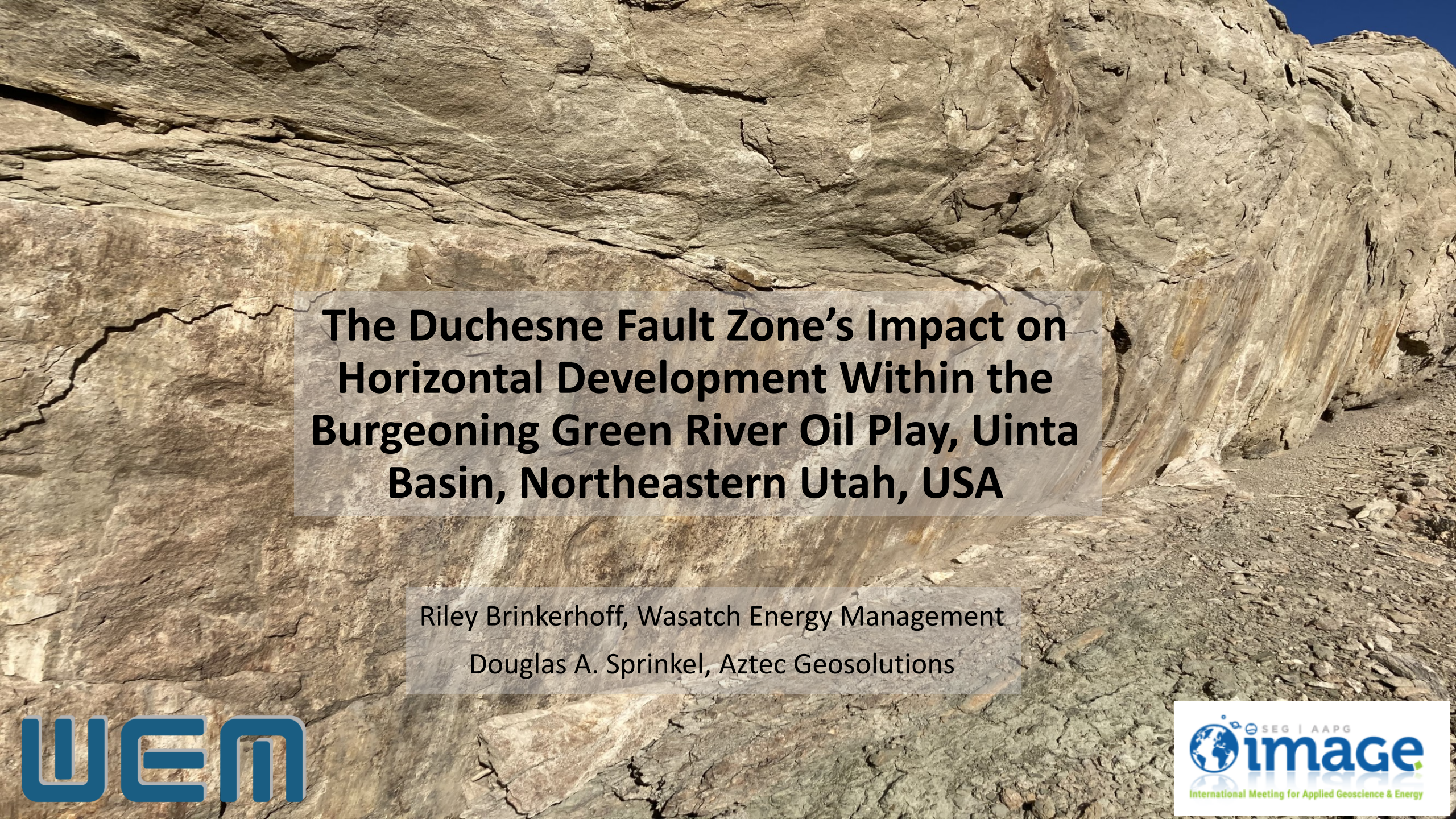

The Duchesne Fault Zone's Impact on Horizontal Development Within the Burgeoning Green River Oil Play, Uinta Basin, Northeastern Utah, USA

Riley Brinkerhoff, Wasatch Energy Management

Douglas A. Sprinkel, Aztec Geosolutions

WEM

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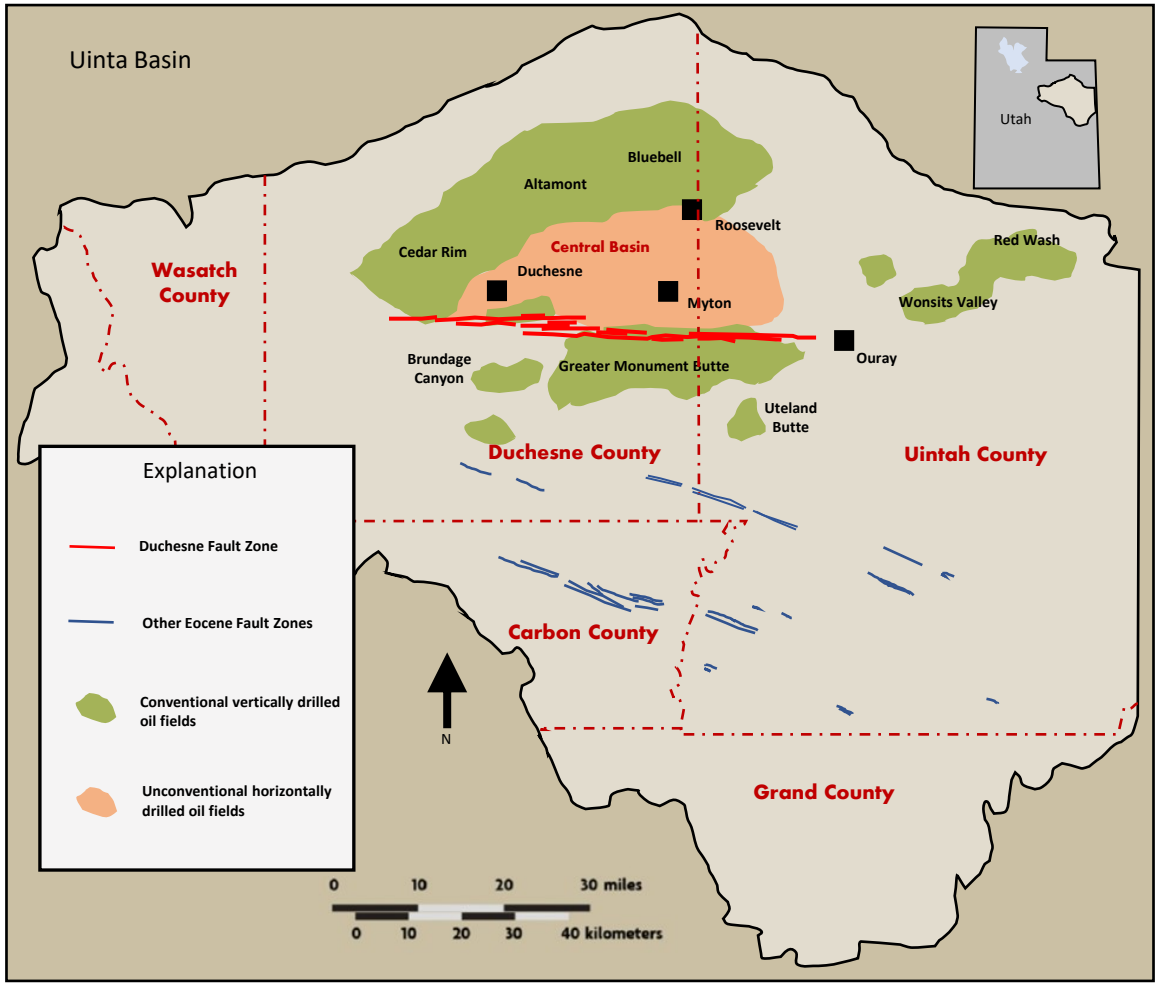
Why you care

- The Green River horizontal play in Utah's Uinta Basin is one of the hottest onshore plays to develop in the last five years
  - New wells IP at 2000 bbl. of oil/day or better
  - Projected EUR's are in the 1 to 1.5 MMBO range
- The Duchesne Fault Zone is in the center of this burgeoning play
  - The fault zone marks the southern boundary of the Uinta Basin overpressure cell
  - Horizontal wells to the south of the fault zone show much less productivity
  - Vertical wells in the fault zone appear to have suffered from reservoir compartmentalization and low bubble points
- The best method to develop Green River oil reserves in the fault zone is an open question
- **Similar fault zones exist in many horizontal plays**



Presentation Outline

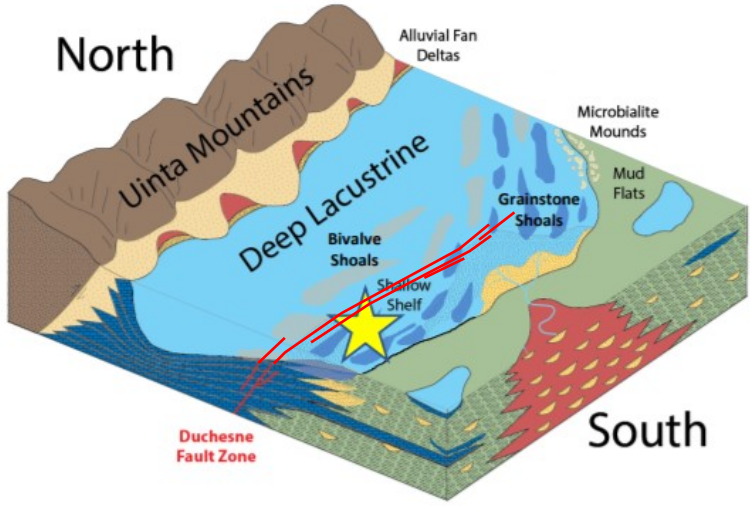
- Status of the Green River Oil Play in the Uinta Basin
- Physical characteristics of the Duchesne Fault Zone (DFZ)
- Reservoir compartmentalization within the DFZ
- The Uinta Basin Stress Field and its relation to the DFZ
- The DFZ's influence on Green River Formation stratigraphy
- Potential development hazards and opportunities

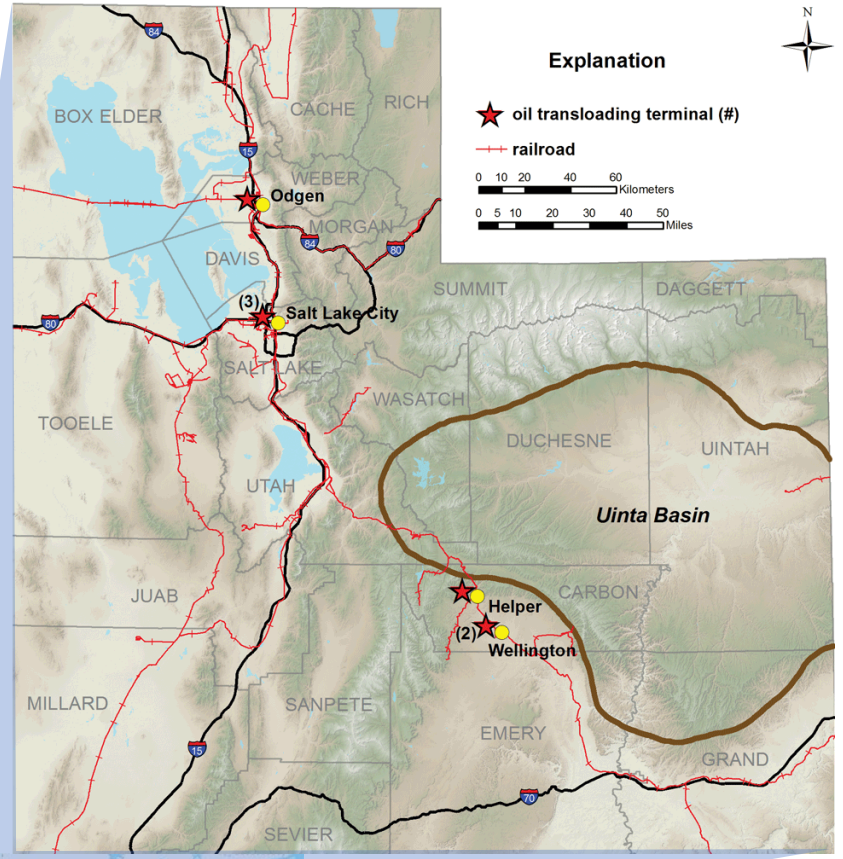
The Uinta Basin

Located in northeastern Utah, the Uinta Basin is a large (nearly 15,000 square miles), multi-target, petroleum basin

Hydrocarbon-charged sediments were deposited in a series of Phanerozoic basins, the latest of which is a deep foreland basin related to the Laramide aged Uinta Uplift (65MA to 45MA)

Oil was first discovered in 1948, the Basin has since produced ~1.5 billion barrels of oil, with a calculated 8.7 billion barrels left to recover





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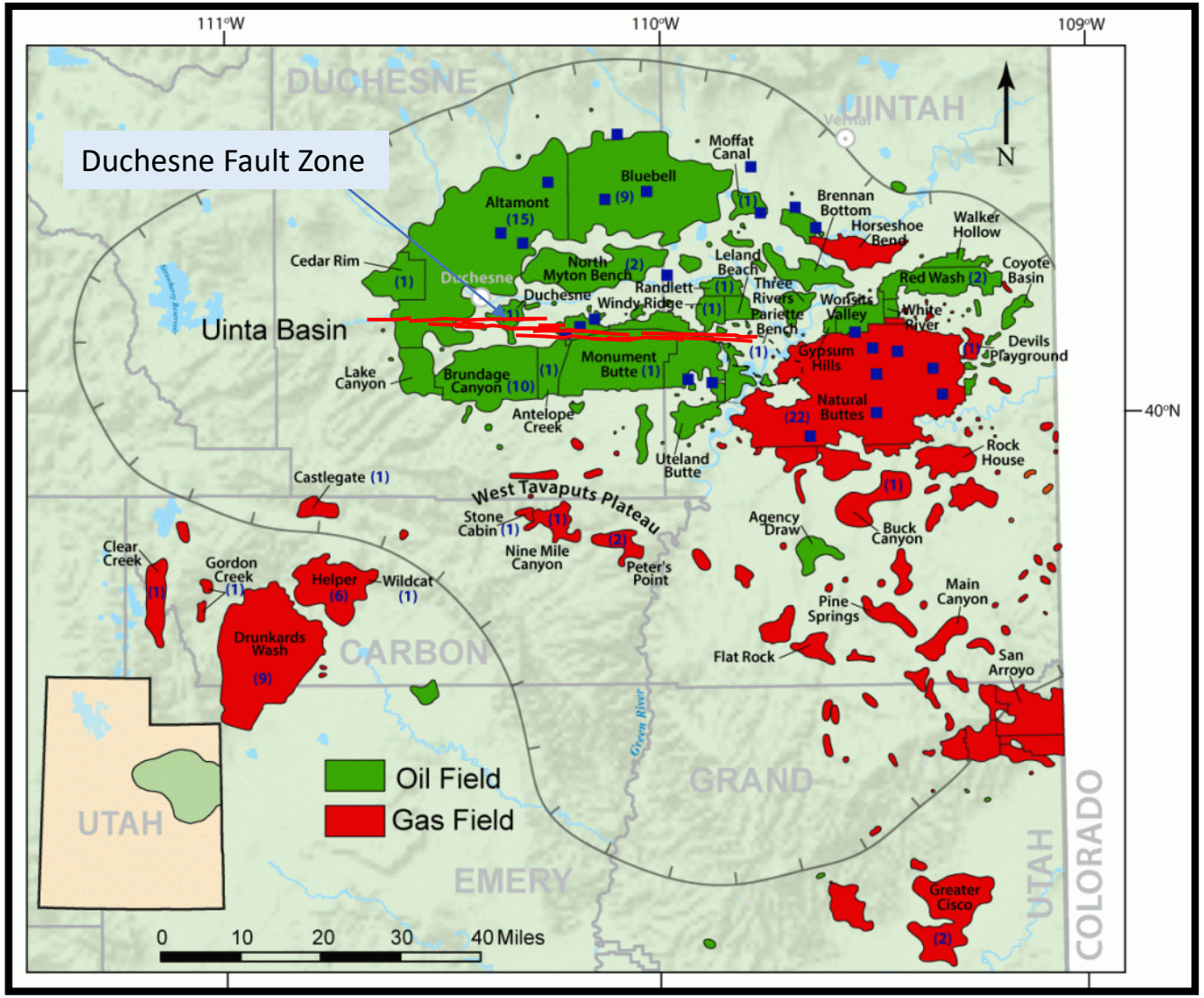
Significant Oil & Gas Reserves

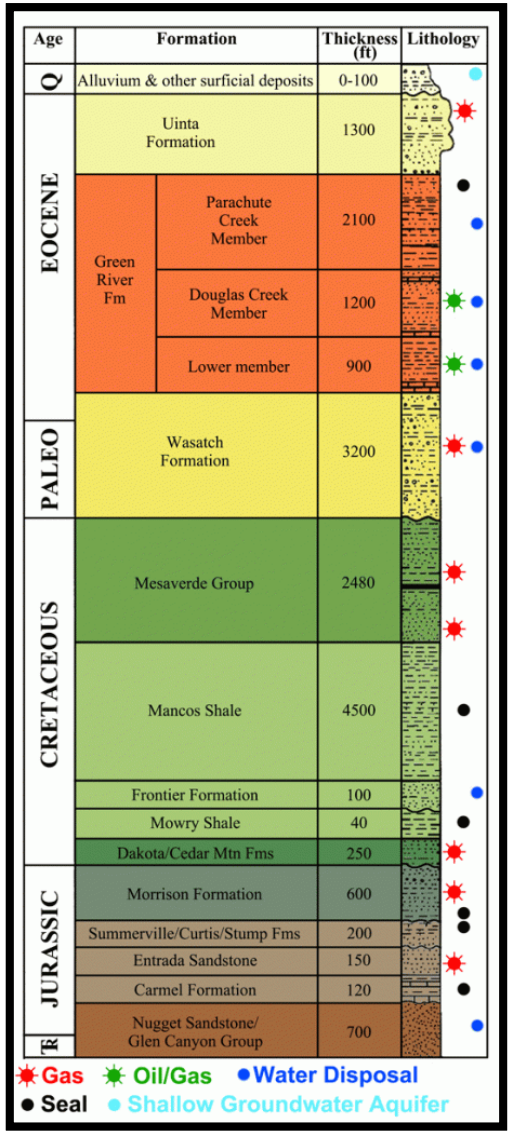
- In global oil and gas terms, the Uinta Basin is only moderately sized
- Phanerozoic sediments in the center of the basin, are almost eight miles thick
- This massive volume of sediments has attracted oil & gas exploration for decades



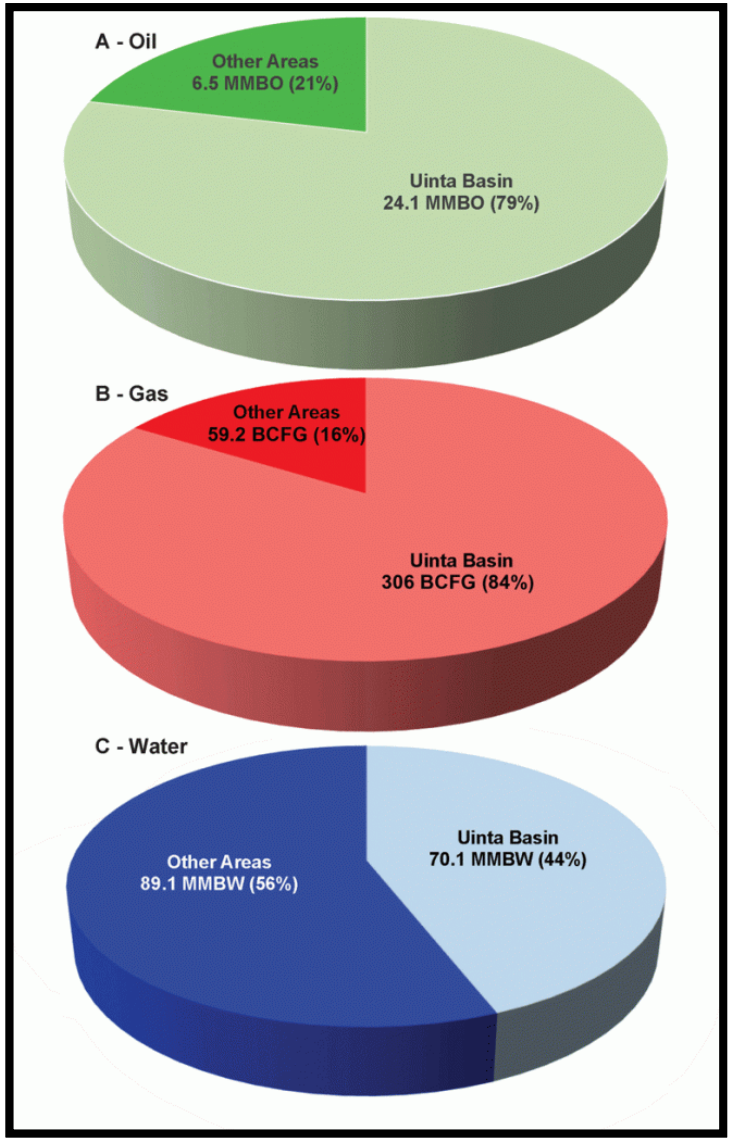
From Chidsey, 2017

The Uinta Basin Dominates Utah Production

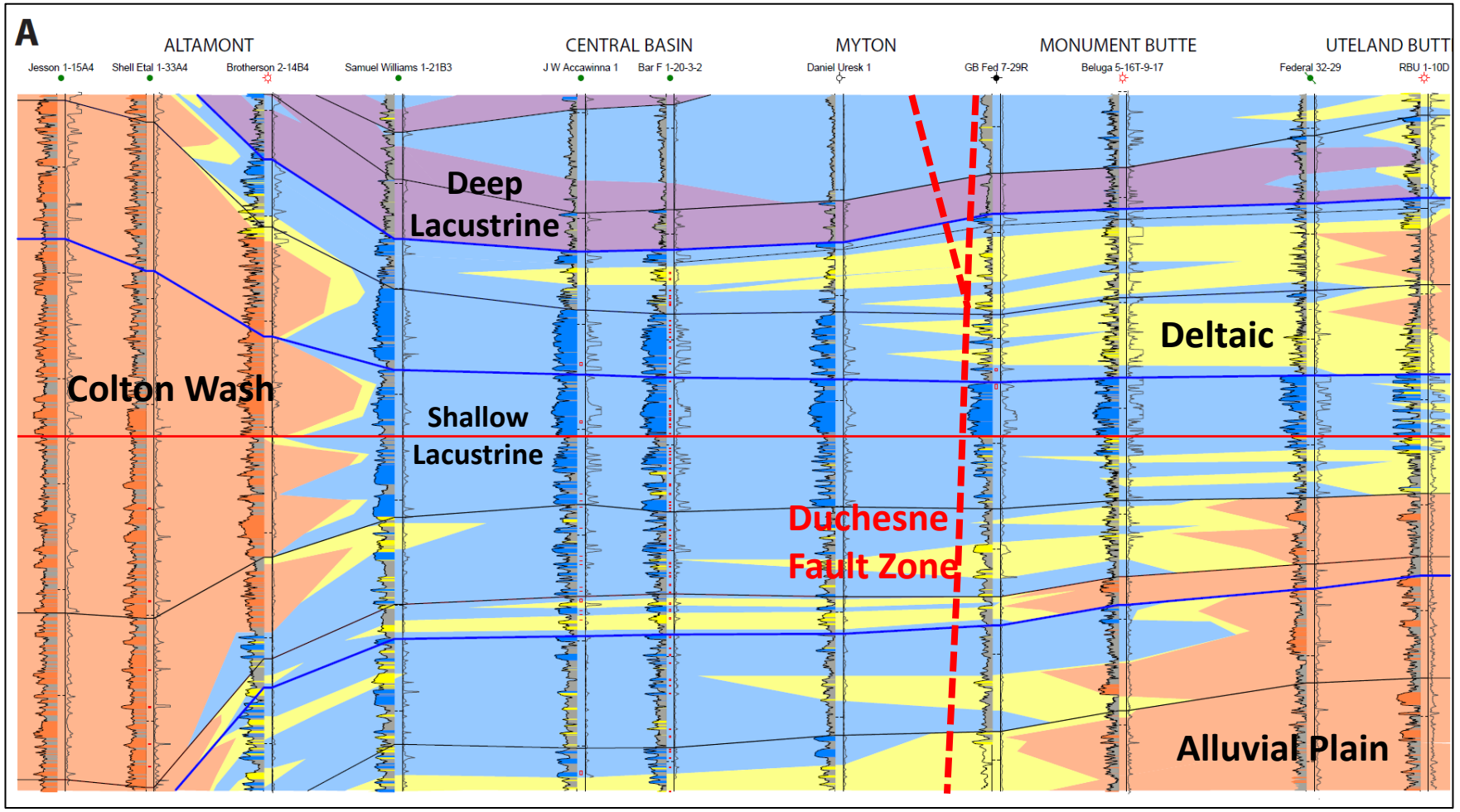
- Hydrocarbons are produced across the state of Utah, but over 80% of its oil and natural gas production comes from the Uinta Basin
- Near term future development is also focused on the basin, with over 90% of the state's active drilling permits
- Eight rigs are currently active in Utah, all in the Uinta Basin



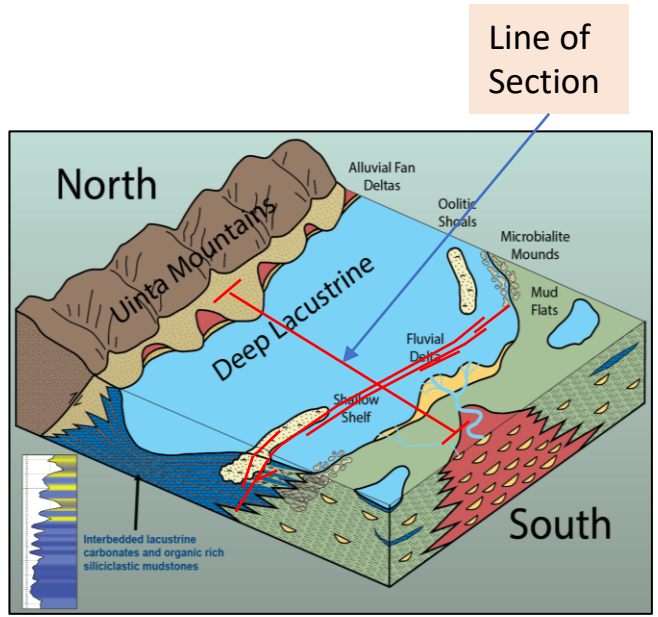
From Chidsey, 2017



Lake Uinta Legacy

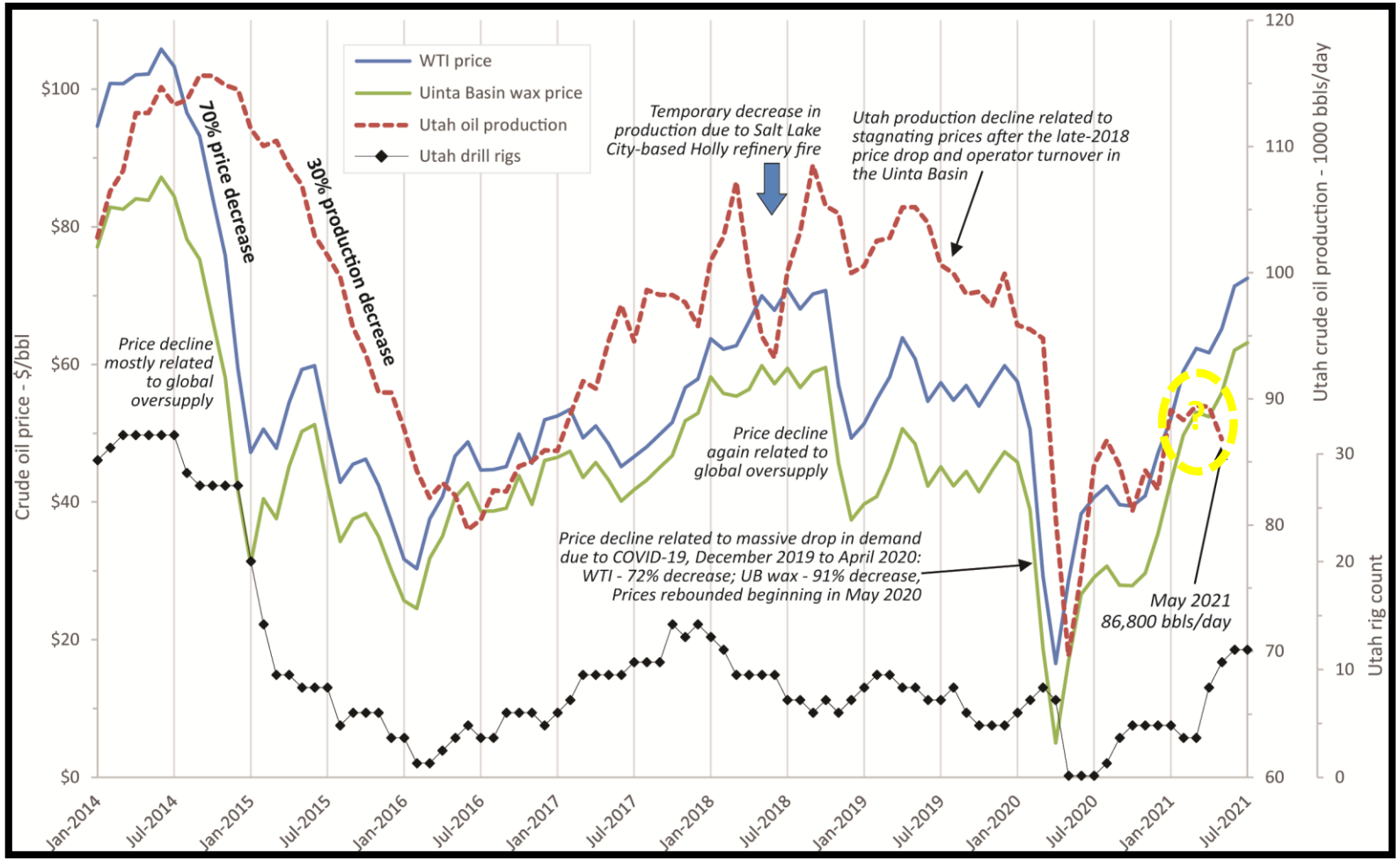


- Multiple lacustrine transgressive-regressive cycles from Wasatch through Lower Green River section
- Basin scale maximum flooding event in Uteland Butte results in increased local organic enrichment of interbedded carbonates and mudstones in the deep and shallow water lacustrine environments during Uteland Butte and Lower Castle peak time



Modified from Brinkerhoff and Woolf - 2019

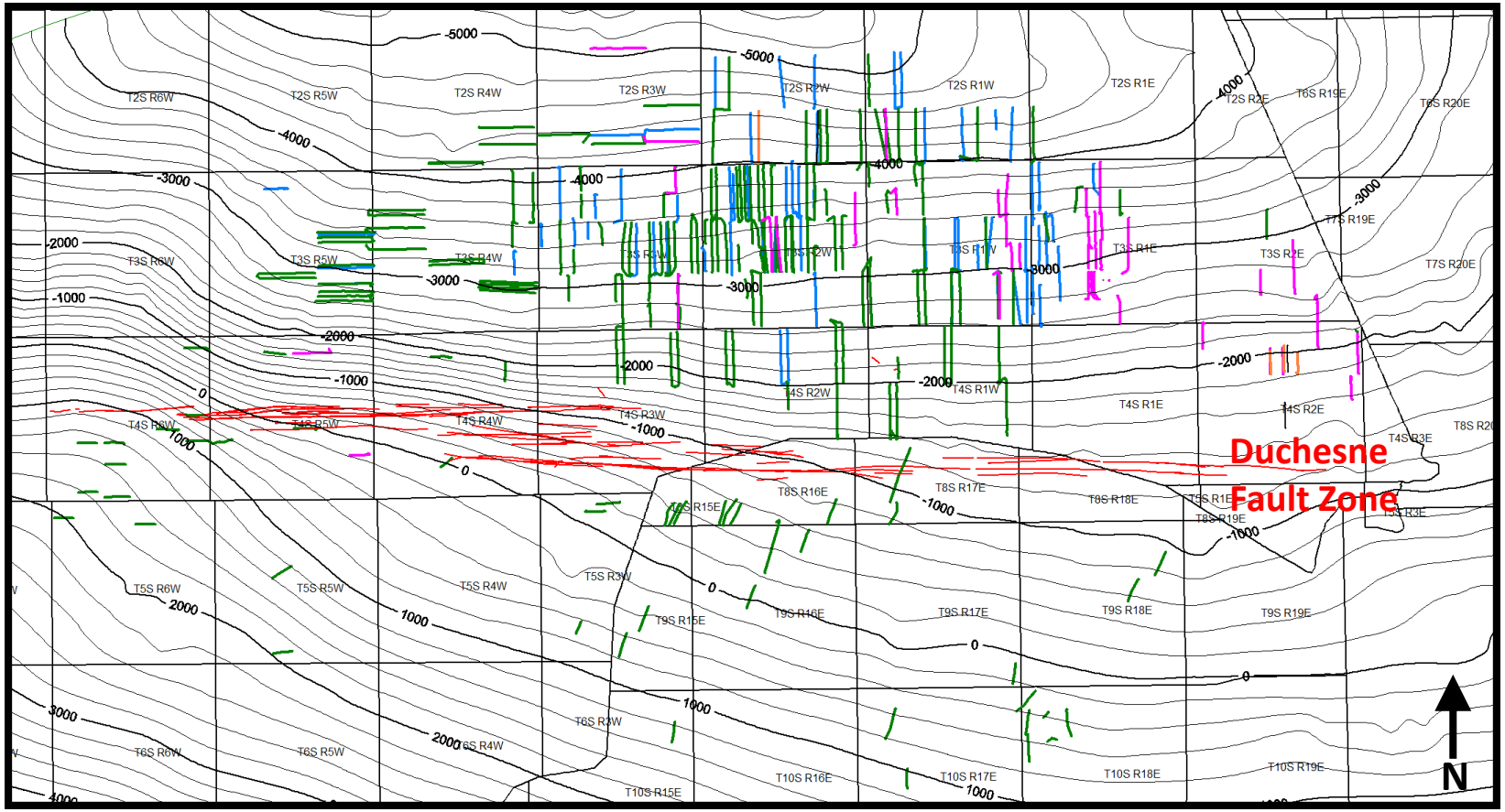
Activity In the Uinta Is Picking Up

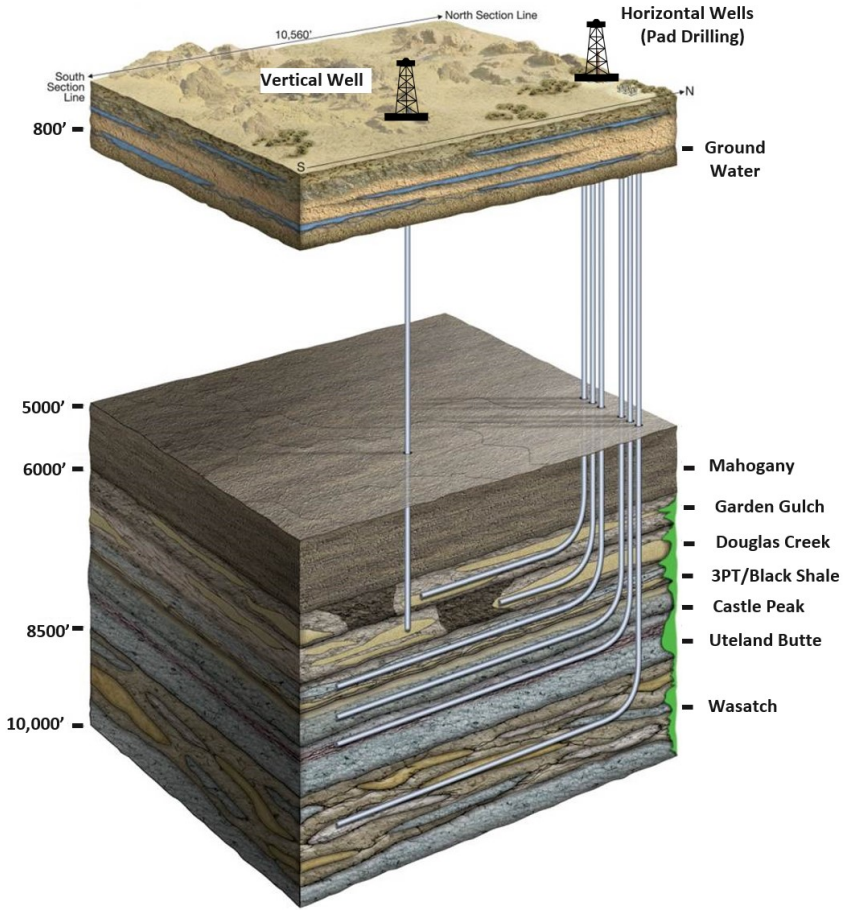


- Like most of the country, activity in the Uinta Basin crashed to almost nothing last year
- Strong well results have made the Uinta a strong competitor for capital investment as oil demand has returned
- With the highest rig count the Uinta has seen in years and the best well results in its history, production is expected to climb sharply

From Vanden Berg, 2021

What is Being Targeted?





The Uteland Butte has been the most frequently targeted GRF interval at ~193 wells, especially towards the margins of the play

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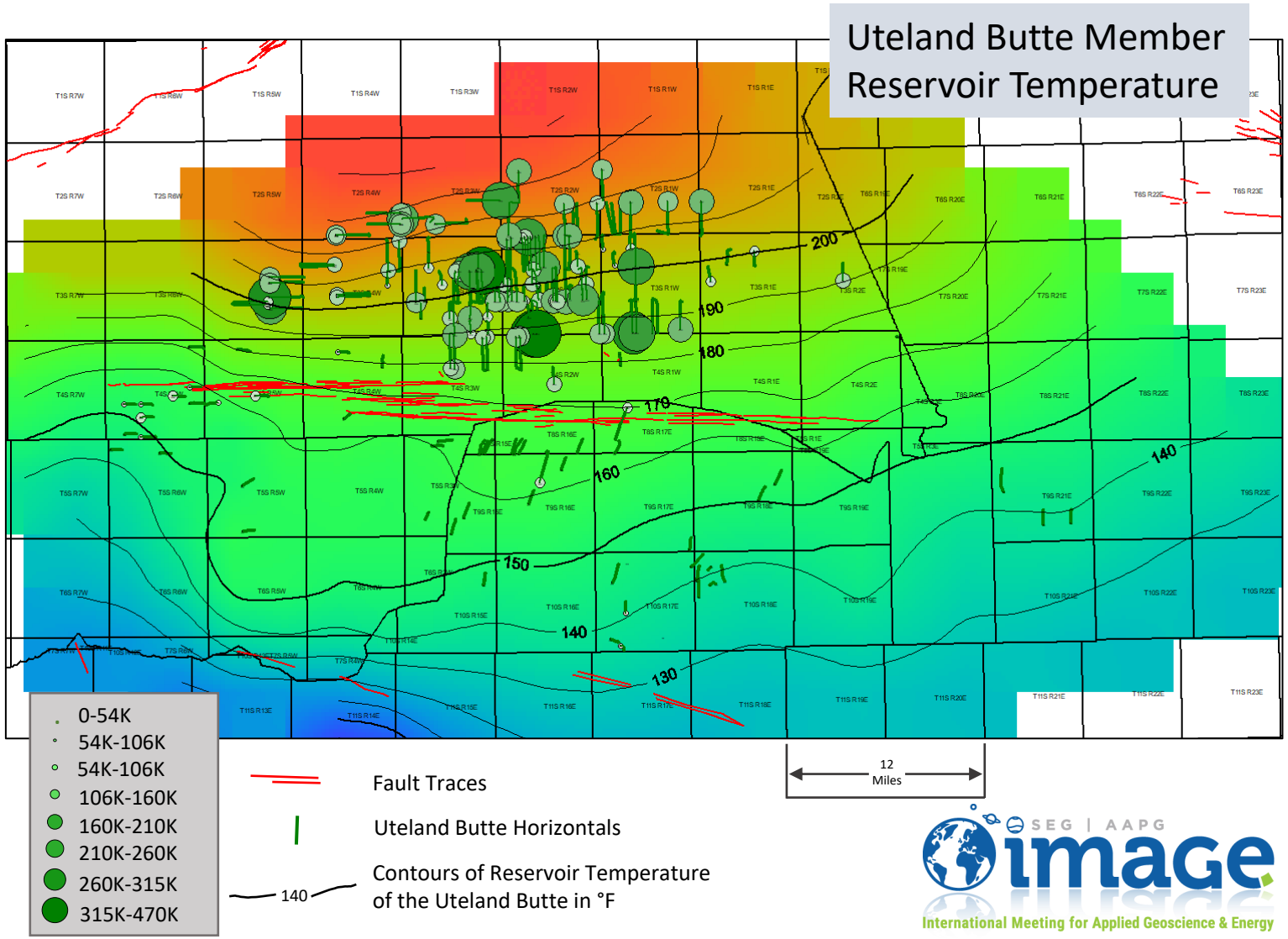
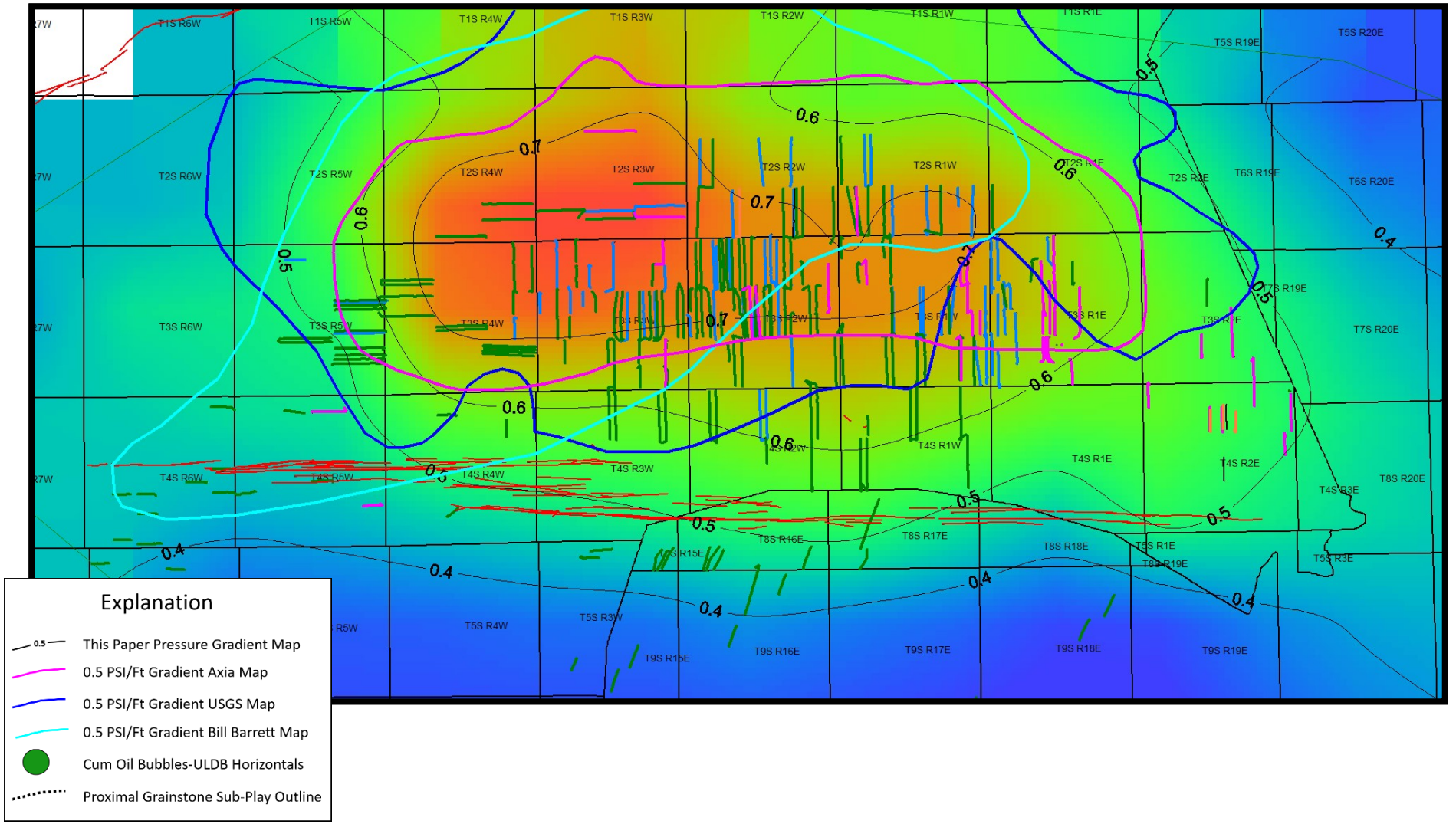
What Are the Well Results?

- Well results are variable across the basin
- Even if we focus on a single target, the Uteland Butte, we can see large differences in well productivity
- Note that the wells north of the DFZ vastly outperform wells to the south
- Currently (2021), two-mile-long laterals with large fracs (greater than 10K tons of prop and 500K bbls of fluid) in the heart of the play have average 30-day IP's greater than 1000 bbls/day
- Pressure and reservoir temperature are important factors in well productivity, which are both strongly influenced by the DFZ



Pore-Pressure and the DFZ

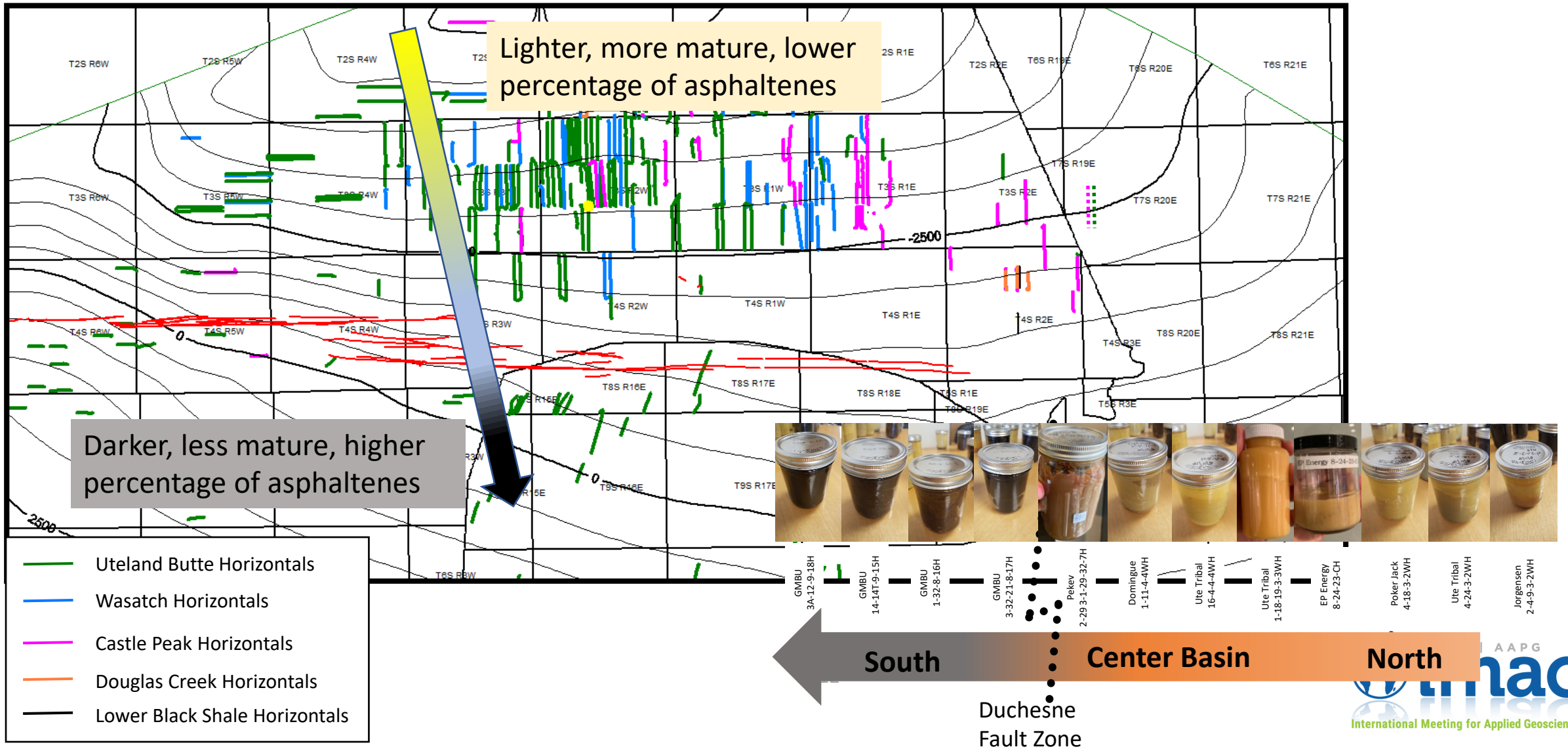


The Green River over-pressure cell is bounded to the south by the DFZ

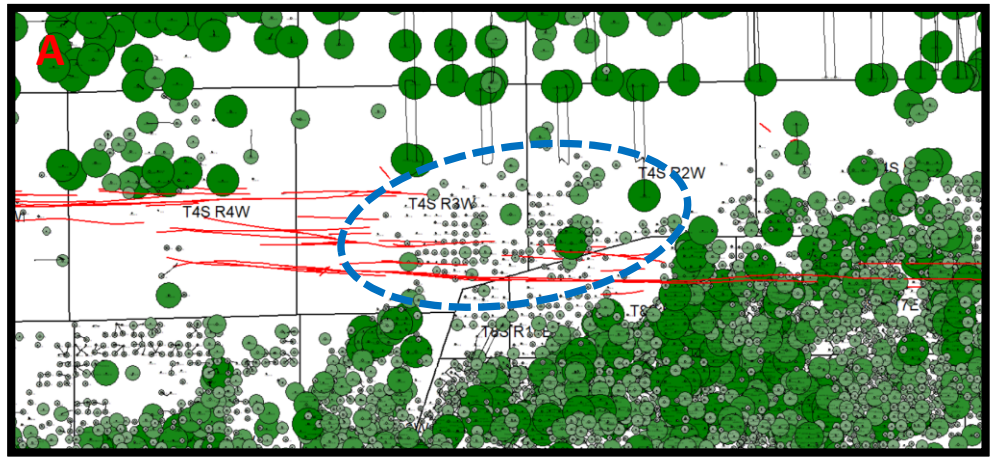
Tar sands and springs are commonly found along the DFZ, supporting the supposition that the DFZ is channeling upward fluid flow

The best production in the basin is in the over-pressured rocks – wells south of the DFZ will encounter normally pressured reservoirs

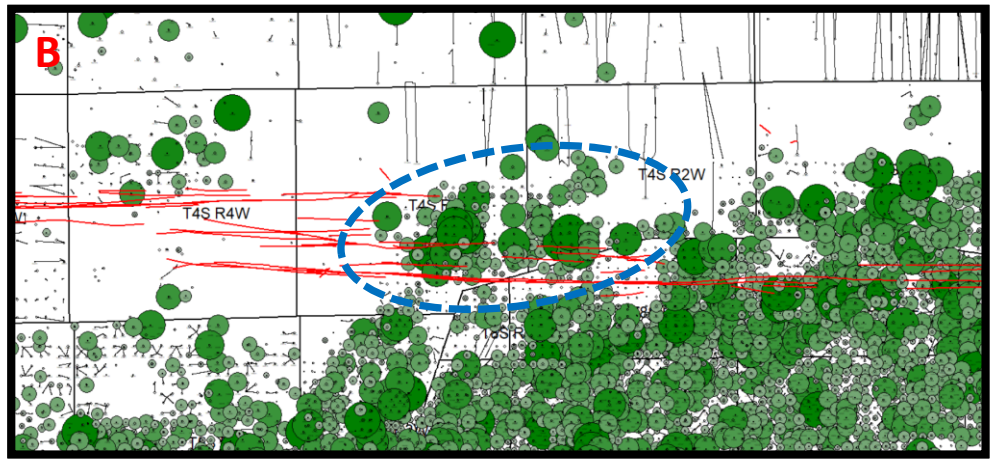
Unconventional Oil Development



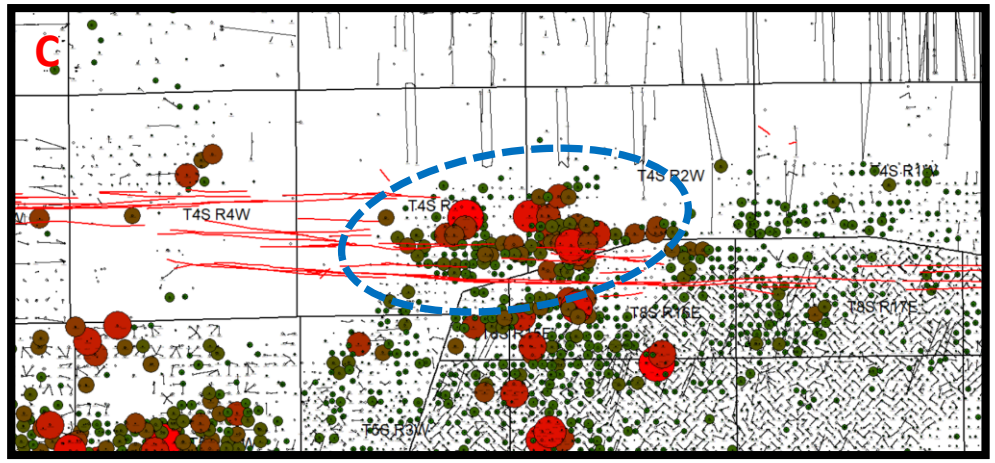
Reservoir Compartmentalization



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



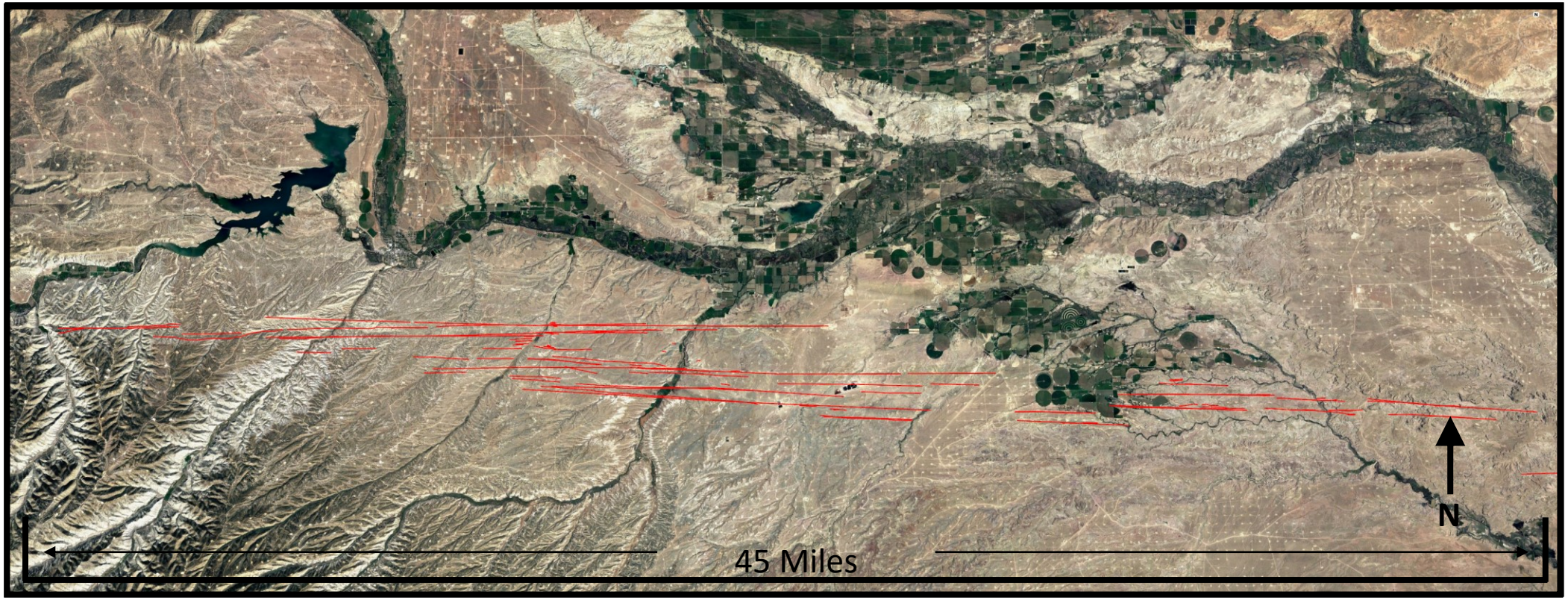
Initial Oil Production in Barrels/Month
0 - 455
455 - 909
909 - 1364
1364 - 1818
1818 - 2273
2273 - 2727
2727 - 3182
3182 - 3636
3636 - 4091
4091 - 4545
4545 - 5000



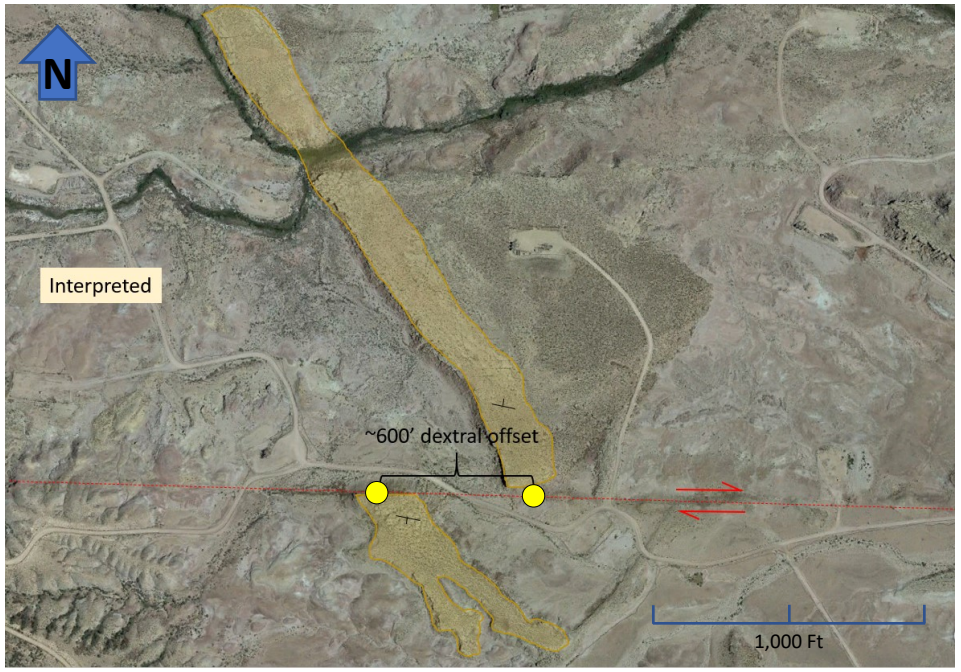
Gas/Oil Ratio (GOR) Standard Cubic Feet/Barrel
0 - 2500
2500 - 5000
5000 - 7500
7500 - 10000
10000 - 12500
12500 - 15000
15000 - 17500
17500 - 20000
20000 - 22500
22500 - 25000

- Production bubble maps from wells along the DFZ
  - **A** - production is undifferentiated and represents all commingled perforations within the Green River Formation of the well's historical tabulation of cumulative oil
  - **B** - first month's oil (IP)
  - **C** - gas/oil ratio (GOR)
- The wells in the blue oval indicate that wells in the DFZ while having higher initial oil production and higher GOR, are ultimately lower cumulative oil producers during the total life of the well
- These series of maps demonstrate the DFZ's influence on oil and gas production from the Green River Formation
  - The wells within the blue oval have much higher GOR's than normal
  - Natural fracturing from the DFZ likely enhanced permeability, leading to strong IP's
  - Compartmentalization led to these wells reaching bubble point early, which forced two-phase flow, and ultimately to poor production
  - The DFZ compartmentalized the reservoirs these wells access

The Duchesne Fault Zone

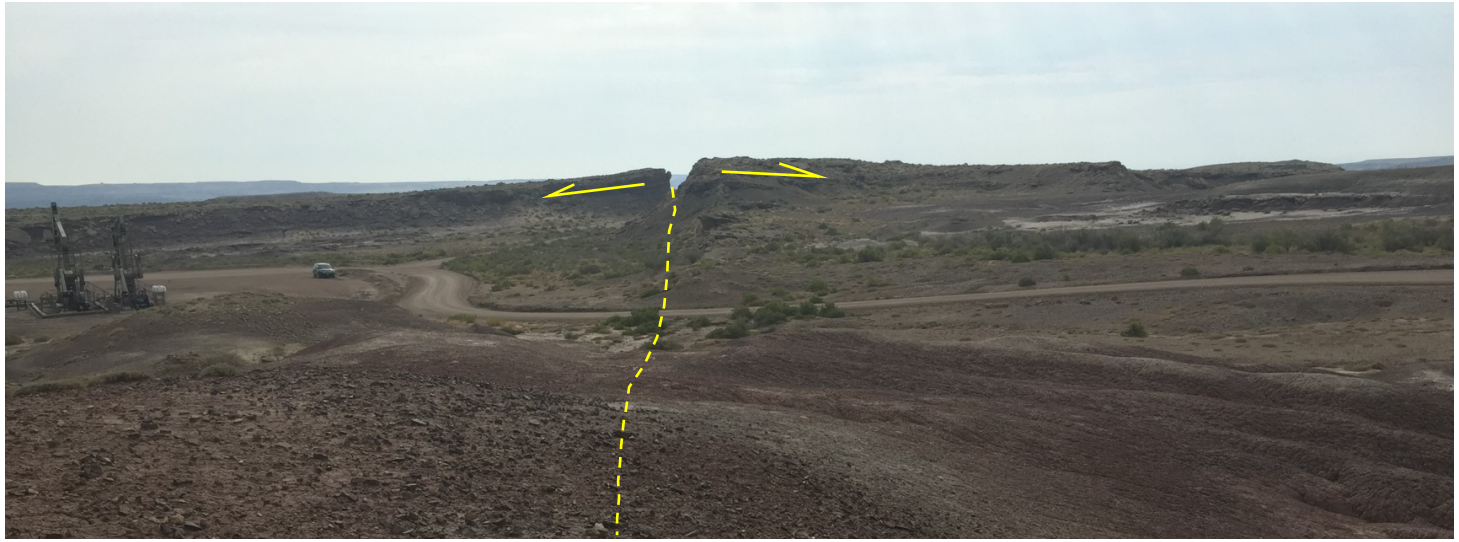


- Satellite imagery of the Uinta Basin, showing the position of the Duchesne fault zone (DFZ) in red
- The traces of the DFZ are particularly straight with extensive grabens and widespread oil & gas development both north and south of the fault zone

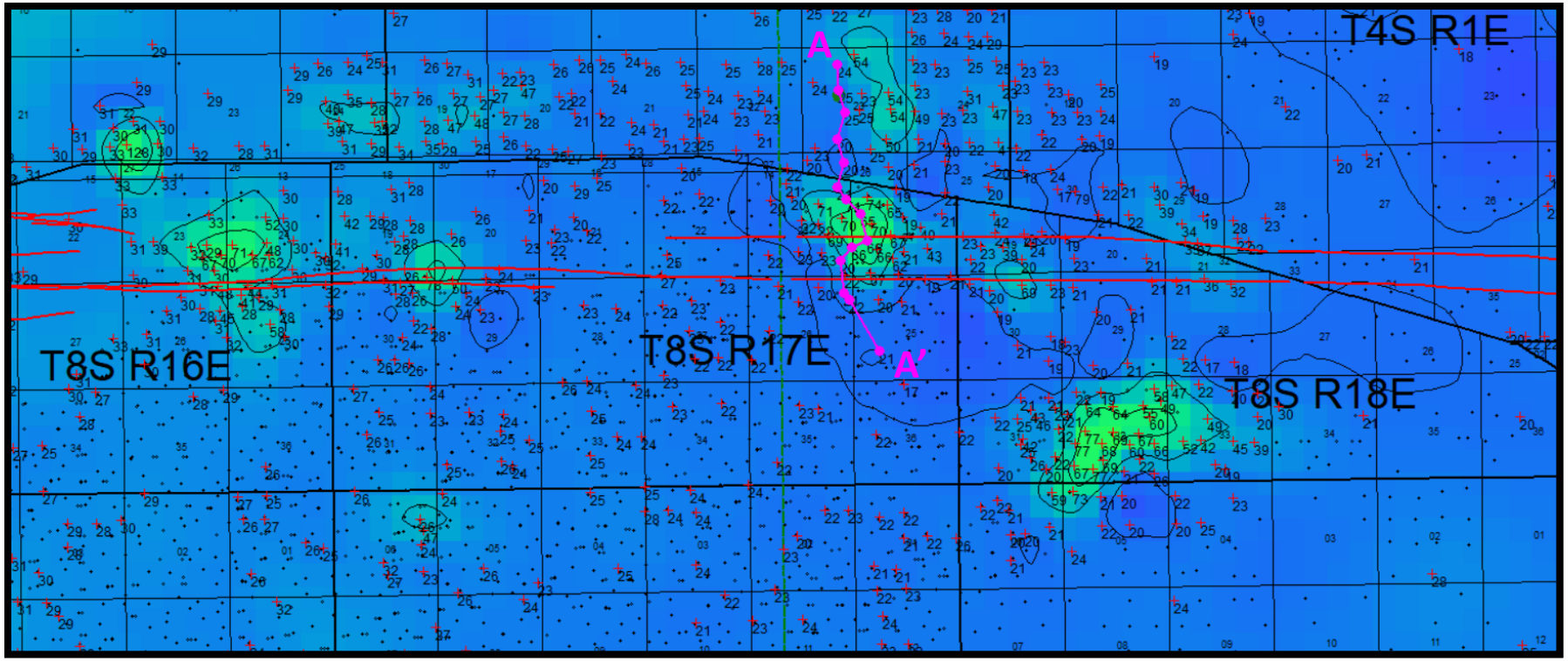


Characterizing the DFZ

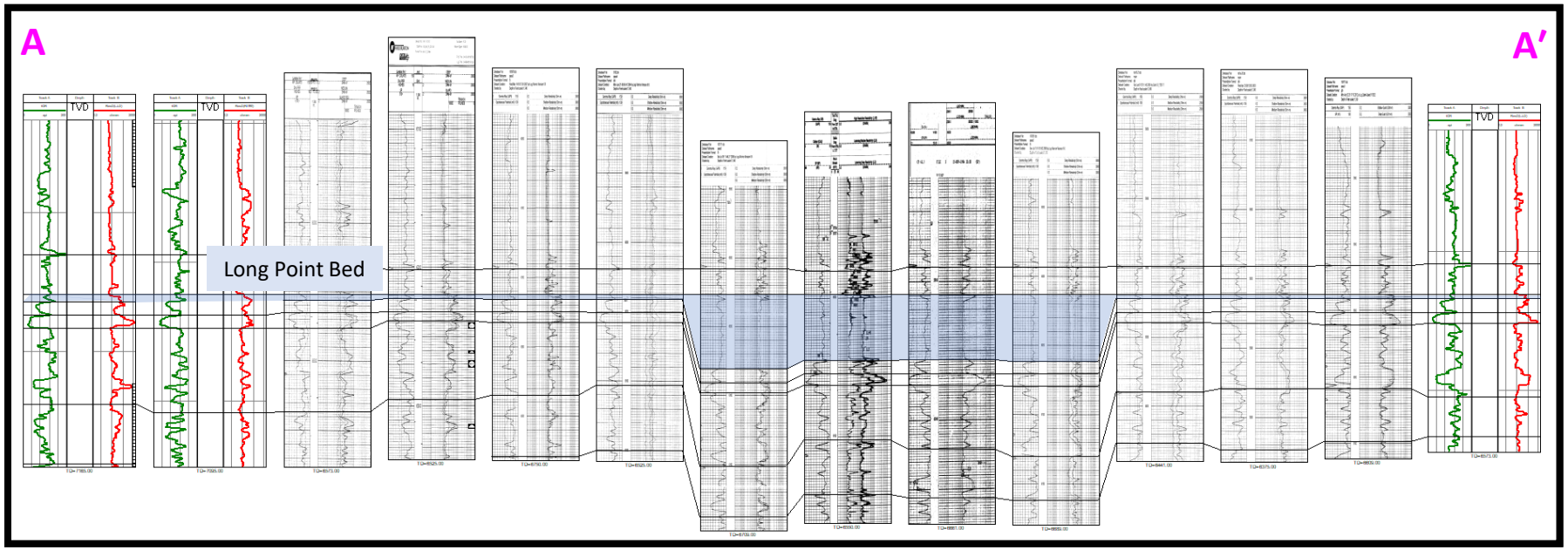
- The DFZ consists of a complex series of fault segments that underwent strike-slip, oblique and then dip-slip deformation
- Importantly from the standpoint of oil and gas development are the complex and intense fractures that are present in all brittle rocks within the DFZ



DFZ Sag Basins



- Oil wells
- $+_{25}$ Isopach of Long Point Bed
- Traces of the DFZ
- Sag basins on cross-section
- Sag basins isopach map with 20’ contours



Isopach map and associated cross section of the Long Point Bed of the lower Green River Formation

Small basins that syndepositionally opened along the DFZ

These are small sag basins or pull-apart basins associated with strike-slip movement along the fault zone

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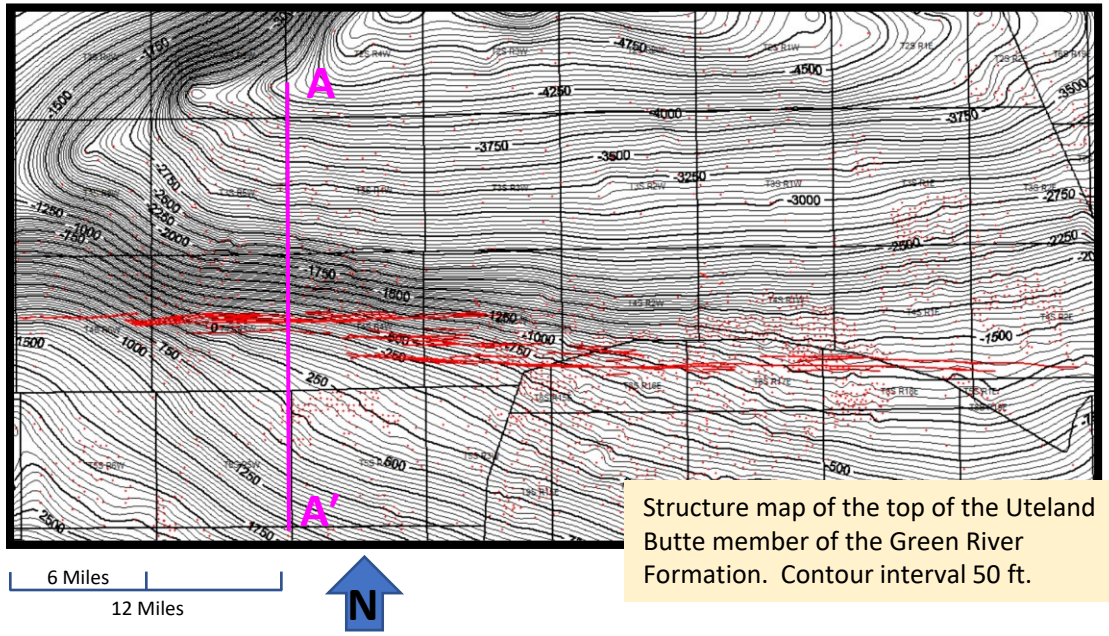
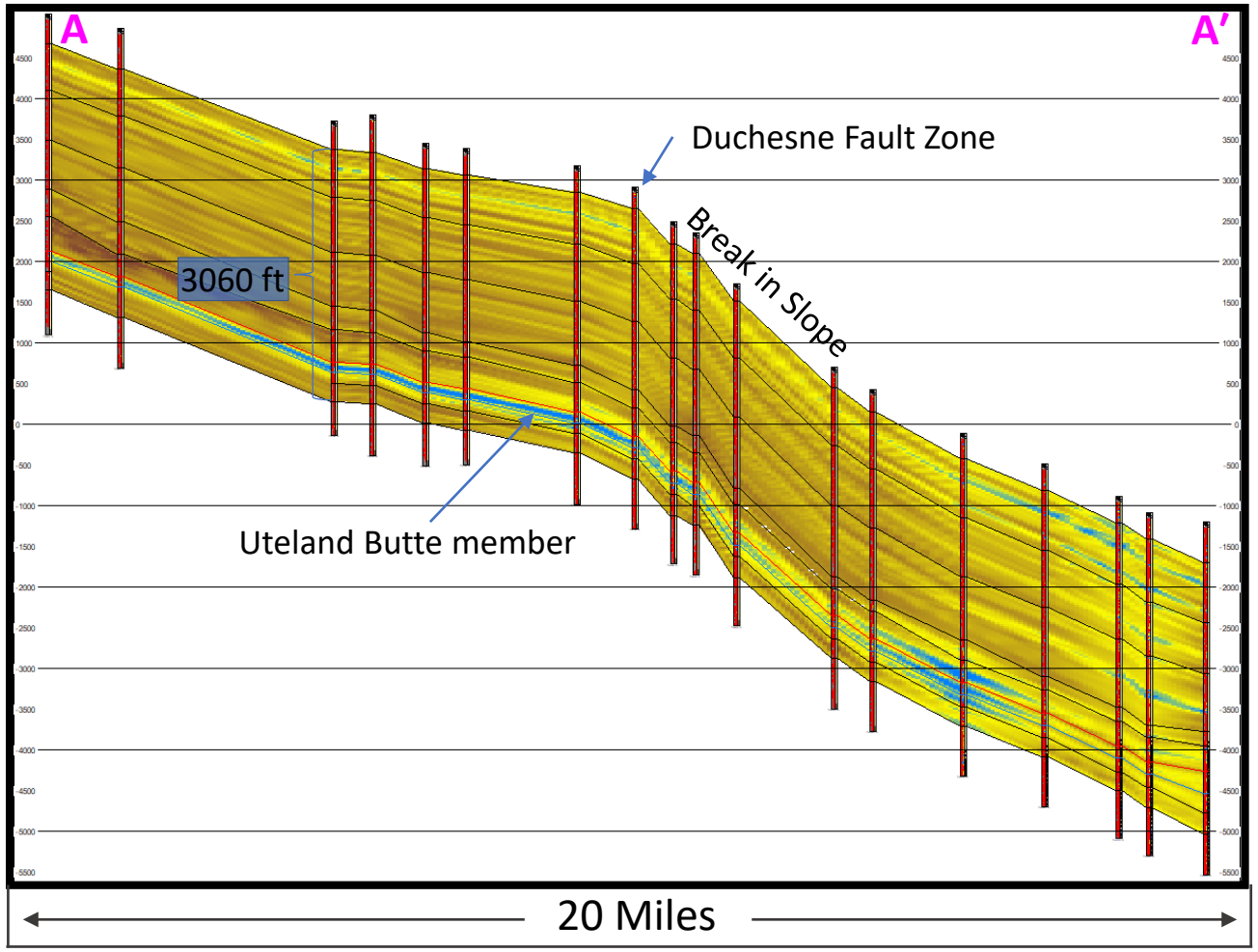
Structure



Structure map of the top of the Uteland Butte member of the Green River Formation. Contour interval 50 ft.



Subsea-true-vertical-depth (SSTVD) structure contour map on the top of the Uteland Butte member of the Eocene Green River Formation

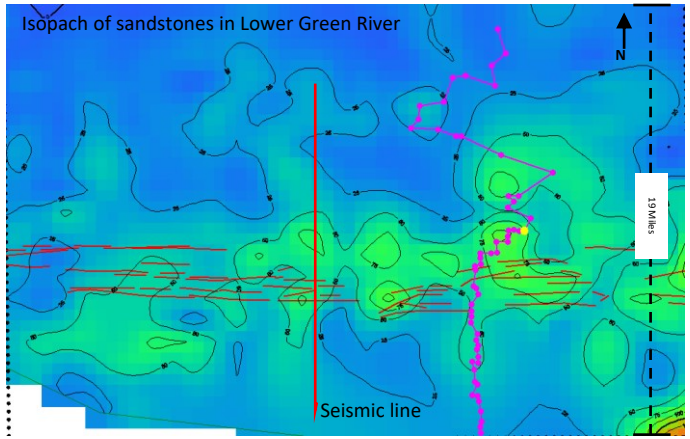
Interpretive gamma-ray well cross section (A-A') demonstrate the DFZ's influence on the greater structural and depositional trends in the Uinta Basin

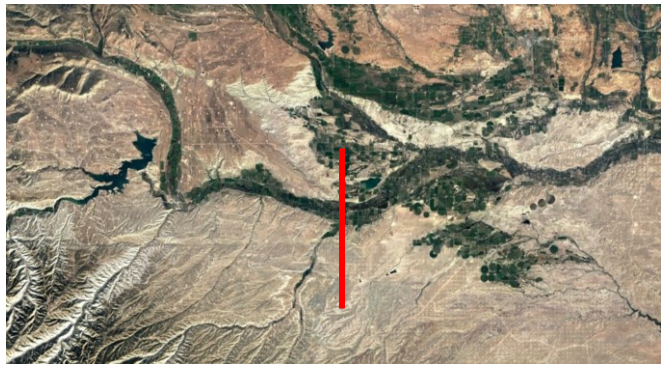
The DFZ acted as a hinge point in the developing Uinta Basin, with steeper stratigraphic dips to the north of the fault zone

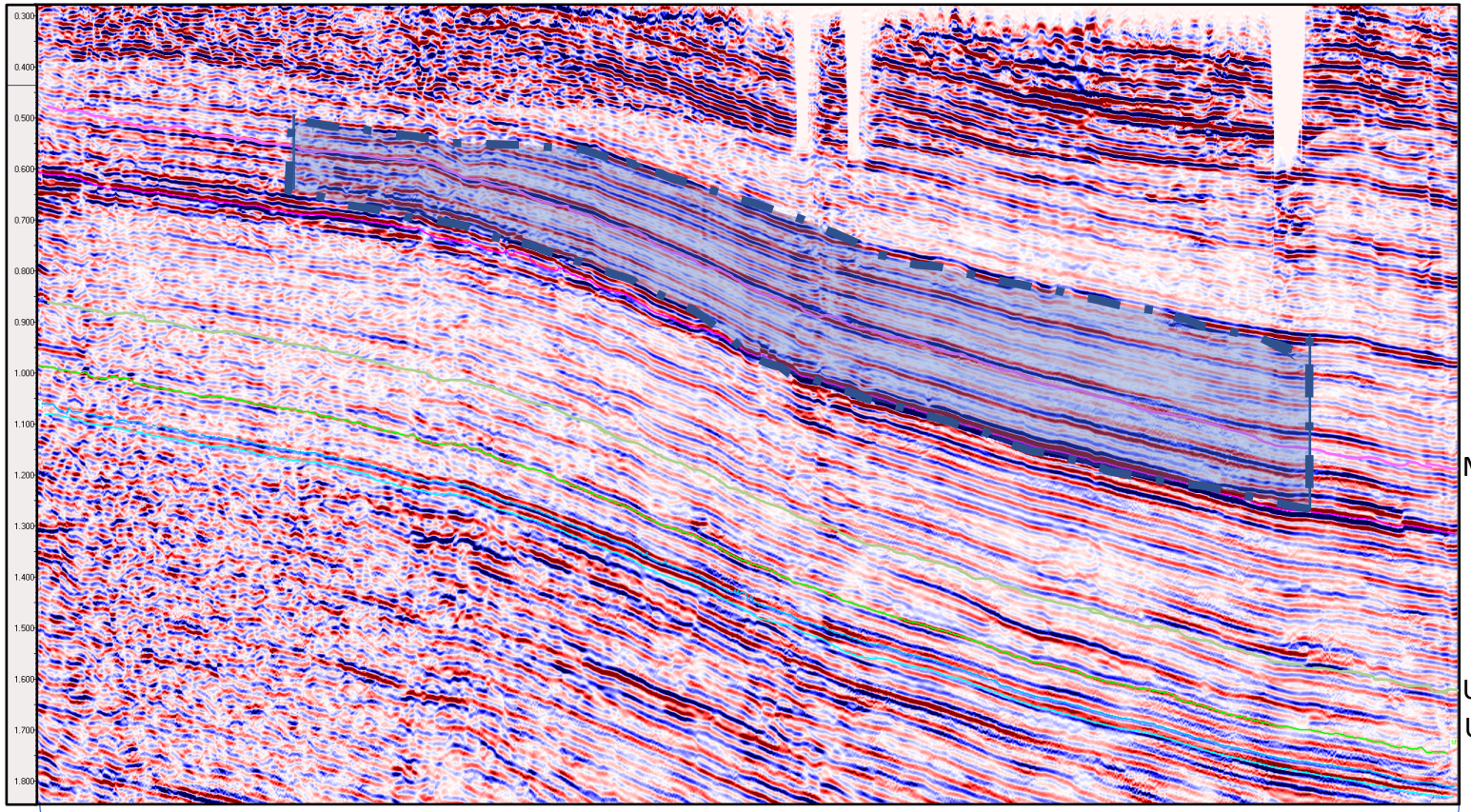
Today the DFZ marks the southern boundary of the deep, overpressured part of the Uinta Basin petroleum system

Relief on 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

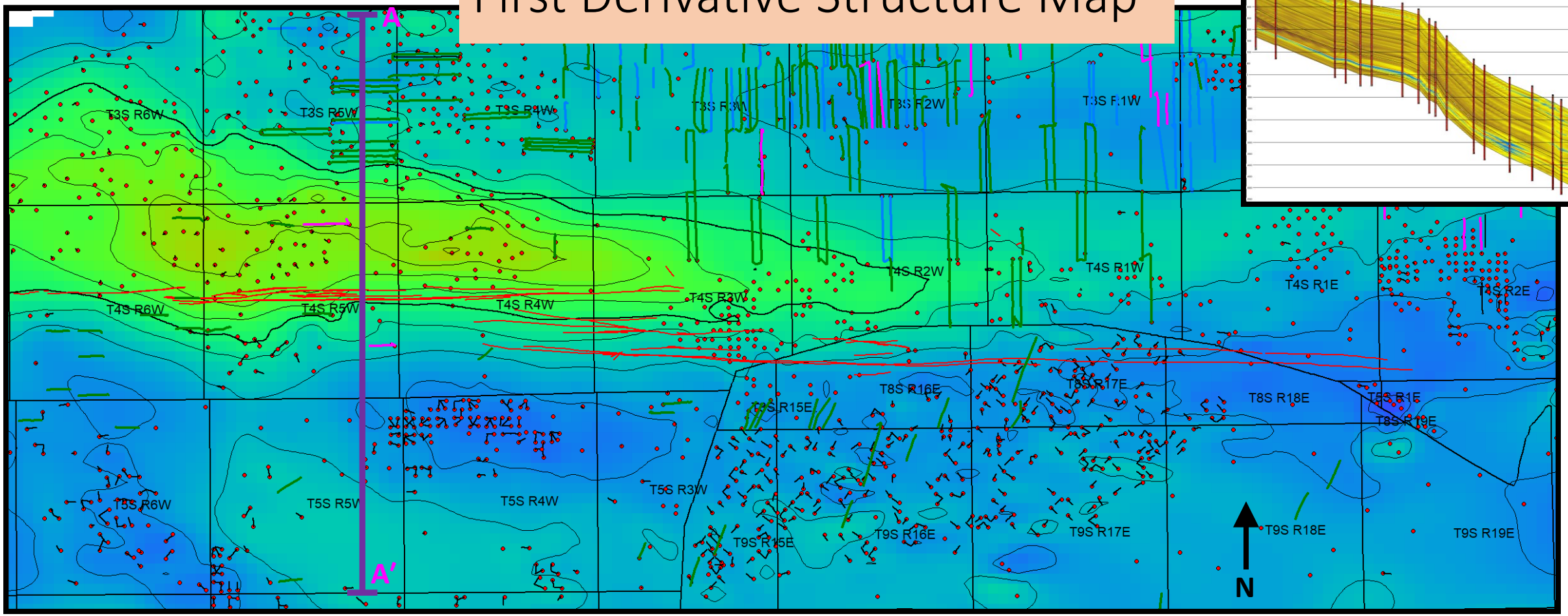






Modified from Brinkerhoff and Woolf - 2019

First Derivative Structure Map

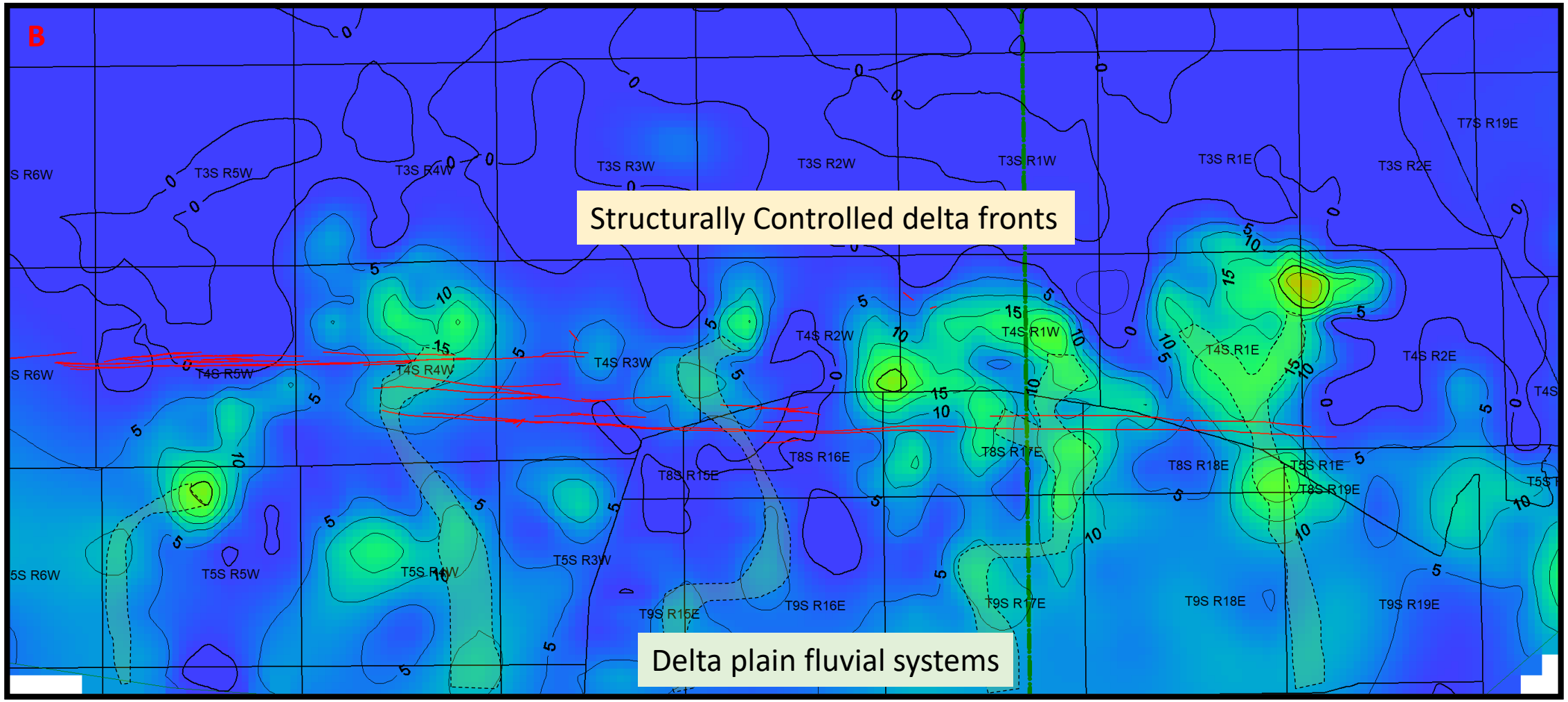


Uteland Butte
Wasatch
Castle Peak
Douglas Creek

12 Miles

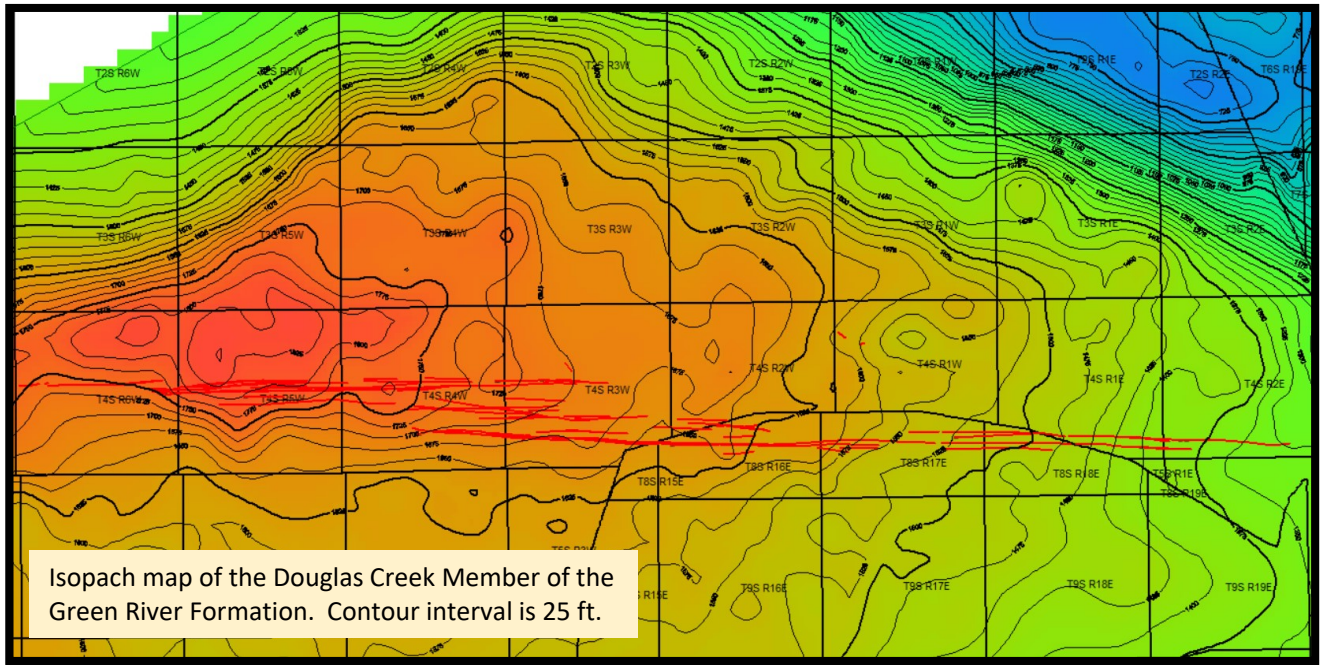
First-derivative structure contour map on the Uteland Butte member showing the portions of the basin with the steepest dips

The DFZ acted as a hinge point in the developing Uinta Basin, with steeper (warmer colors) stratigraphic dips to the north of the fault zone

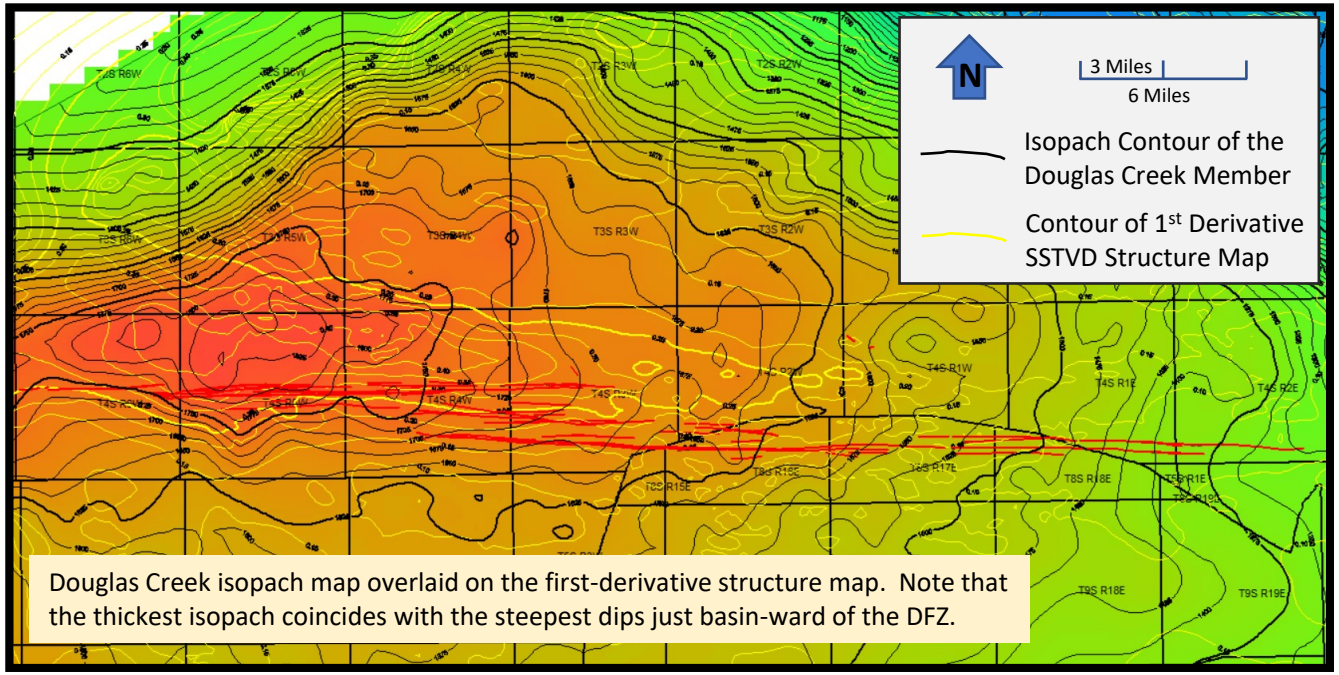


- The more rapid subsidence of the basin north of the fault created greater accommodation, resulting in much thicker stratigraphic thicknesses just basinward of the fault

Stratigraphic Effects



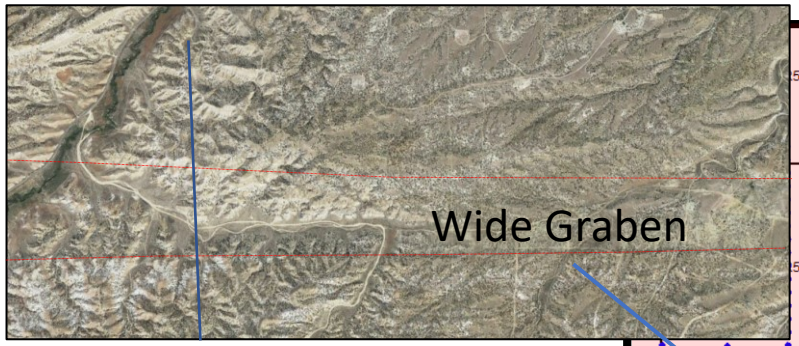
Isopach map of the Douglas Creek Member of the Green River Formation. Contour interval is 25 ft.

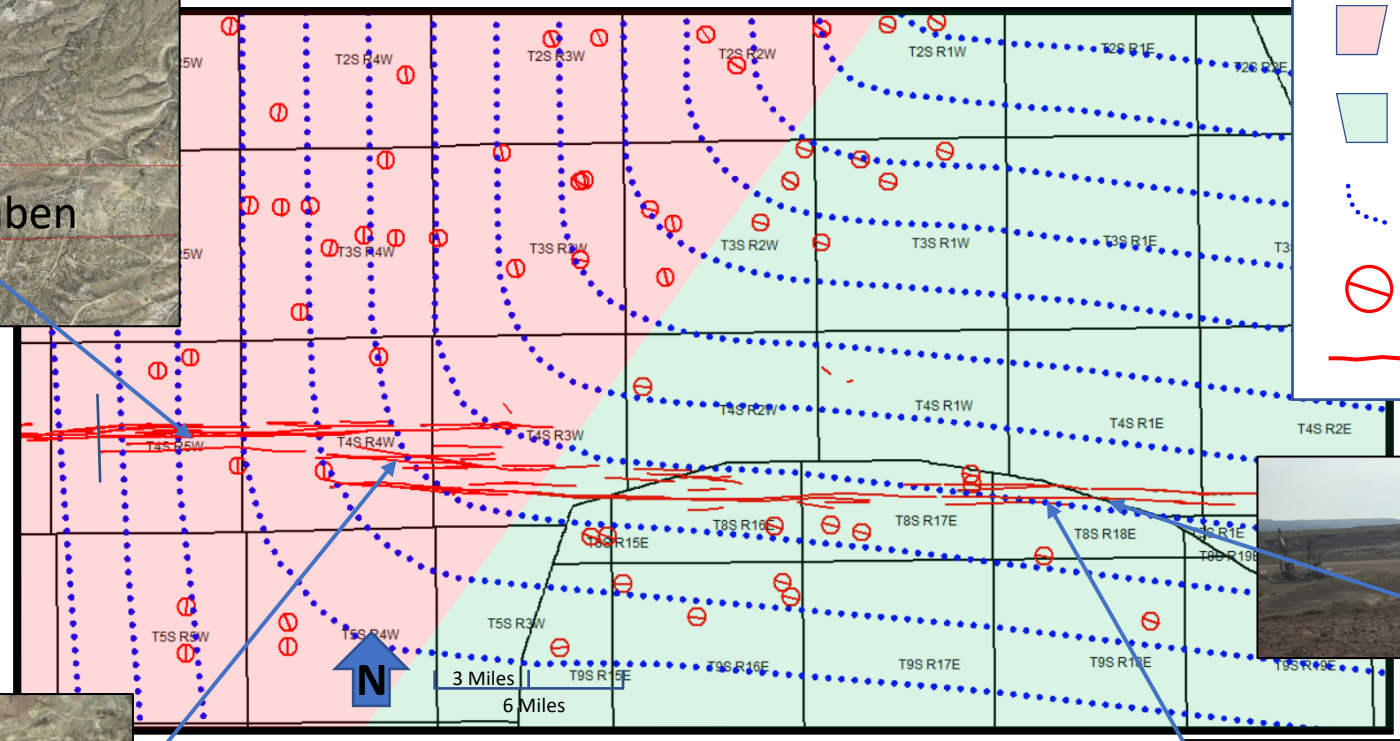


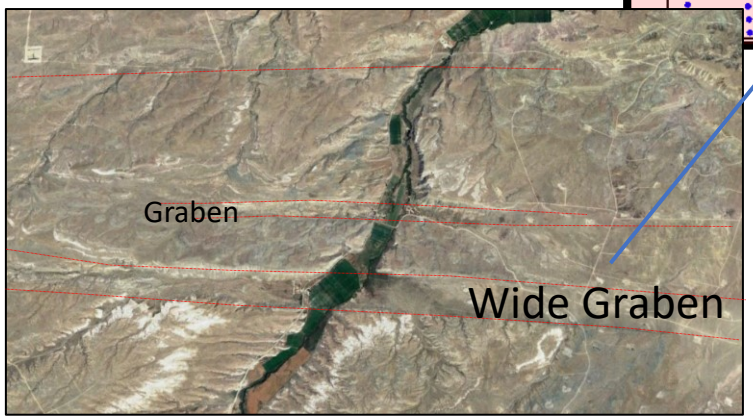
Douglas Creek isopach map overlaid on the first-derivative structure map. Note that the thickest isopach coincides with the steepest dips just basin-ward of the DFZ.

- The increased accommodation space created as the basin subsided more rapidly to the north of the DFZ allowed greater volumes of lacustrine sediments to accumulate near the fault zone
  - Douglas Creek Member of the Green River Formation (and equivalents) isopach map show growth just north of the fault zone
- The overlay of the isopach map with contours from the first derivative of the Uteland Butte structure map (previous slide) shows the correlation of steepest dips related to the DFZ and the greatest accumulation of sediments
  - Suggesting strongly that movement was syndepositional.

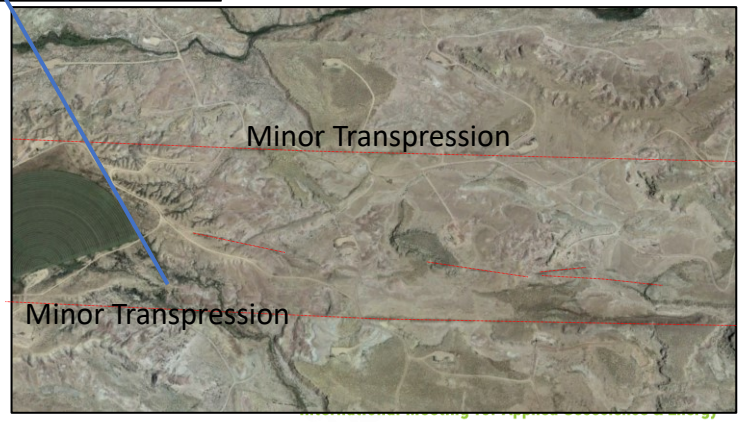
Stress Effects

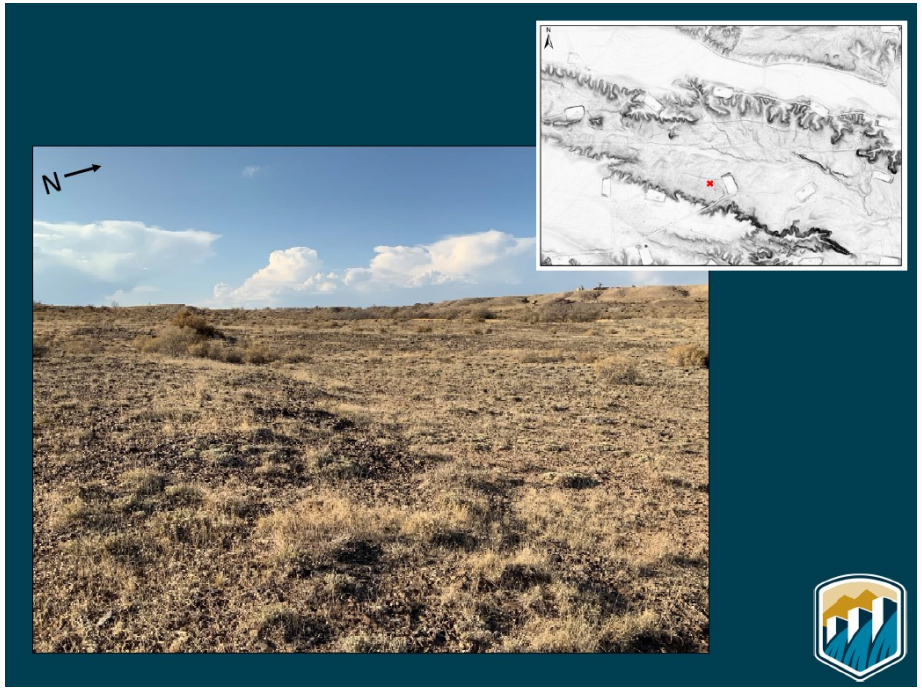


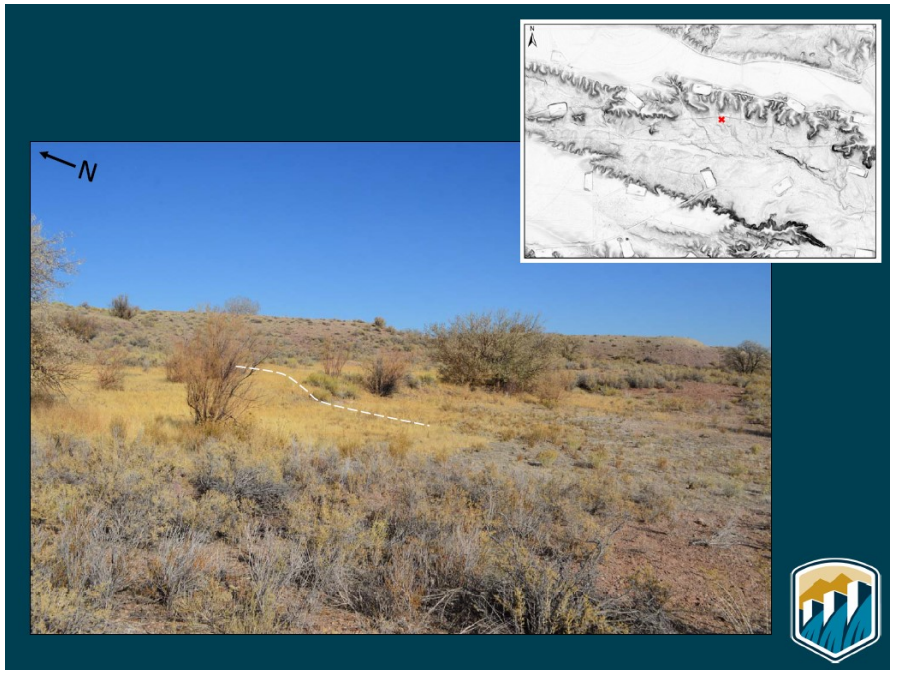




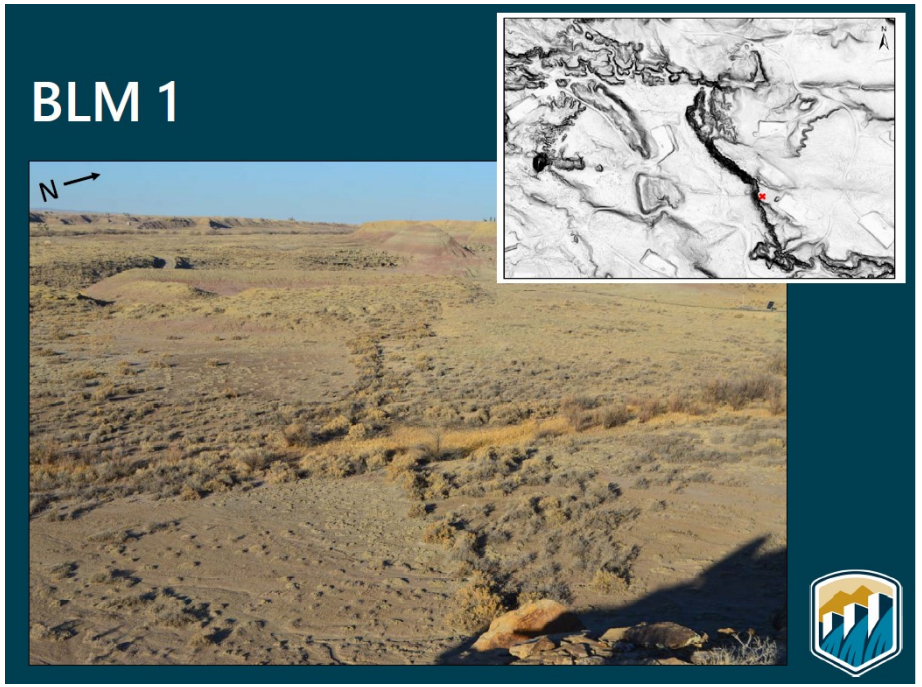
The western side of the Uinta Basin and the DFZ are experiencing extension related to Basin & Range tectonics, resulting in a change in the stress regime across the Basin







2021 Bureau of Reclamation Study



Preliminary Interpretations

- There are scarps across Quaternary surfaces of multiple ages, suggesting Quaternary fault activity
- Scarps do not consistently correlate to lithologic contacts, which would be expected if scarps were formed by differential erosion
- The overall geomorphic expression of the fault suggests that its contemporary movement is right lateral

Howe, J., and Klinger, R., 2021, Evidence for Quaternary activity on the Duchesne-Pleasant Valley fault, Uinta Basin, Utah: Seismological Society of America Seismological Research Letters, v. 92, no. 2B, p. 1335, doi: https://doi.org/10.1785/0220210025.

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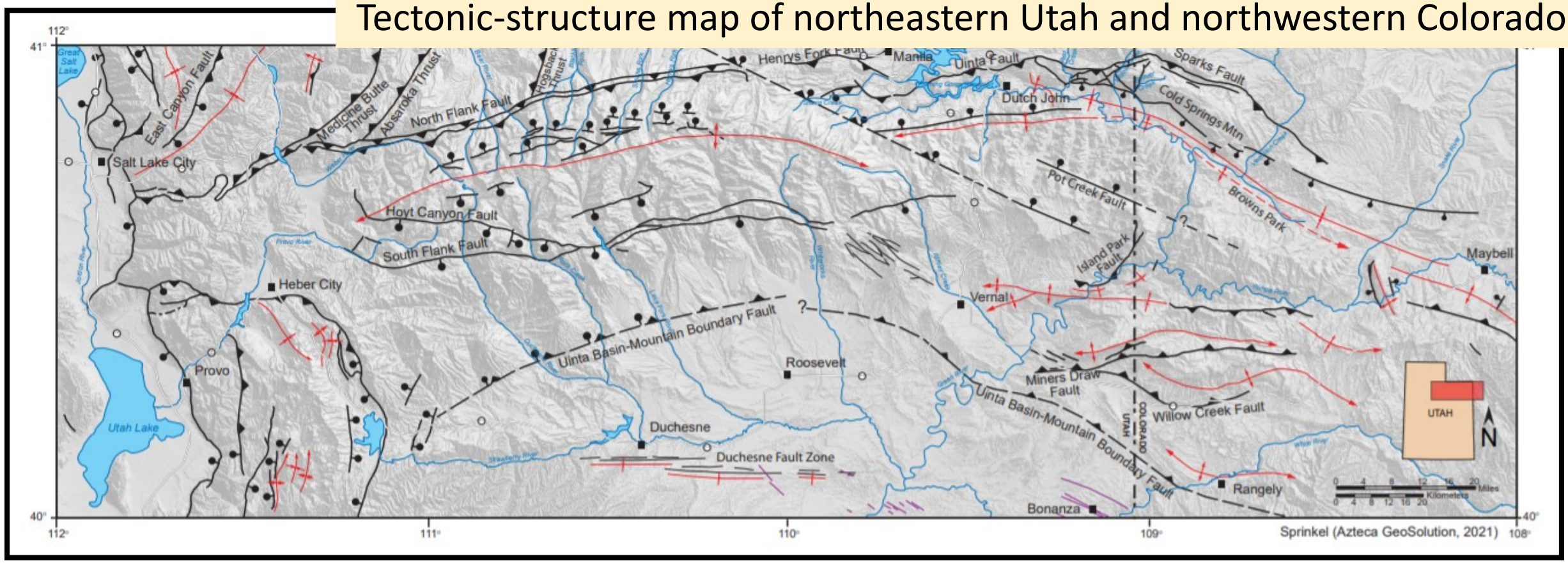
Holocene Extension

- The Tonawata Flat graben cuts Pliestocene aged glacial outwash sediments
- Together with modern deformation on the DFZ, these features are strong evidence for widespread extensive stresses on the western Uinta Basin

Tectonic-structure map of northeastern Utah and northwestern Colorado



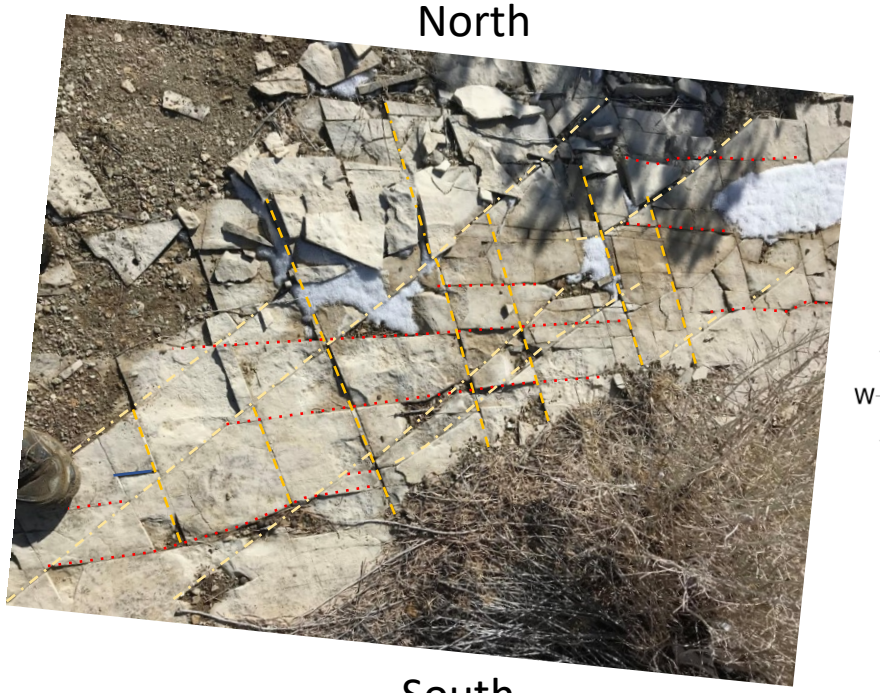
Explanation

- Normal faults
- Thrust-reverse faults with later normal offset
- Thrust-reverse faults
- Strike-slip faults with possible later normal offset
- Gilsonite vein
- Anticline
- Syncline
- Monocline

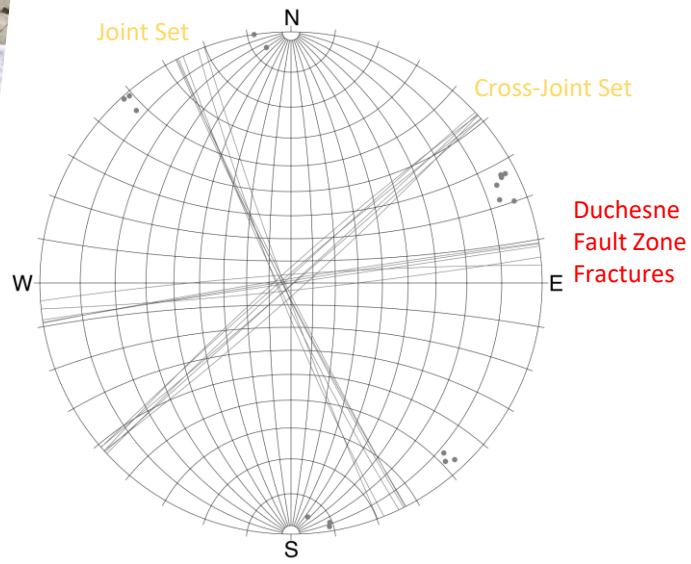
- The DFZ lies in the center of the Uinta Basin, paralleling the general structure of the Laramide aged Uinta Mountain uplift
- On the west lie normal faults, some reactivating Sevier aged thrust faults, related to Neogene Basin and Range extension
- On the east of the DFZ are Laramide thrusts and uplifts that have not undergone extension
- The Uinta Basin-Mountain Boundary Fault to the north of the DFZ shows the transition from Basin and Range extension on the west to relict Laramide compression on the east

Intense Fracturing Parrel to the DFZ

North



South

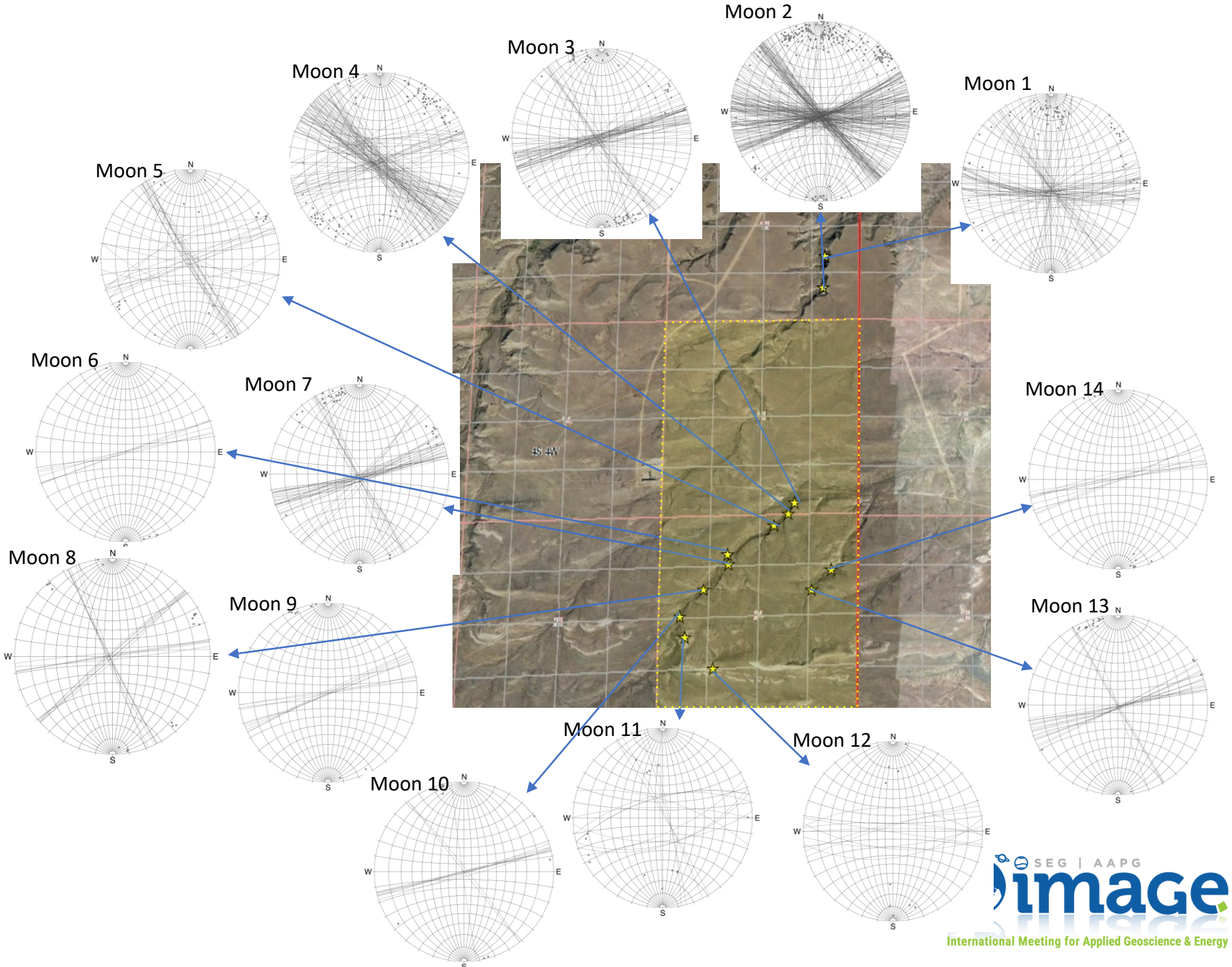


- Natural fractures and faults can increase reservoir permeability, but also compartmentalize the reservoir, channel fluids vertically and create barriers to induced hydraulic frac job
  - Understanding fractures within the reservoir is critical

Stereonets

- The study methodology consisted of walking washes in separate identified fault blocks and taking fracture orientation measurements
- Fracture orientations were then plotted on stereonets to separate and identify the dominant fracture trends

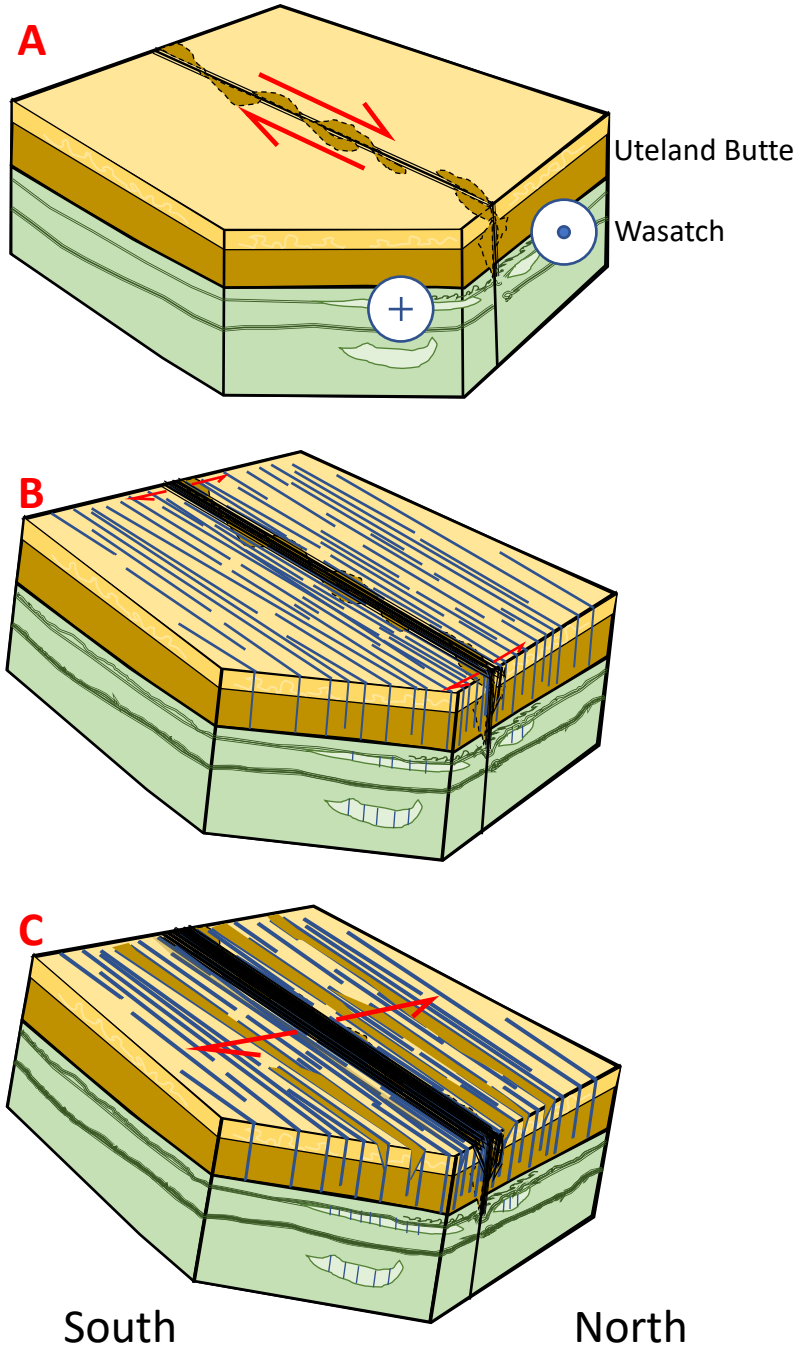
The dominate open fractures across the project area parallel the Duchesne Fault Zone



Models

All models are wrong, but some are useful

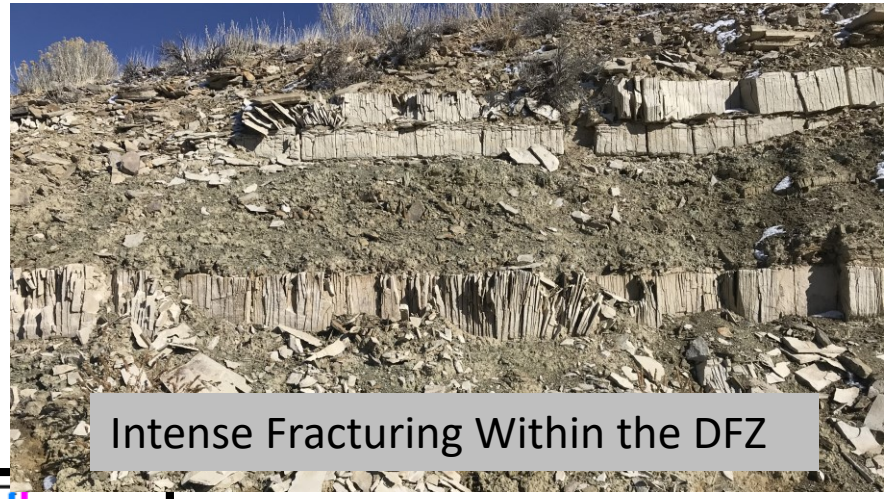
George E.P.Box



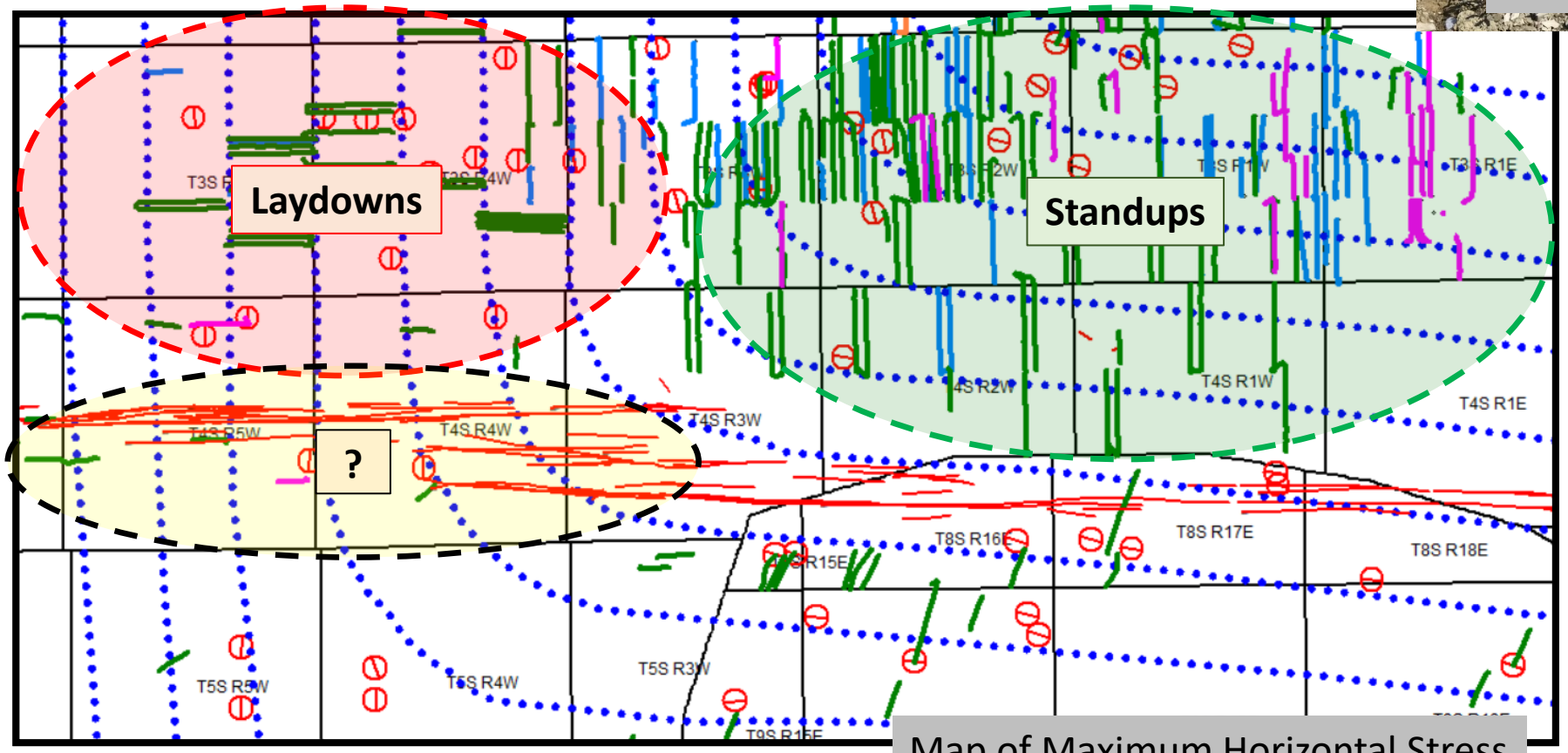
- Time A – Before lithification, no fractures could form, but the DFZ was active, moving in a right lateral sense and creating several small to medium sized sag basins
- Time B – After lithification, more brittle rocks, such as the carbonates in the Uteland Butte Member and sandstone channels within the Wasatch Formation, fractured, with increasing intensity nearer faults. Minor extension occurred above the neutral surface as a result of broad folding at the DFZ, with the entire region continuing to subside to the north
- By late Neogene time the DFZ was experiencing significant extension, with small vertical faults and grabens opening, with greater extension towards the western portion of the Uinta Basin

Lay-Downs or Stand-Ups?

The west side of the DFZ may be difficult to develop horizontally as the horizontal maximum stress is perpendicular to the fault zone



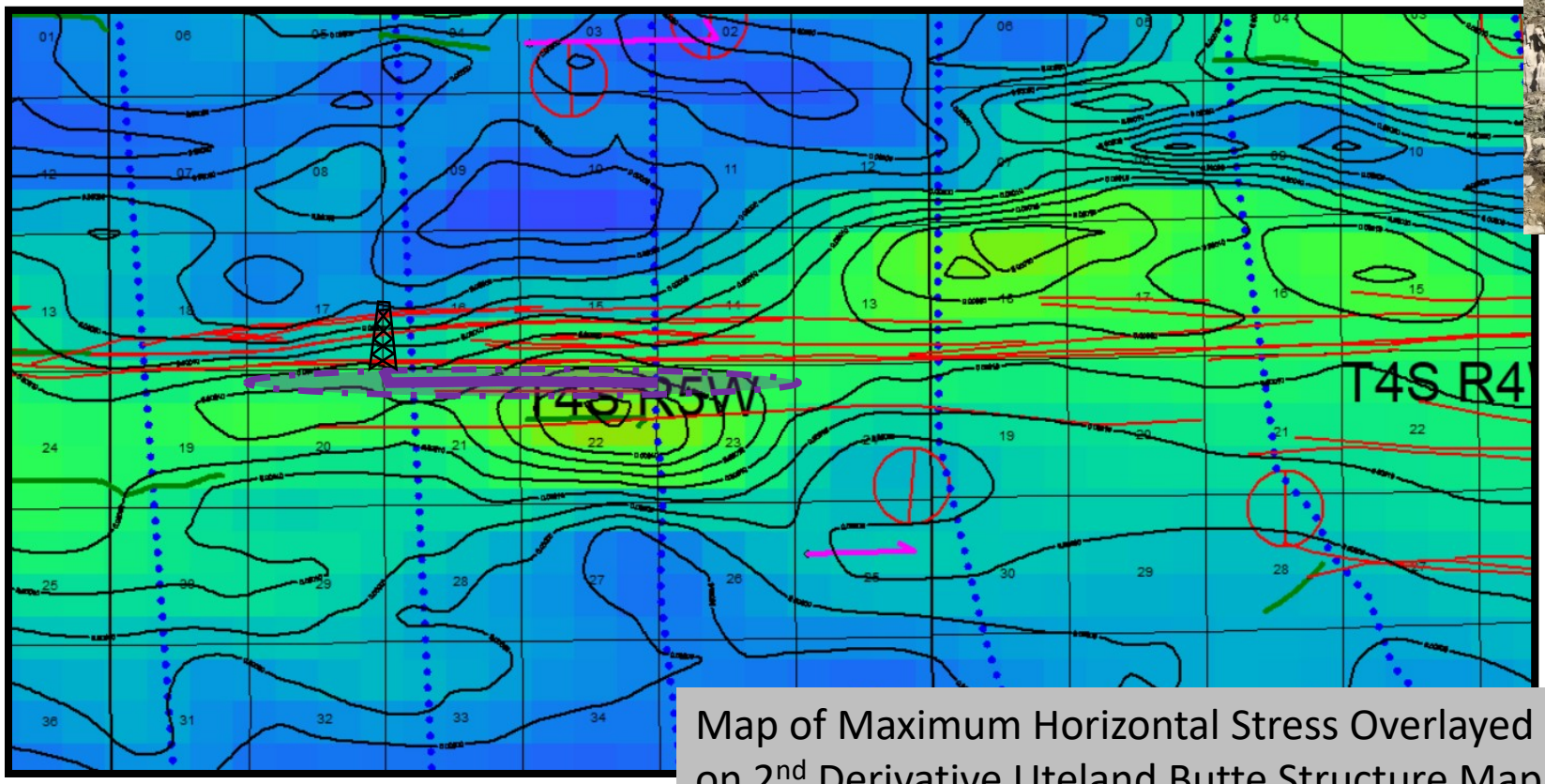
Intense Fracturing Within the DFZ



Map of Maximum Horizontal Stress

- Typically, operators drill horizontal wells perpendicular to the maximum horizontal stress so that induced frac will propagate away from the wellbore
- In the DFZ, horizontals would be paralleling the fault zone
  - Induced fracs would have to propagate across the DFZ damage zone

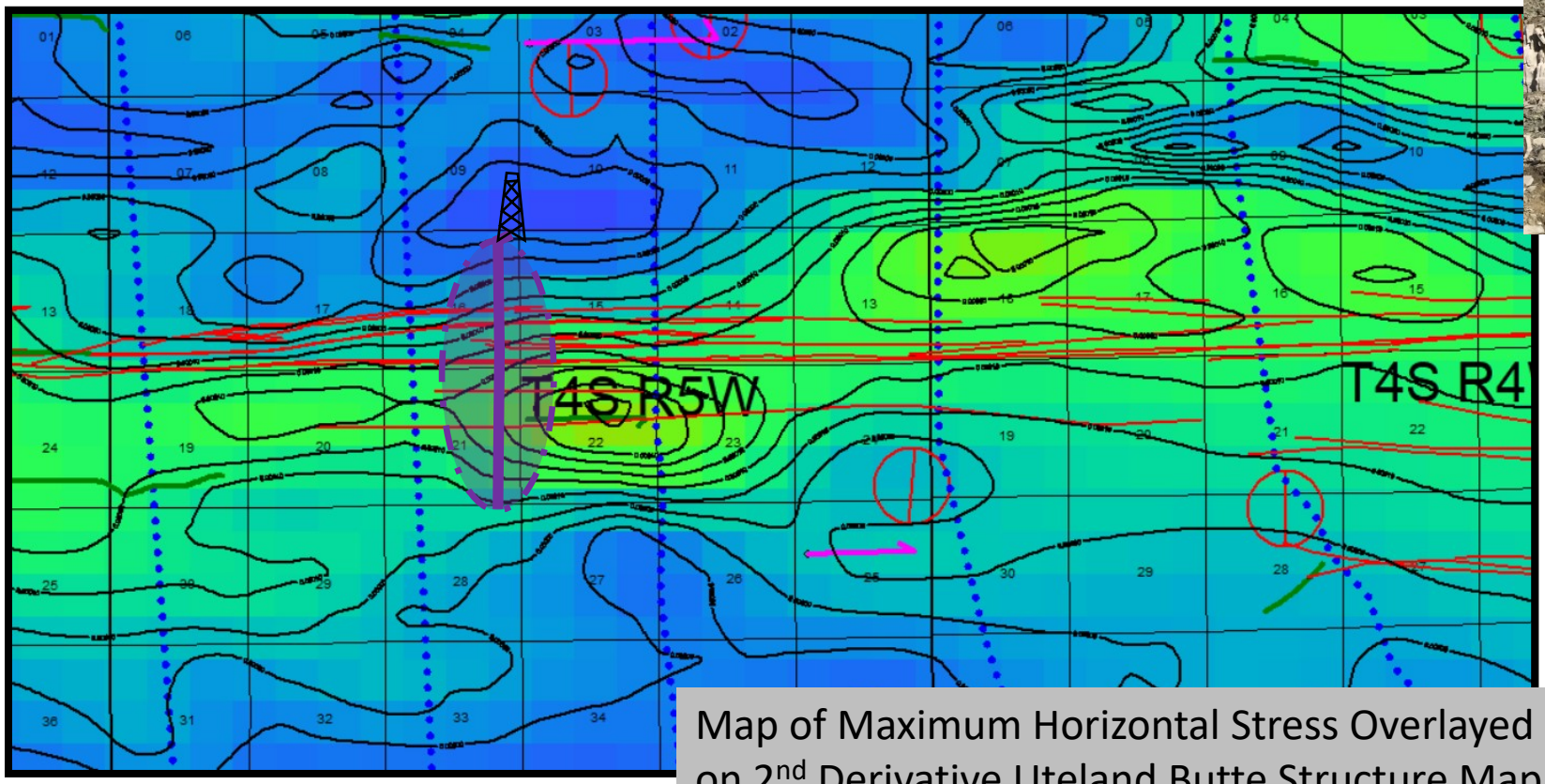
Hypothetical Laydown



Map of Maximum Horizontal Stress Overlayed on 2nd Derivative Uteland Butte Structure Map

Modeling suggests that induced, hydraulic fractures will likely propagate vertically along the DFZ rather than across it, leading to large volumes of out of zone fracs and low stimulated rock volumes (SRV's)

Hypothetical Standup



Map of Maximum Horizontal Stress Overlayed on 2nd Derivative Uteland Butte Structure Map

In the tug-of-war between the in-situ horizontal maximum stress and the DFZ, our modeling shows that the existing planes of weakness represented by the DFZ will dominate, suggesting that here wells should be drilled as standups

Conclusions

- The Duchesne Fault Zone exerted a massive influence on the structural and stratigraphic development of the Uinta Basin
- It currently marks the southern boundary of the Green River horizontal oil play due to
  - Pressure
  - Viscosity
  - Structural risk
- Tight fracture and stress measurements and modeling are the key to successful development
  - Turning the DFZ into a development asset rather than the edge of the play