinta Basin, Utah*

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Search and Discovery Article #51623 (2019)**
Posted December 16, 2019

*Adapted from oral presentation given at 2019 AAPG Rocky Mountain Section Meeting, Cheyenne, Wyoming, September 15-18, 2019
 DOI:10.1306/51623Brinkerhoff2019

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Abstract

Sand dominated clastic deposits form an important component of the rapidly developing Green River horizontal play in the Uinta Basin of NE Utah. Reservoir quality within the Green River is highly variable, with one cause being sedimentary deformation compartmentalizing clastic reservoirs, creating discontinuities and degrading intergranular porosity and permeability values. This occurs within fluvial and marginal lacustrine sandstone facies of the Flagstaff, Castle Peak and Douglas Creek Members of the Green River Formation. In many cases, well and seismic data demonstrate stratigraphic discordance that is interpreted to be related to sedimentary deformation shortly after burial. Evidence includes sudden thickening or thinning of reservoir units with undeformed strata above and below these features, stratigraphic zones of pervasive deformation (seismites?) and proximity to concurrently active faulting. These features appear to partition these sandstone reservoirs, making their characterization important for operators in the Uinta Basin. On the eastern flank of the Uinta Basin, there exists a large series of growth faults, slump blocks, mass transport deposits, mud volcanoes and diapirs, all related to fluvial sandstone deposits in a near shore settings of ancient Lake Uinta. Studied intervals include the Uinta A, Douglas Creek and Lower Black Shale informal members of the Green River Formation. The deformed sandstone blocks exhibit brittle deformation in the form of micro faults and minor brecciation, with limited ductile deformation. Dark oil shales acted as undeformed glide planes on which these blocks moved. These blocks range in size from 100 yards to nearly a quarter mile across and display everything from gently dipping rotations to being nearly overturned. Mud volcanoes and diapirs are often in close spatial association to the blocks, and deformed intervals will sometimes stack vertically, with undeformed lacustrine mudstones in between. Geographically, the deformed blocks appear to cluster in paleo valleys and along main-stem fluvial deposits. It is expected that a better characterization of these deformed deposits with allow for more accurate modeling of similarly deformed reservoirs within the active Green River oil play.

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Ali, Syed A., W.J. Clark, W.R. Moore, and J.R. Dribus, 2010, Diagenesis and Reservoir Quality: Oil Field Review, Summer 2010, p. 14-27.

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Characterizing outcrop growth faults, slump blocks, mud volcanoes and other sedimentary deformation features for use as reservoir analogues for observed features in targeted reservoirs in the Green River Formation, Uinta Basin, Utah

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Acknowledgments

- Mike Vanden Berg
- Joe Phillips
- Eli Lopez
- Nathan Rogers
- Wasatch Energy Managment

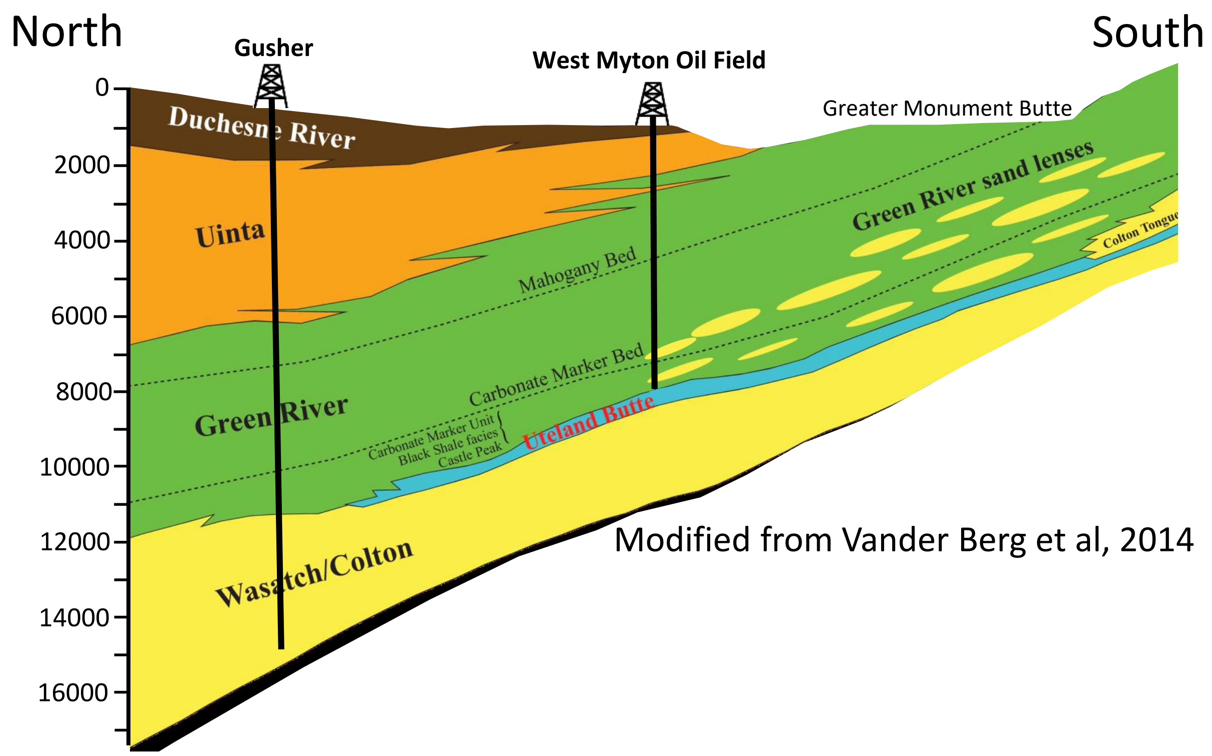
WASATCH ENERGY MANAGEMENT

Problem

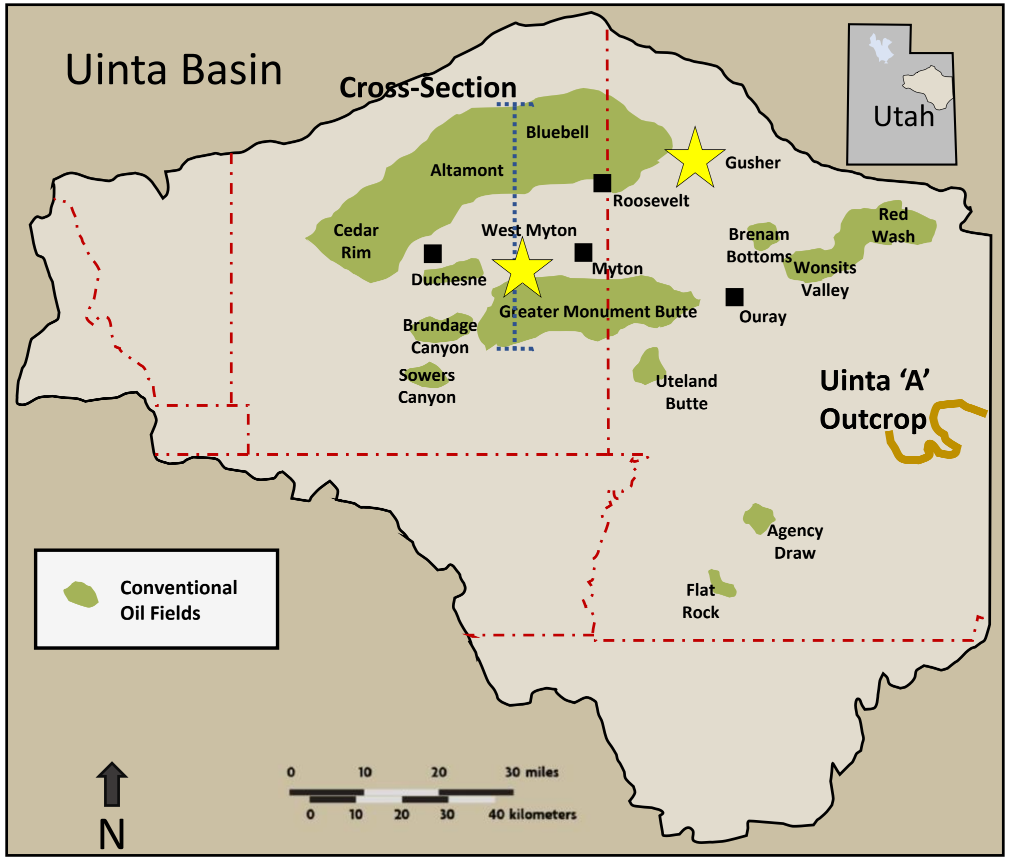
- Some Green River Formation Sandstones produce much more poorly than they should based on:
  - Offset production
  - Pay encountered/OOIP
  - Initial production volumes
  - Completion practices (frac size)

Study Location

- Study involves production anomalies in the West Myton oil field in Duchesne County
- Deformation in Uinta 'A' outcrops in Uinta County
- Core in the Gusher oil field in Uinta County

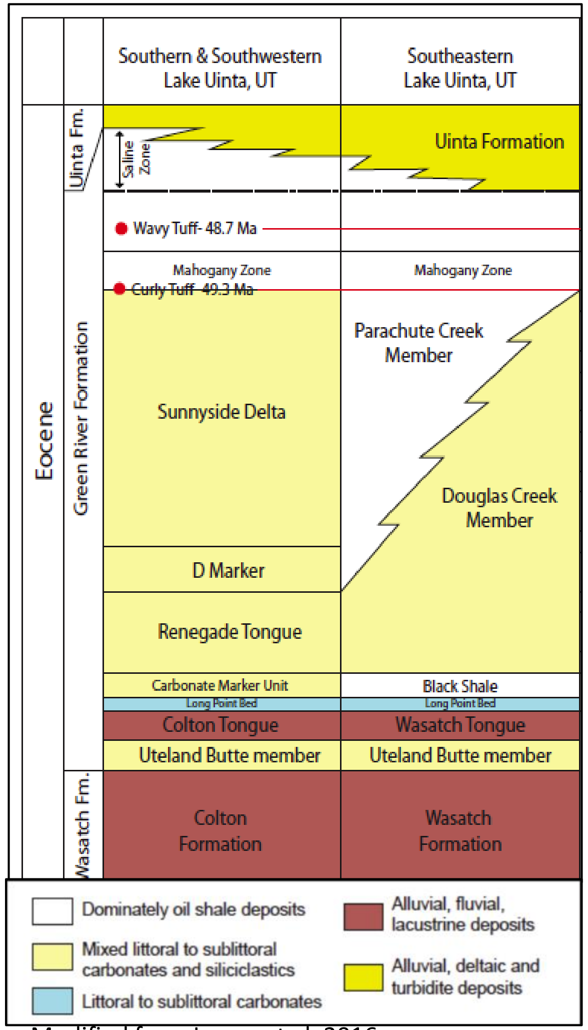


Modified from Vander Berg et al, 2014



Modified from Brinkerhoff & Woolf, 2018

West Myton Targets



Modified from Logan et al, 2016

Vertical wells were commonly drilled ~300' into the Wasatch, then every sand and porous carbonated from the TGR-3 to TD would be completed

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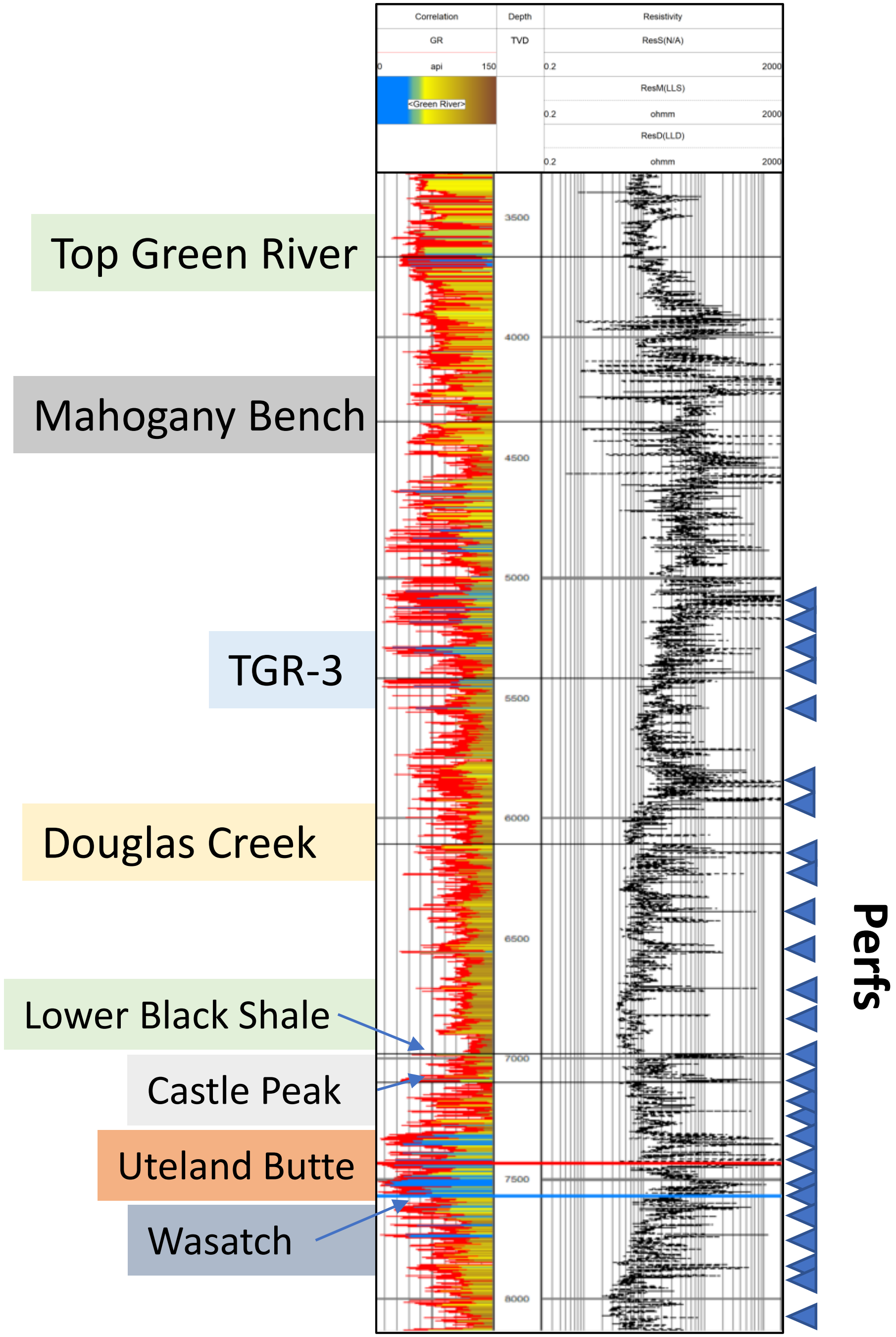
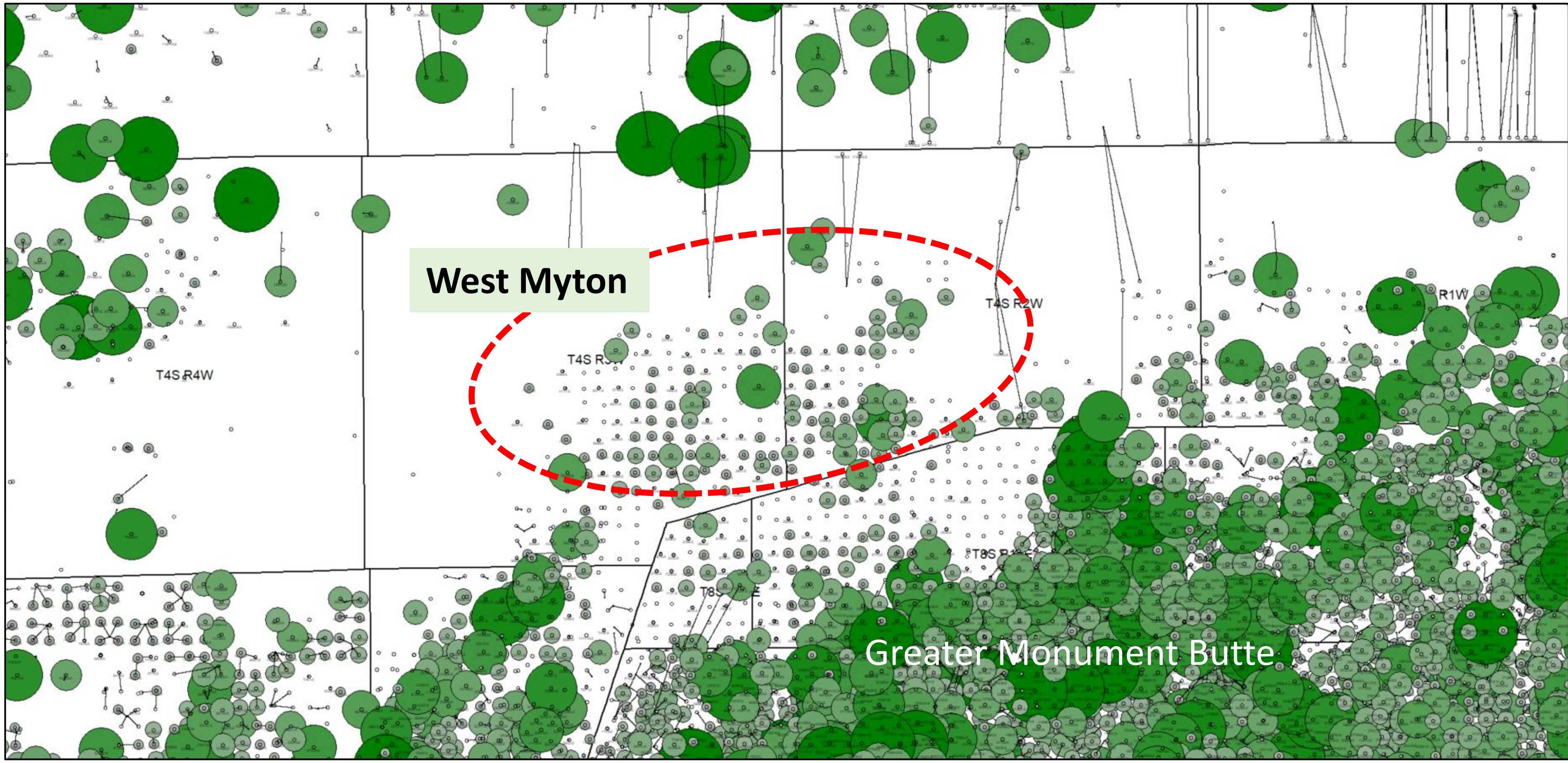


Cumulative Oil Production of All Green River Wells

Note that the West Myton wells are underperforming versus offset wells

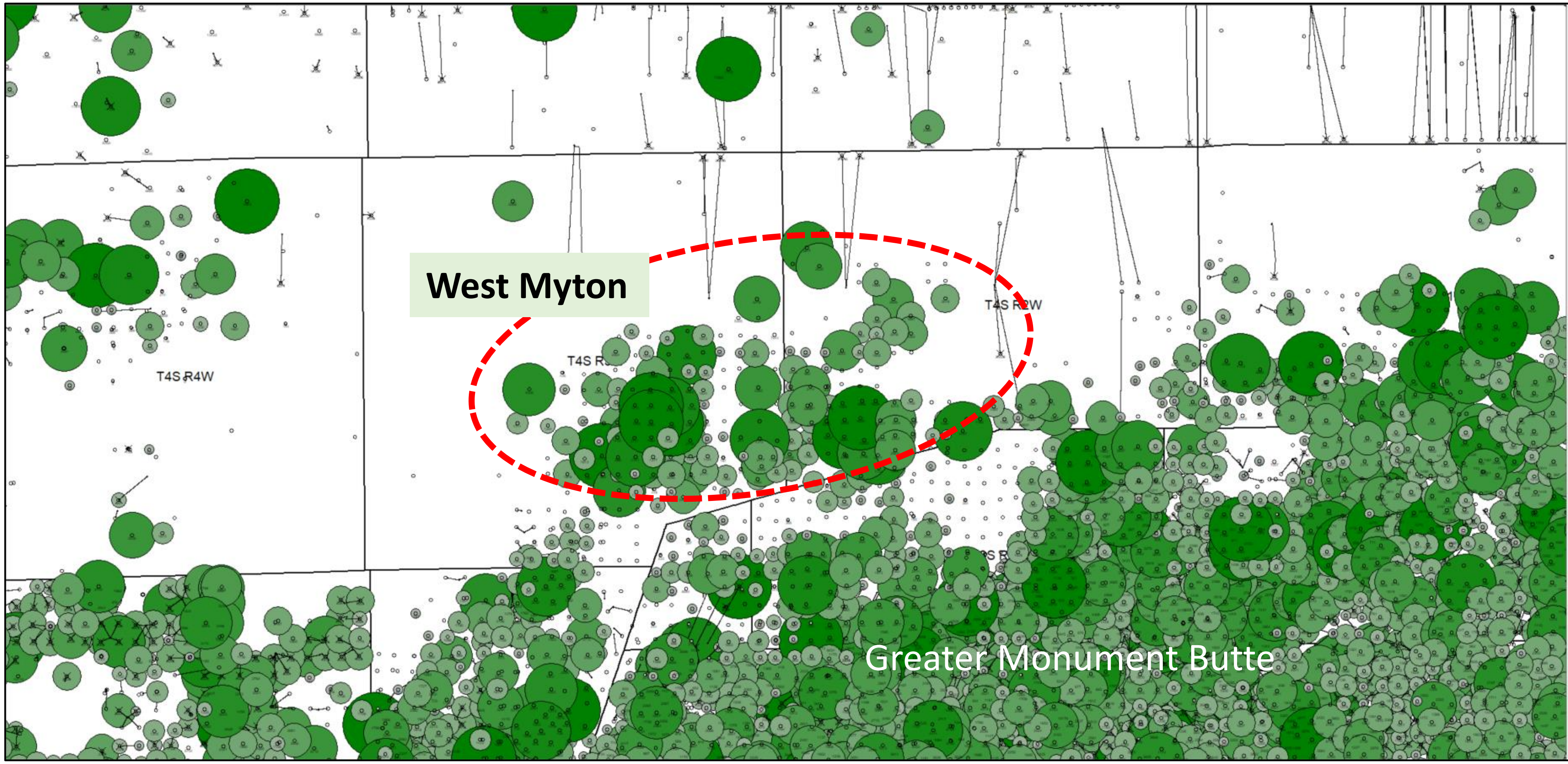
Cumulative Oil Production in Barrels	
0 - 10000	
10000 - 20000	
20000 - 30000	
30000 - 40000	
40000 - 50000	
50000 - 60000	
60000 - 70000	
70000 - 80000	
80000 - 90000	
90000 - 100000	



Initial Oil Production (IP's) of Green River Wells

At IP, these wells were doing about average or better than offset wells

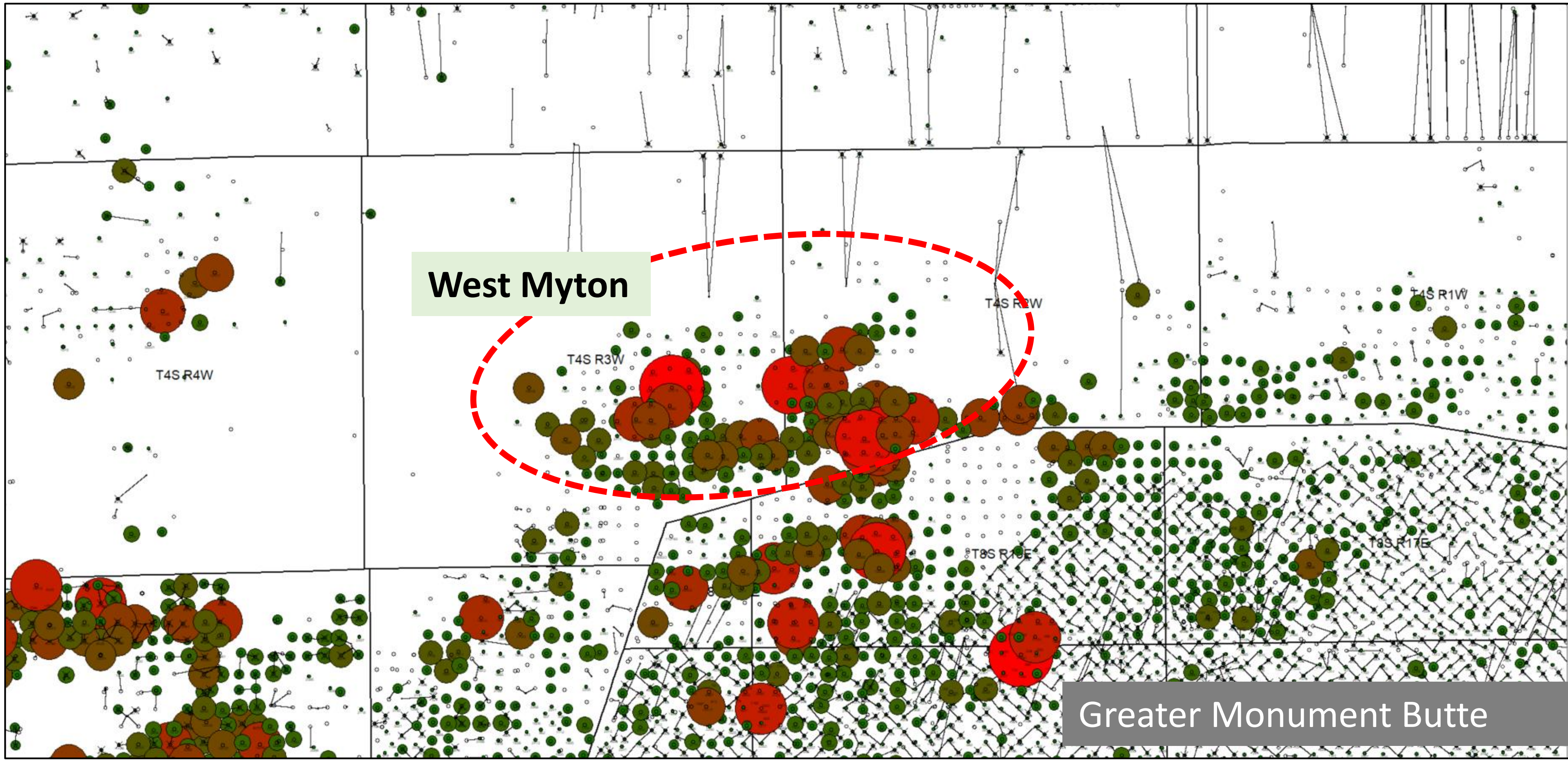
Initial Oil Production in Barrels/Month	
0 - 455	
455 - 909	
909 - 1364	
1364 - 1818	
1818 - 2273	
2273 - 2727	
2727 - 3182	
3182 - 3636	
3636 - 4091	
4091 - 4545	
4545 - 5000	



Gas/Oil Ratio (GOR) of All Wells

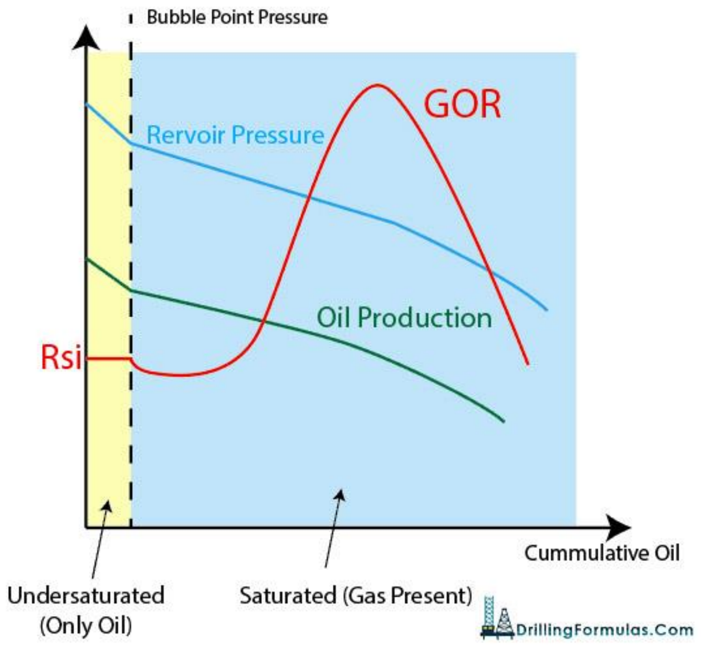
Finally, note that the GOR's for West Myton are much higher than average for the area

Gas/Oil Ratio (GOR) Standard Cubic Feet/Barrel	
0 - 2500	
2500 - 5000	
5000 - 7500	
7500 - 10000	
10000 - 12500	
12500 - 15000	
15000 - 17500	
17500 - 20000	
20000 - 22500	
22500 - 25000	

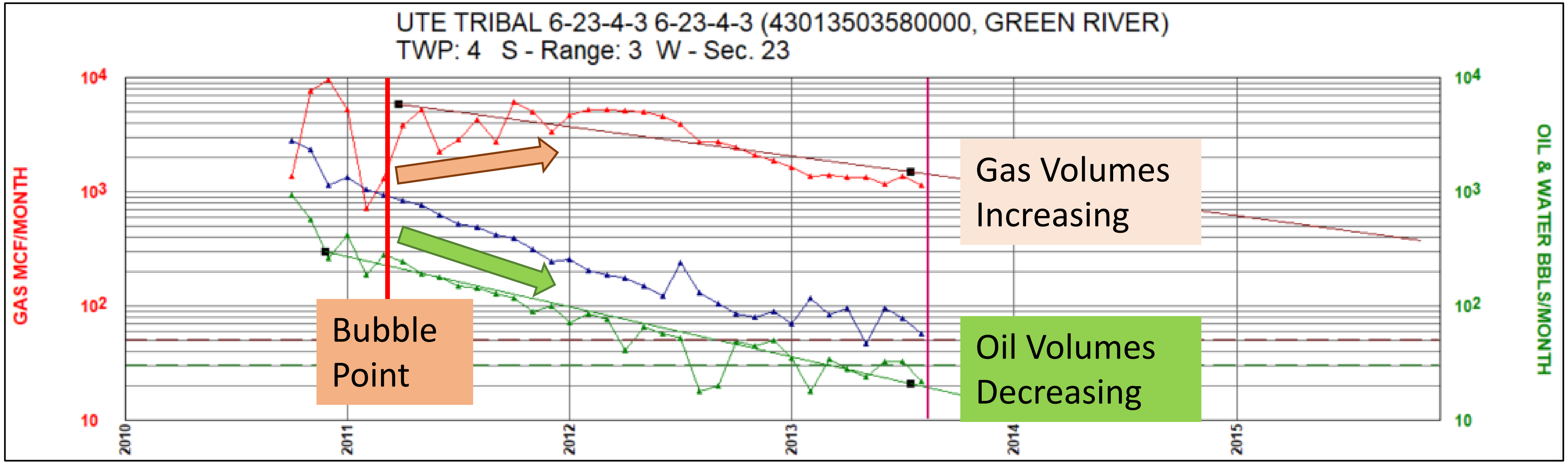


West Myton's Early Achievement of Bubble Point

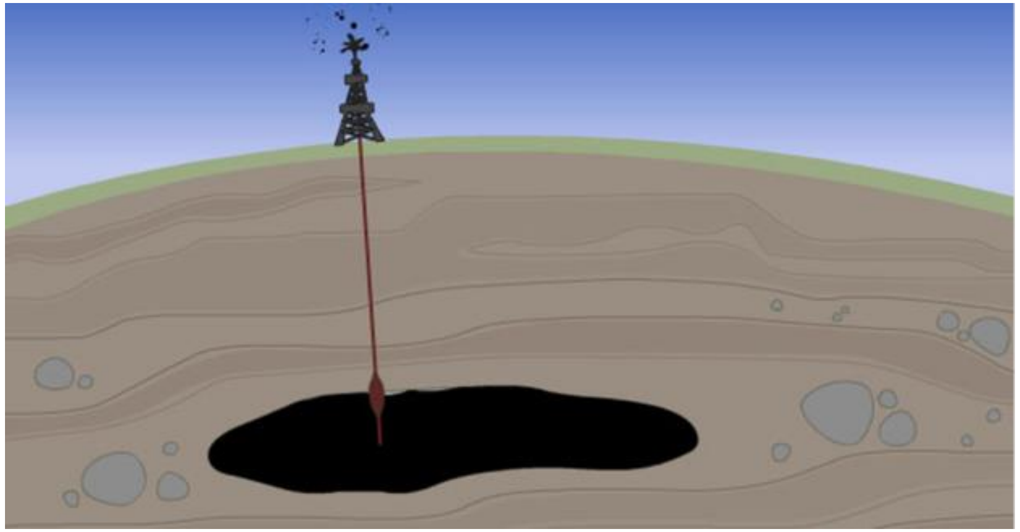
- Bubble point is the pressure at which gas begins to come out of solution within the reservoir
- When a well reaches bubble point much earlier than is normal for the area, it typically indicates the well is only producing from a limited reservoir



A Typical West Myton Well



Reservoir Engineering (For Geologists)



- Production removes volume, decreasing pressure
- The greater the pressure decline per given volume, the smaller the reservoir

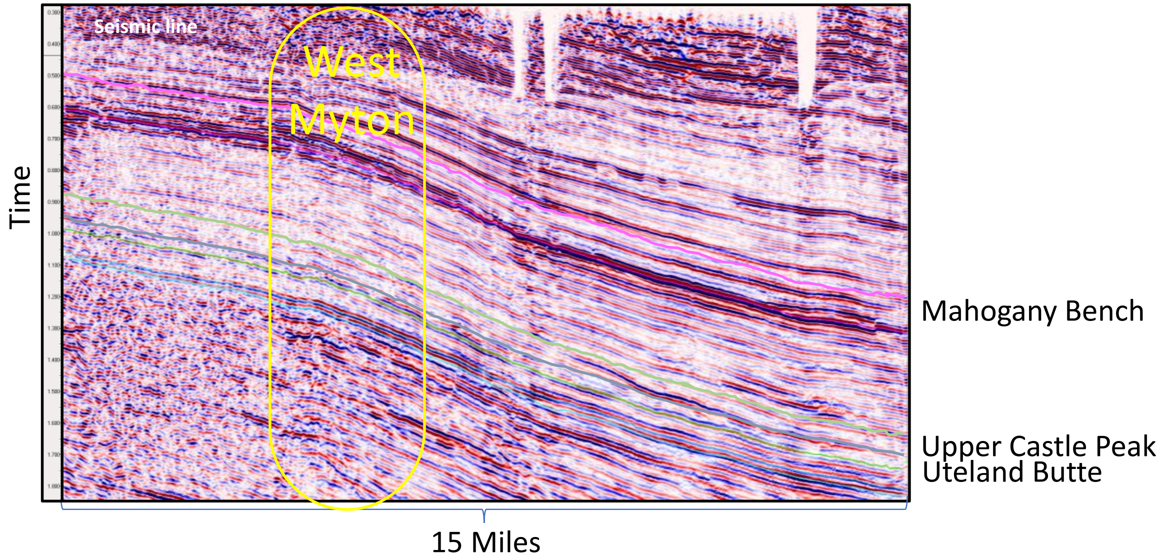
For Myton, Production Statistics are

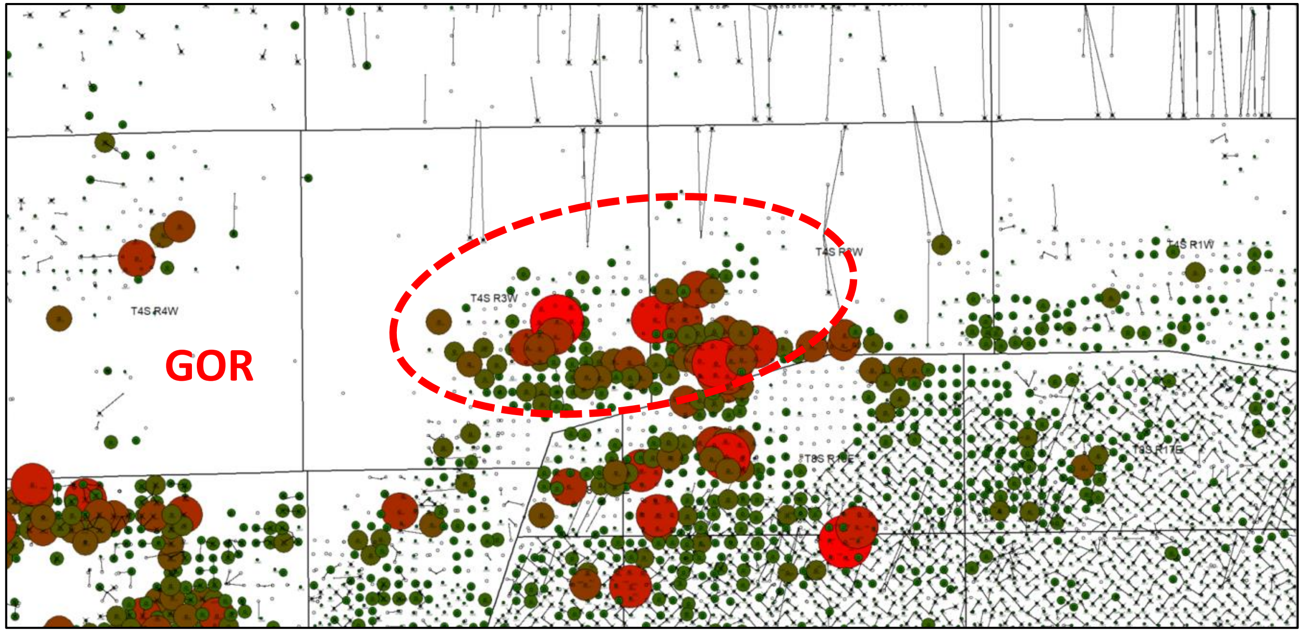
- Average IP's
- Smaller cumulative oil production than surrounding areas
- Reach bubble point much earlier than surrounding wells
- Higher GOR's

Why Are Reservoirs in West Myton So Limited?

- Stratigraphic controls are unlikely as offset fields with very similar geology are not similarly affected
- Structural controls are possible
  - No faulting with significant vertical offset are present
  - Are there other possible structures?

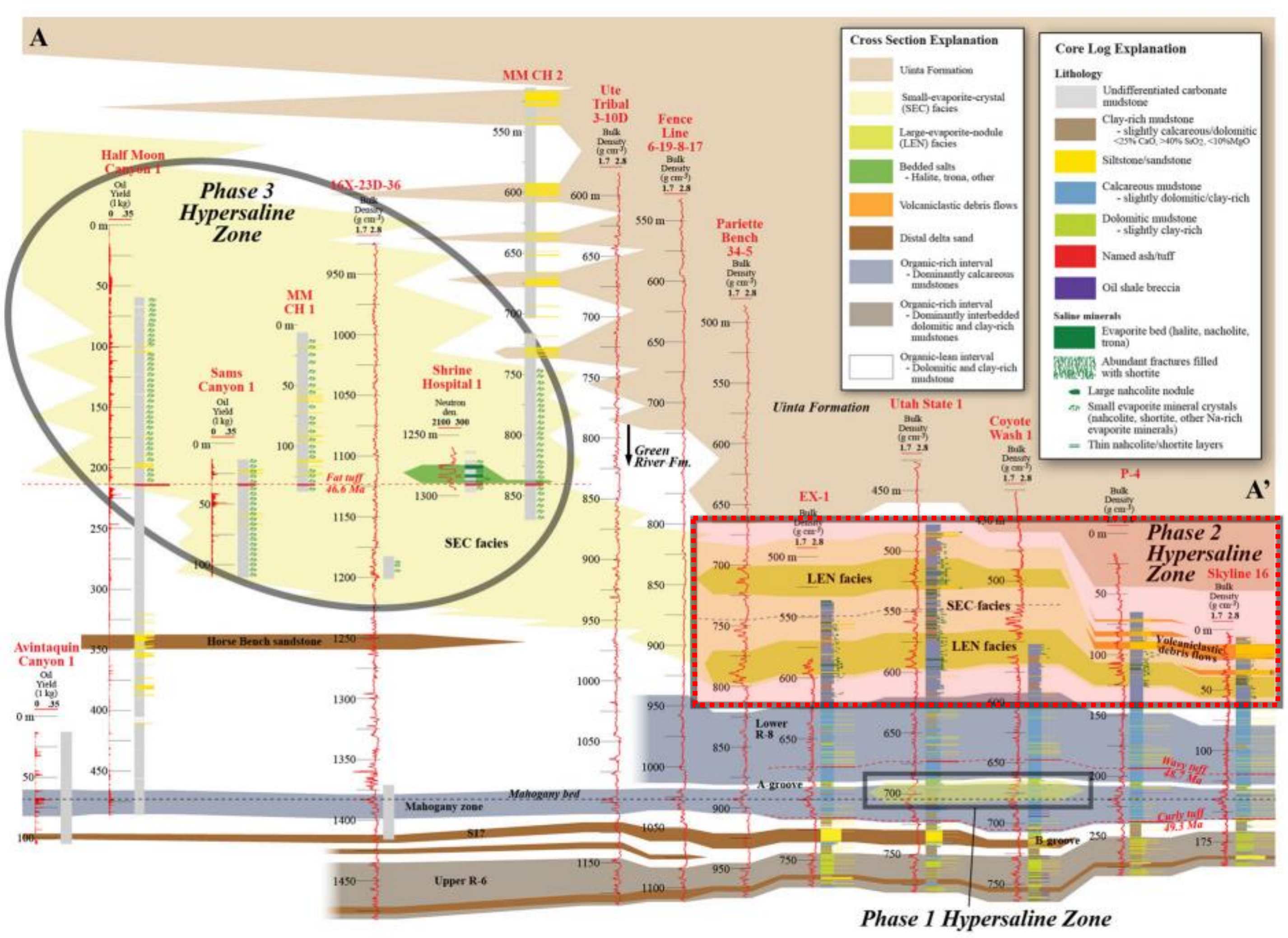
Maybe something we could see in outcrop?





Rapidly Prograding Sandstone Deposits

- The Uinta A consists of deltas quickly spreading south and west over shallow lacustrine deposits
- The lake gradually becomes more restricted on the western portion of the Basin
  - However, it often transgresses over recently deposited deltaic sediments during wetter periods
  - Interbedded sandstones and lacustrine shales are a common feature of the lower Uinta A



Vanden Berg and Birgenheier, 2017

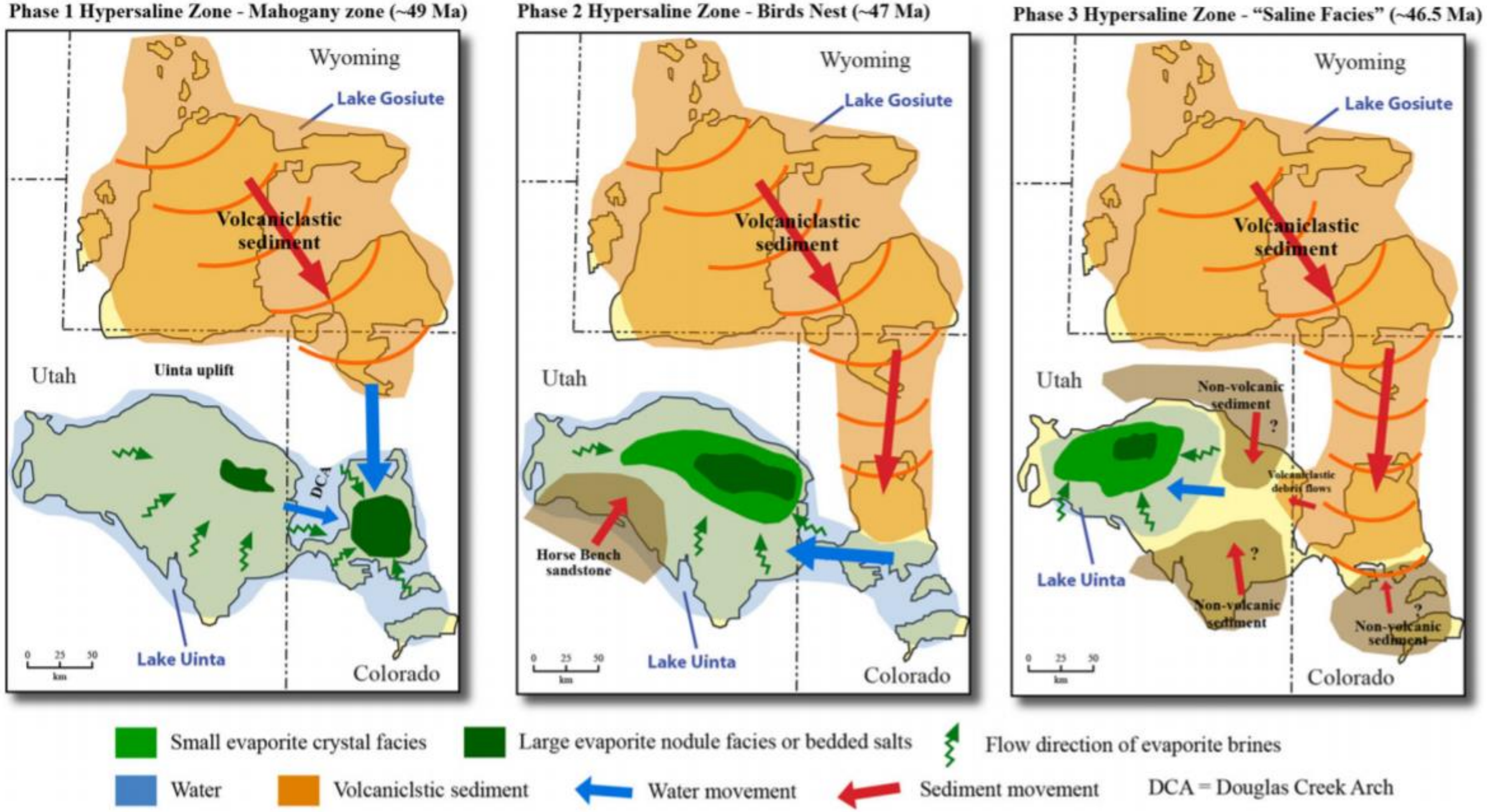
Deformation in the Uinta A Sandstone (West Myton Analogue?)

Uinta A sandstone (Wagonhound Member) at its type section

- The Uinta A is justifiably famous for its fossils and soft sediment deformation
  - SSD is pervasive in the Uinta A
- Flame, ball and pillow, and flow structures are common and represent a degradation of sandstone reservoir quality
- **This study focuses on larger block movements that compartmentalize reservoirs**

Falling Dominoes

- A change in regional drainage trends directed large amounts of sediment into the intermountain lake system
- After filling the Green River and Piceance Basins, this massive flow of sand dominated sediment was directed into the eastern Uinta Basin
  - These rapidly deposited sandstones are the Uinta A and B

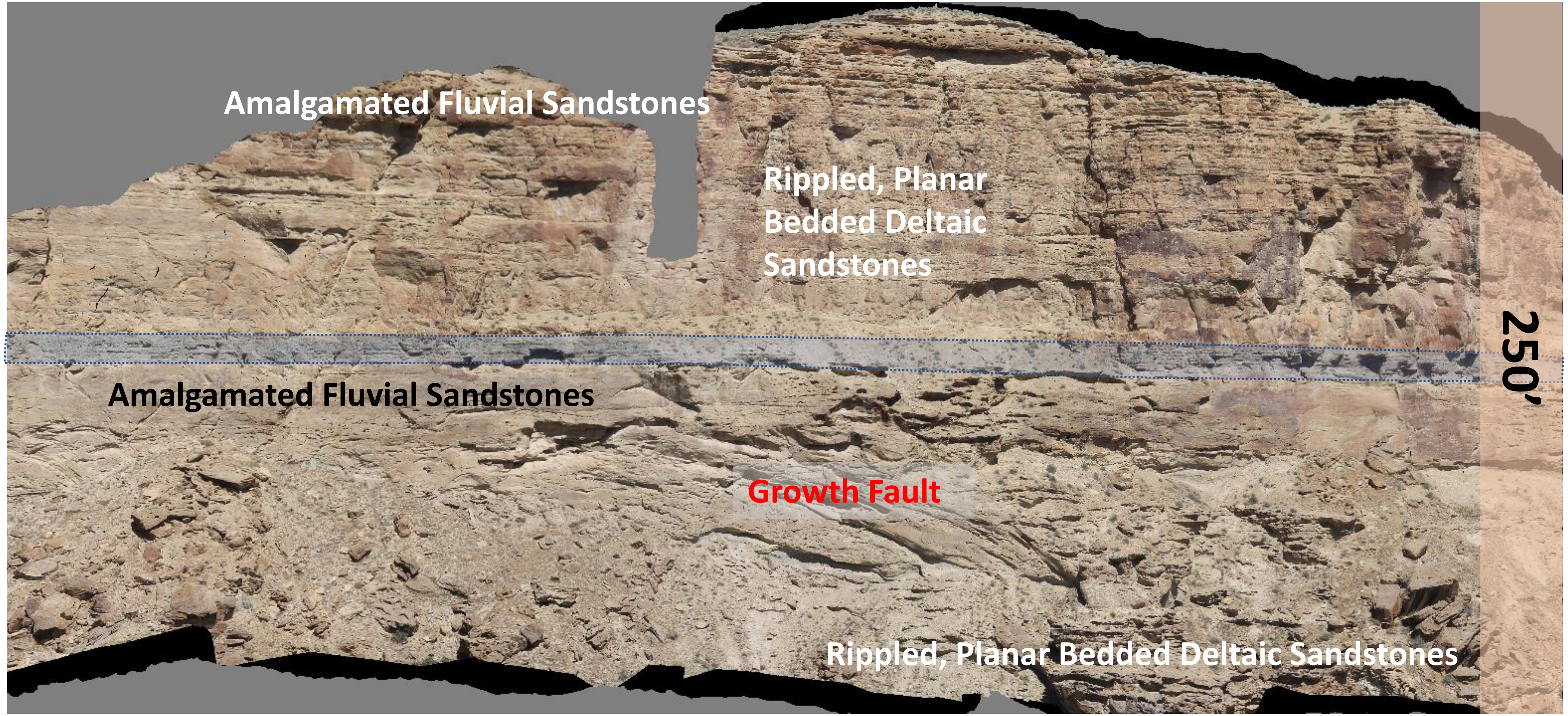


Vanden Berg and Birgenheier, 2017

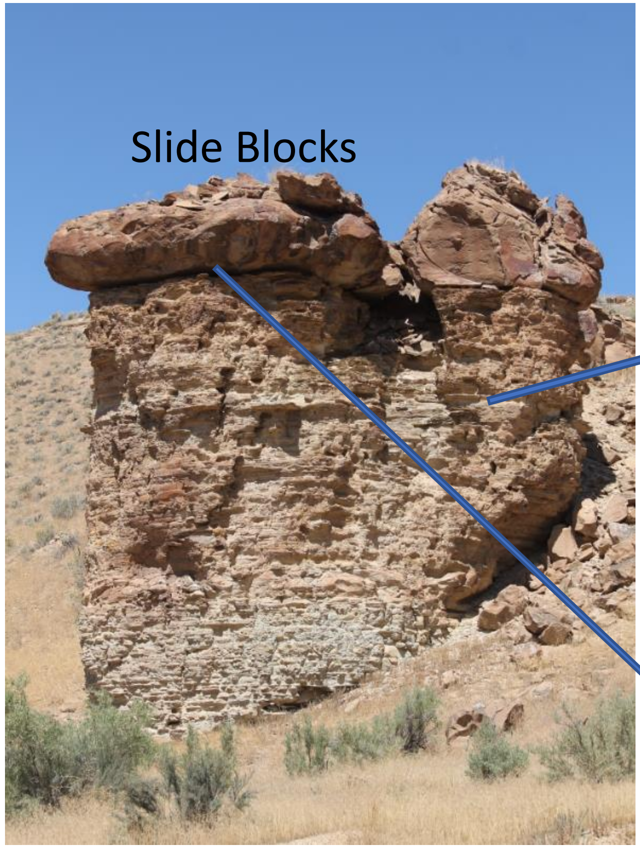
Type Section of the Uinta A (Wagonhound Member)

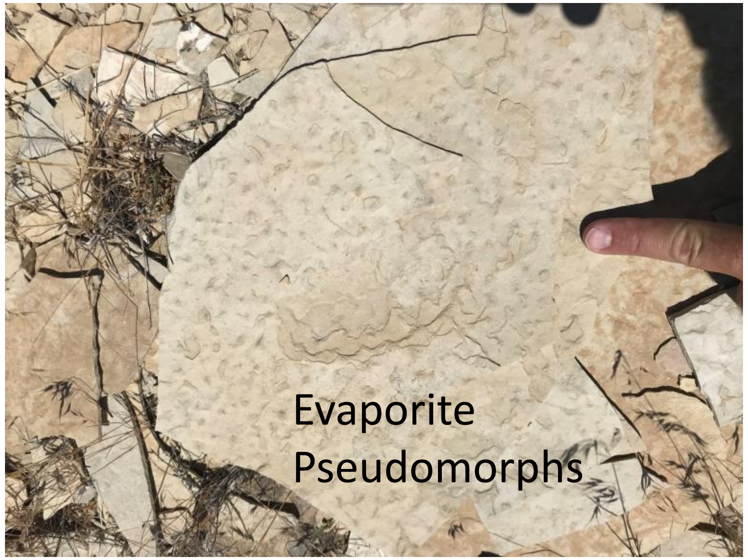
Channels flow from east to west (Stagner, 1941)

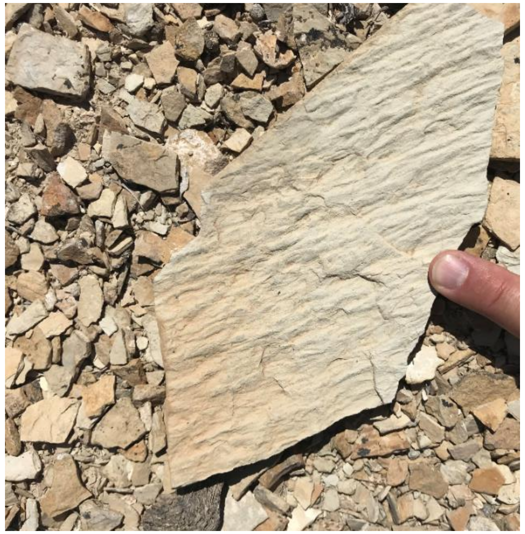
Transgressive Lacustrine Shale (15' thick)



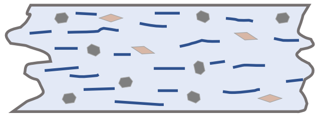
Parachute Creek Shale (Grease for the System)





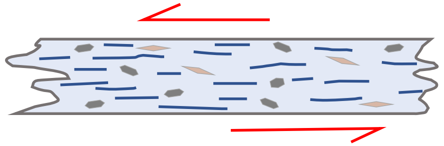


Vanden Berg's (2017)
"Phase 2 Hypersaline Zone"



Three factors combine to make Parachute Creek shales particularly weak

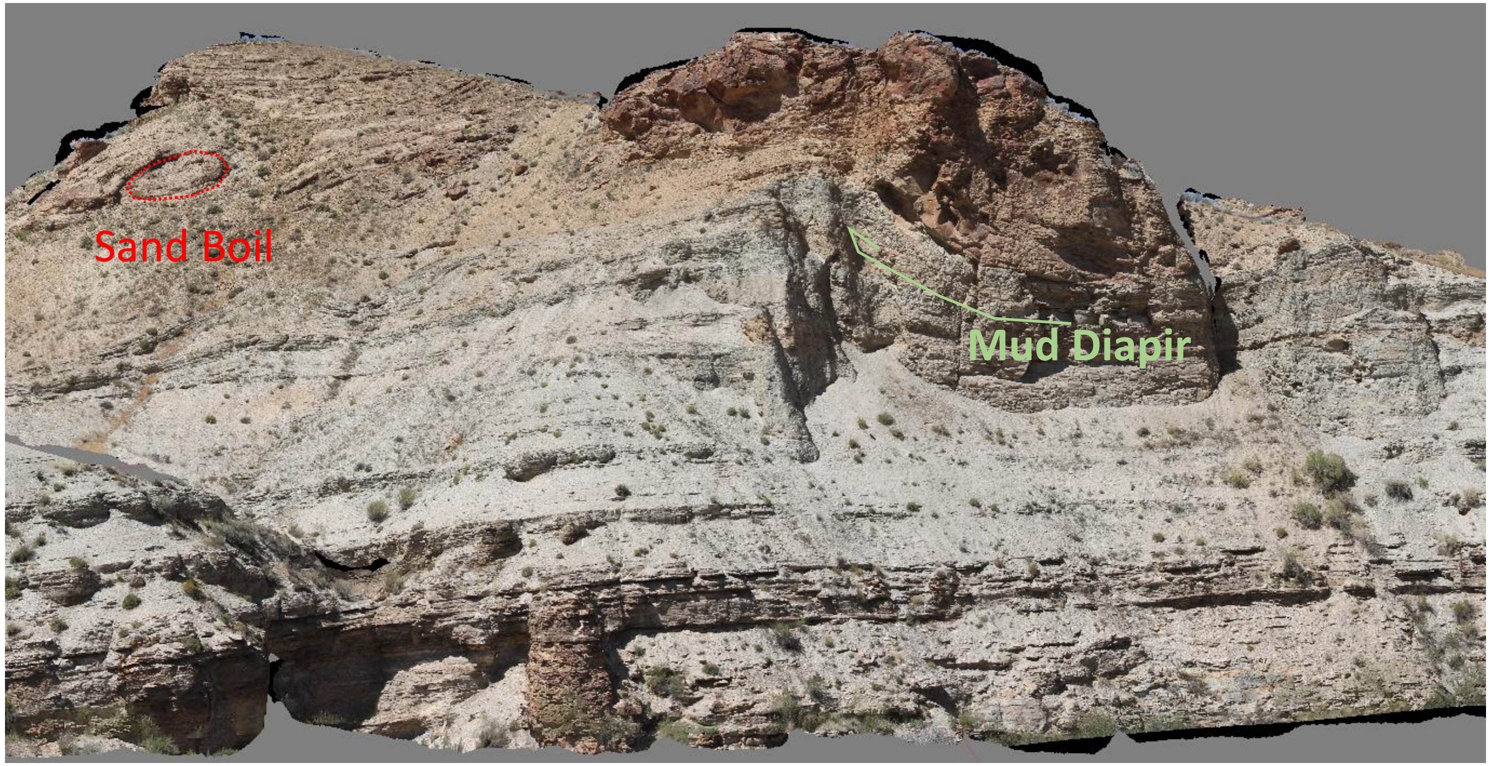
- Medium to high total organic carbon (TOC)
- High smectite percentage in the clays
- Claystone fabric disrupted by evaporite crystals



- Very low shear strength
- **Loads easily slip down-slope**

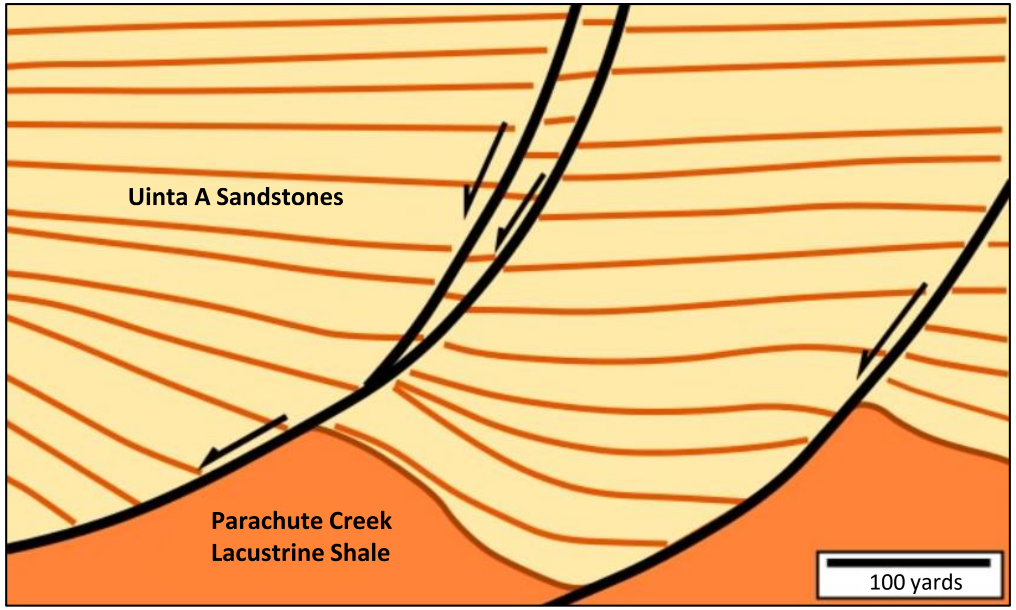
Weak Enough to Form Mud Diapirs

- Parachute Creek shales are weak enough to flow in response to lateral loads
- Movements are typically tightly stratabound



Growth Faulting

- Growth faults are the most common type of block movement observed
- Syndepositional
- Serves to sever or baffle adjacent sandstone reservoirs



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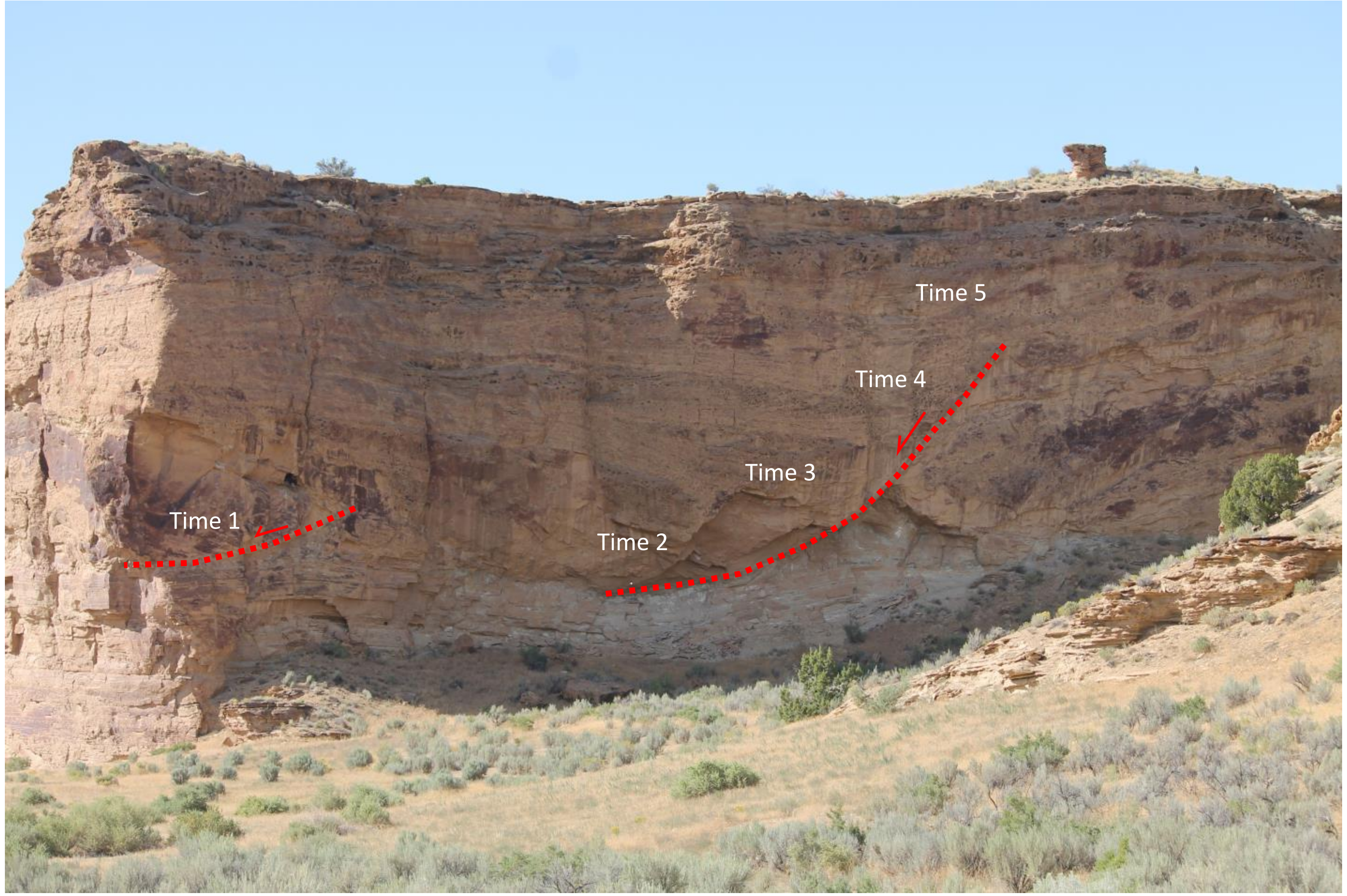
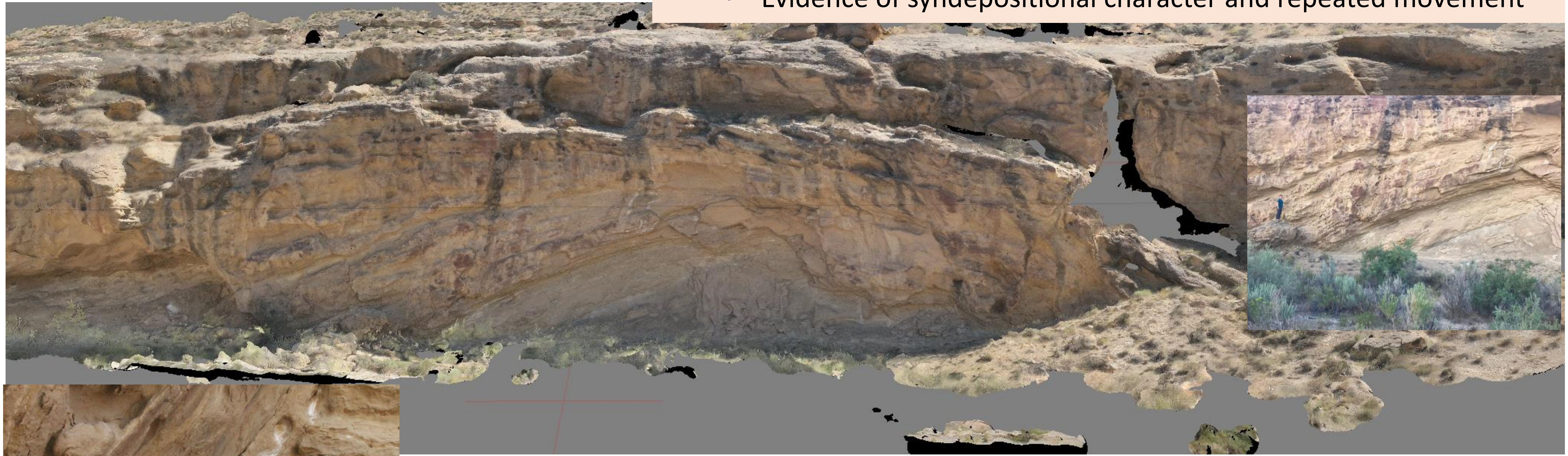


Growth Faults

- Uinta A growth faults lay directly on either the main body of the Parachute Creek or on thin tongues of lacustrine shale interbedded with the deltaic sandstones
  - Tightly stratabound with stratigraphic growth within the involved block
  - Evidence of syndepositional character and repeated movement



- Growth fault with evaporites deposited along fault trace
- Evidence for the impermeability of the fault

Rotated Blocks

- Large (100’s of yards across) slide blocks are found rotated 40°-90°
- Undeformed shale at their bases
- Tool marks at the base of the blocks show they slid down slope (into the lake)

Internally Deformed

- Unsurprisingly, the rotated blocks suffer significant internal deformation
  - Micro faults
  - Folding
  - Mud injections and dikes

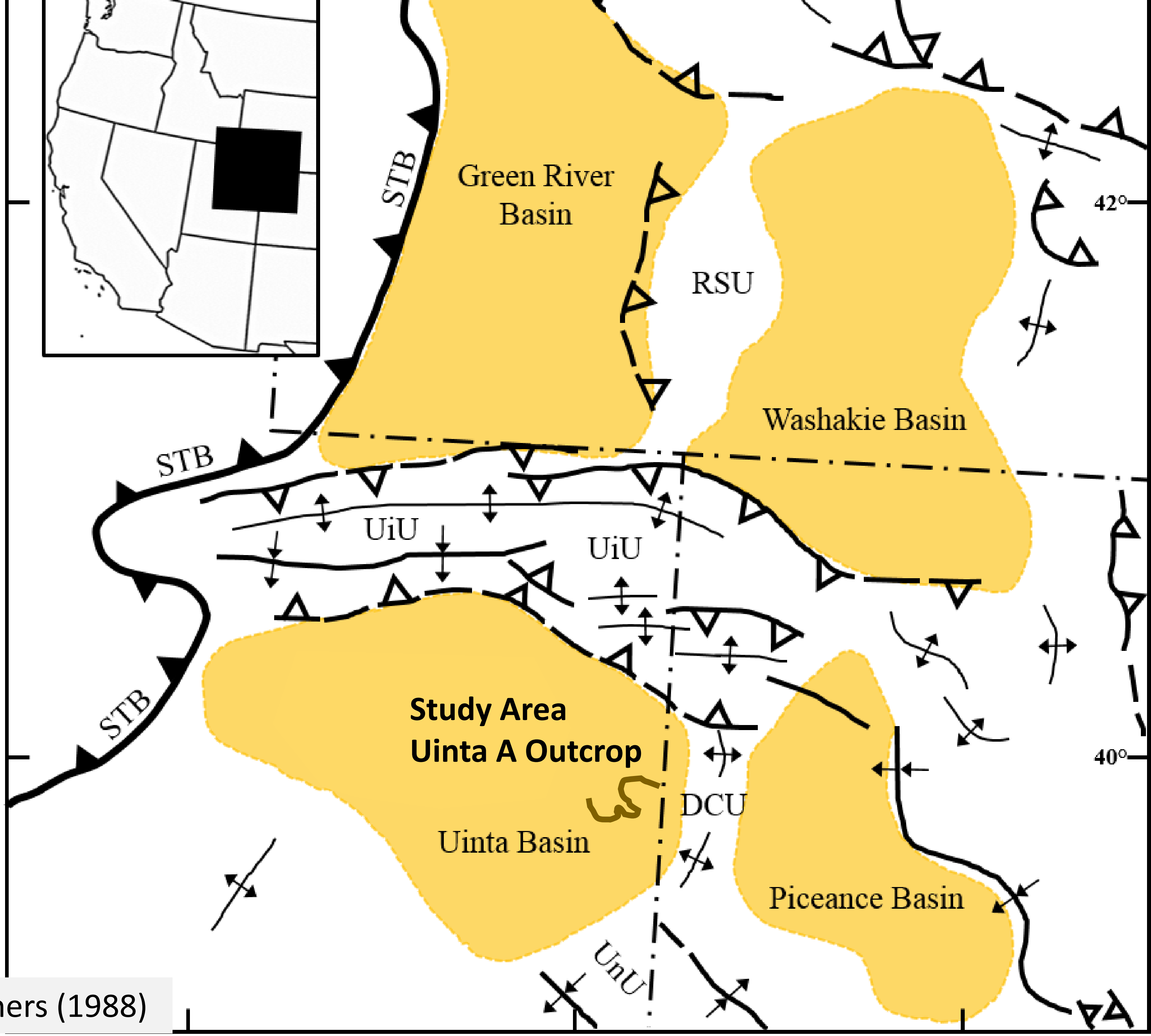
Foundered Blocks

Associated Sand Boil

- In areas where Parachute Creek shales are thick enough some detached blocks founder into and are partially encased by shale

Late Eocene Uinta Basin Tectonics

- During the deposition of the Uinta A sandstones, the Basin was surrounded by actively moving uplifts
- Large earthquakes were recurrent events in the Basin
- It is assumed that shocks associated with these quakes activated movement on the observed large slump blocks



Modified from Dickinson and others (1988)

What are Sand Boils?

Sand blow crater in Thousand Springs Valley, ID, that erupted in the 1959 Hebgen Lake, MT, and the 1983 Borah Peak, ID, quakes 140 mi apart

Nisqually earthquake of 2001
Photo: Pat Pringle/DNR

Cross section of a sand boil in County Clare, Ireland

- Sand boils can occur anytime that buried, saturated sandstones are loaded beyond their containment pressure
  - Flooding
  - Construction
  - **Earthquakes**

- The vast majority of sand boils or "blows" occur during the liquefaction of sediments during earthquakes

Fossil Sand Boils

Large scale sand boils are observed frequently in association with slide blocks, growth faults and diapirs in the Uinta Formation

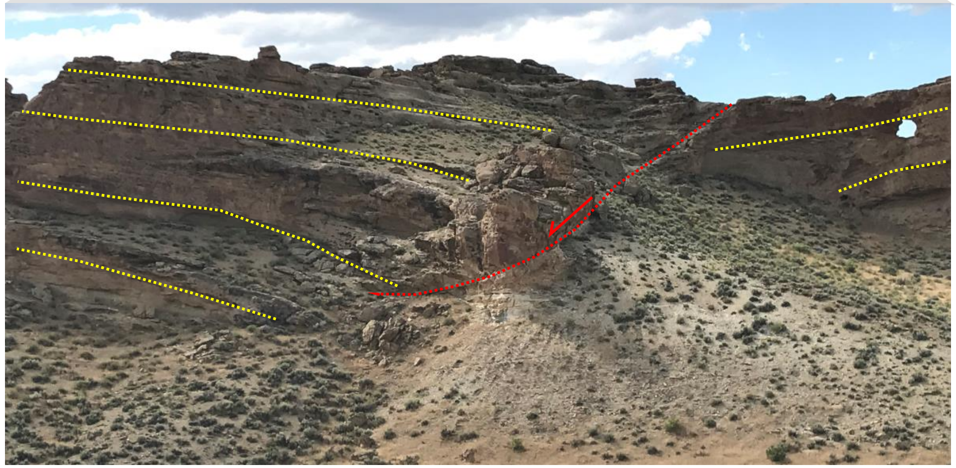
Fossil Sand Boils

In outcrops they appear as circular or elongated zones of concentrically upturned strata

Fun, But How Does this Relate to Production?

Block rotated 90° and broadly deformed

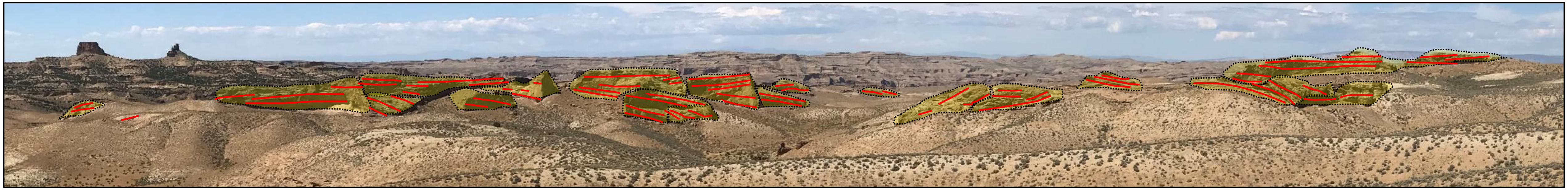
Growth fault separating blocks of opposing dips



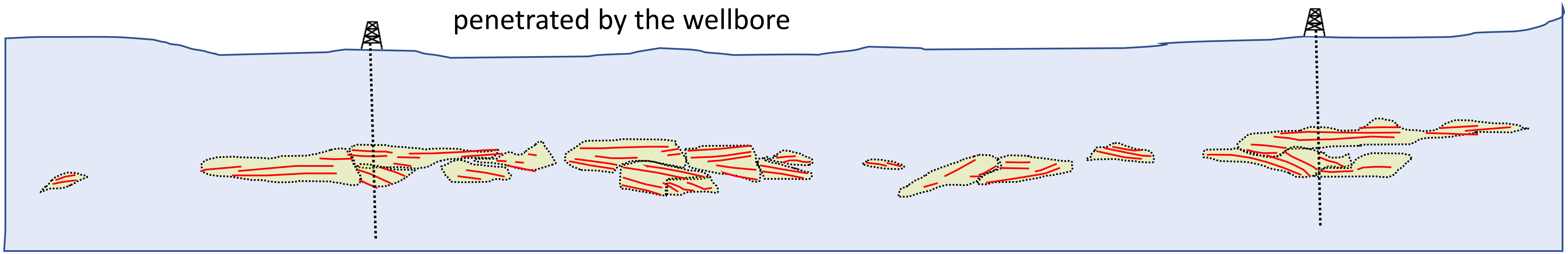
Slump block sliding down slope into the lake

Interpreted

- Slumping of large blocks of Uinta A sandstones compartmentalized individual reservoirs
- Blocks that are not hydraulically isolated by slumping still experience significant baffling

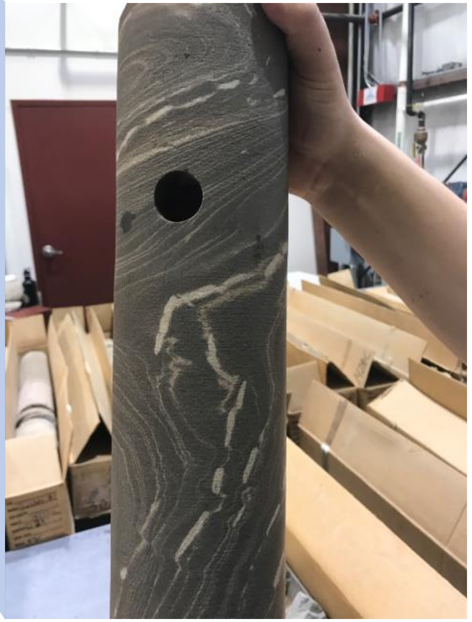


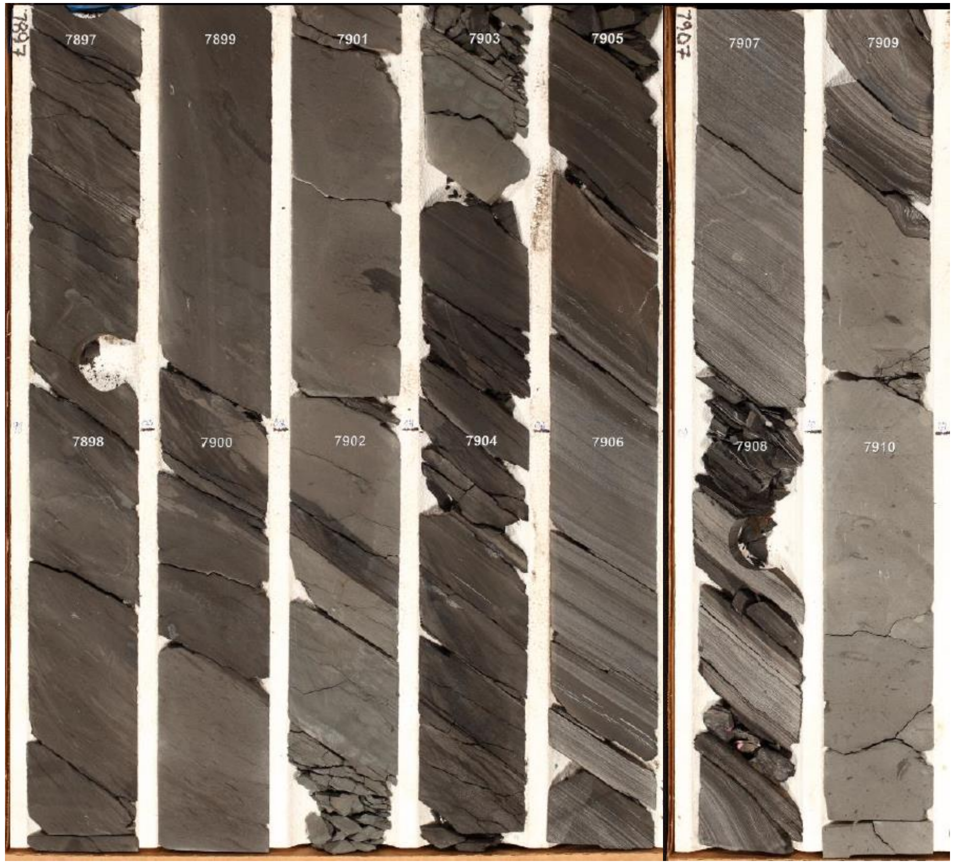
Vertical wells will not access reserves in blocks not penetrated by the wellbore



Isolated?

The Gusher 1 core shows Uinta A sandstones as a rotated block



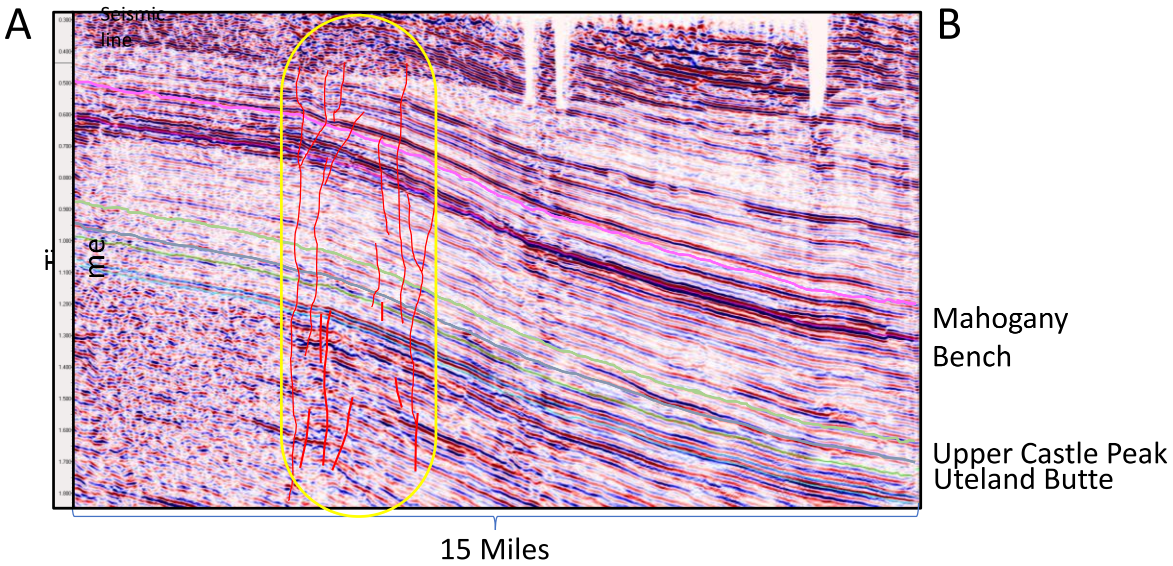


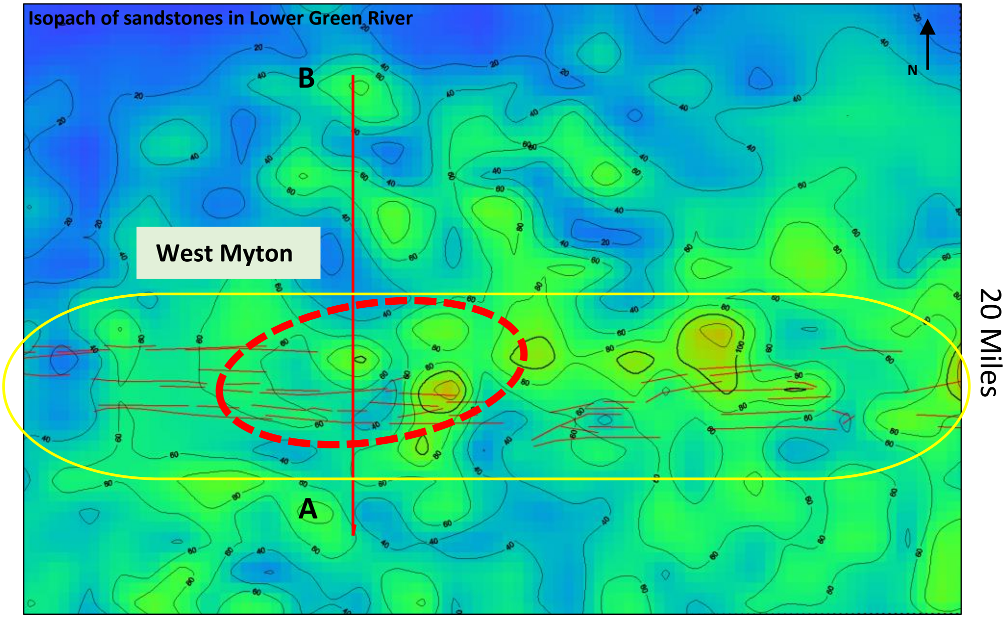
Rotated block in the Lower Black Shale

The core begins in the rotated block, so it is unknown how large the block is

Terminal Deltas and the Duchesne Fault Zone

- The Duchesne Fault Zone acted as a point of structural rotation, marking the southern limit of the deep basin
- The change of structural dip focused deltaic sediments at the at the fault zone
  - **Meaning that large volumes of terminal deltaic sediments were deposited on thick lacustrine shales in a zone with a high potential for earthquakes**



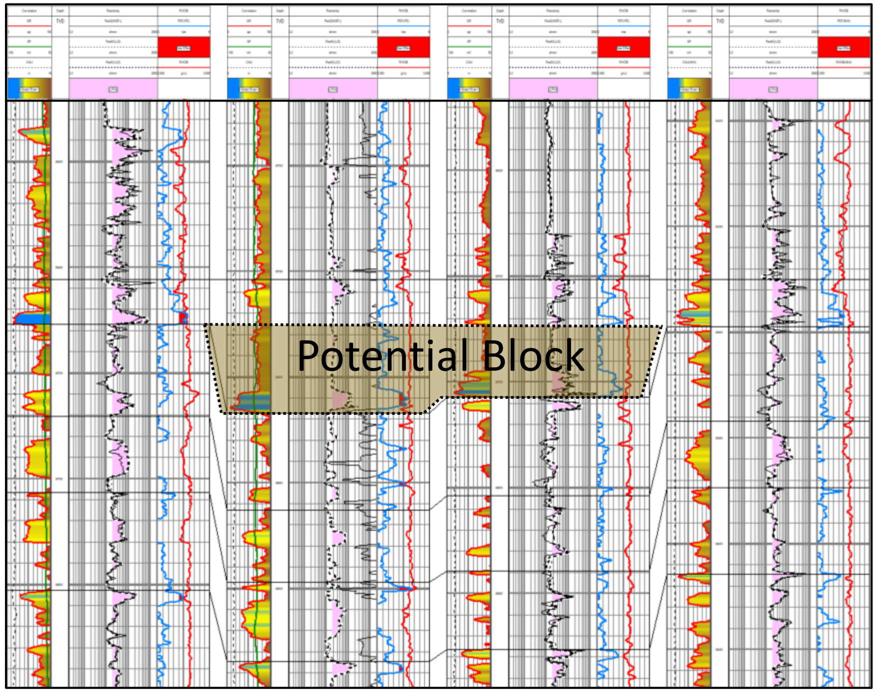


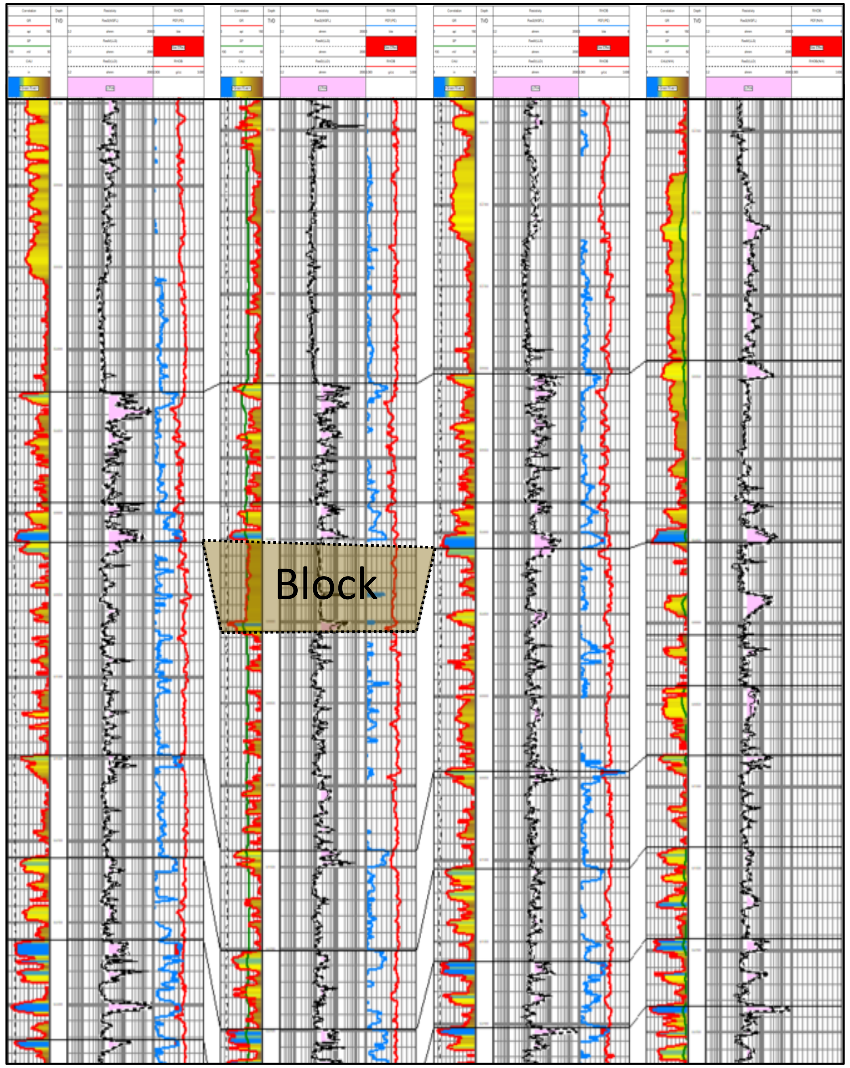
Brinkerhoff and Woolf, 2018

Observed Blocks Near West Myton

For much of the stratigraphic section in the West Myton area, the lack of markers makes identifying structured blocks difficult

Fortunately, these two blocks occurred in a zone with frequent markers





Conclusions

- Production anomalies in West Myton likely related to limited reservoir extents
- Outcrop examples of synsedimentary and early post sedimentation block movements are plentiful, particularly in the Uinta A in the eastern Uinta Basin
- Similar large slump blocks are observed in other portions of the basin and near West Myton
  - **It is very possible that features similar to those observed in the Uinta A contribute to West Myton's limited reservoir extents**

References

- Reduction of reservoir quality

- Ali, Syed A., Clark, W.J., Moore, W.R., Dribus, J.R., Diagenesis and Reservoir Quality, Oil Field Review, Summer 2010, p. 14-27
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