Structural Geometry, Kinematics, and Timing of the Duchesne Fault Zone, Uinta Basin, Northeastern Utah, USA

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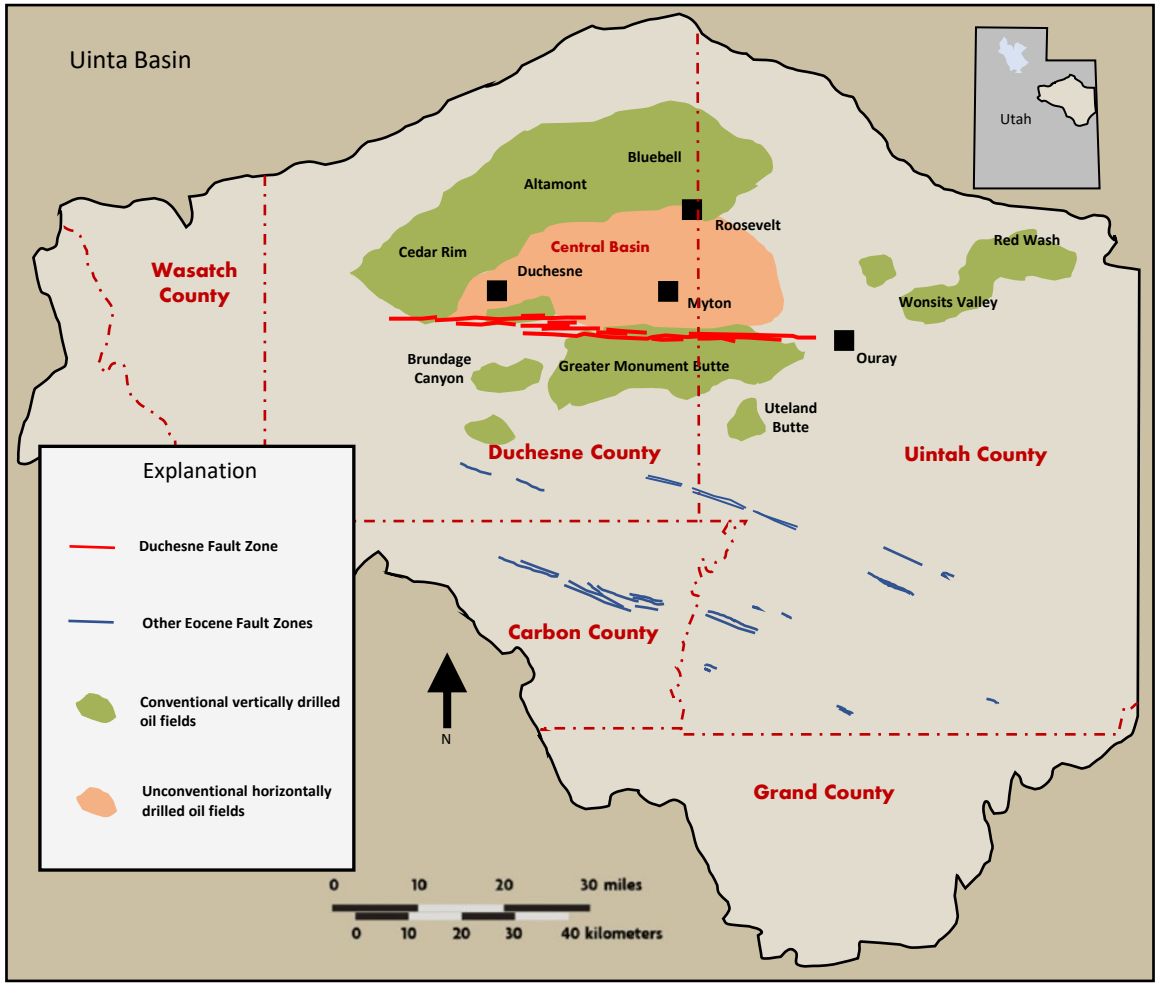
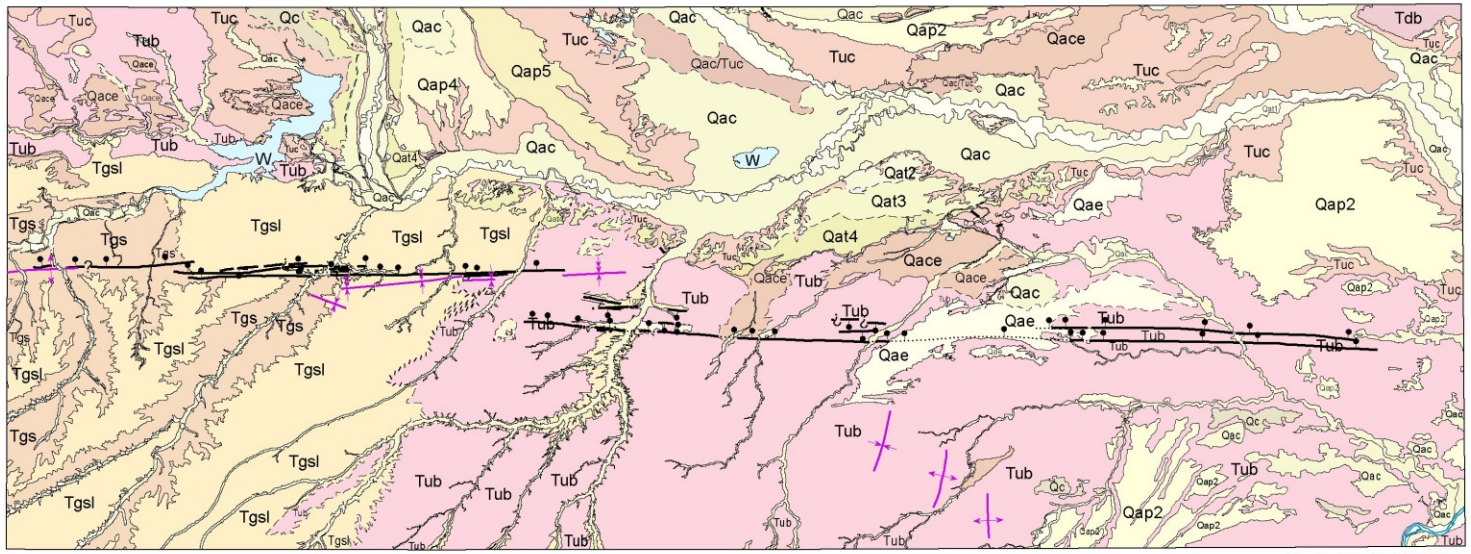
Azteca GeoSolutions

Presentation Outline

- Introduction
- Duchesne fault zone location and general description
- Kinematic data and evidence for multiple episodes of deformation
  - Laramide
  - Neogene extension
- Deformation
  - Evidence for pull-apart basins
  - Evidence for hinge point
  - Derivative maps
- Regional tectonics and relation to Uncompahgre uplift
- Conclusions

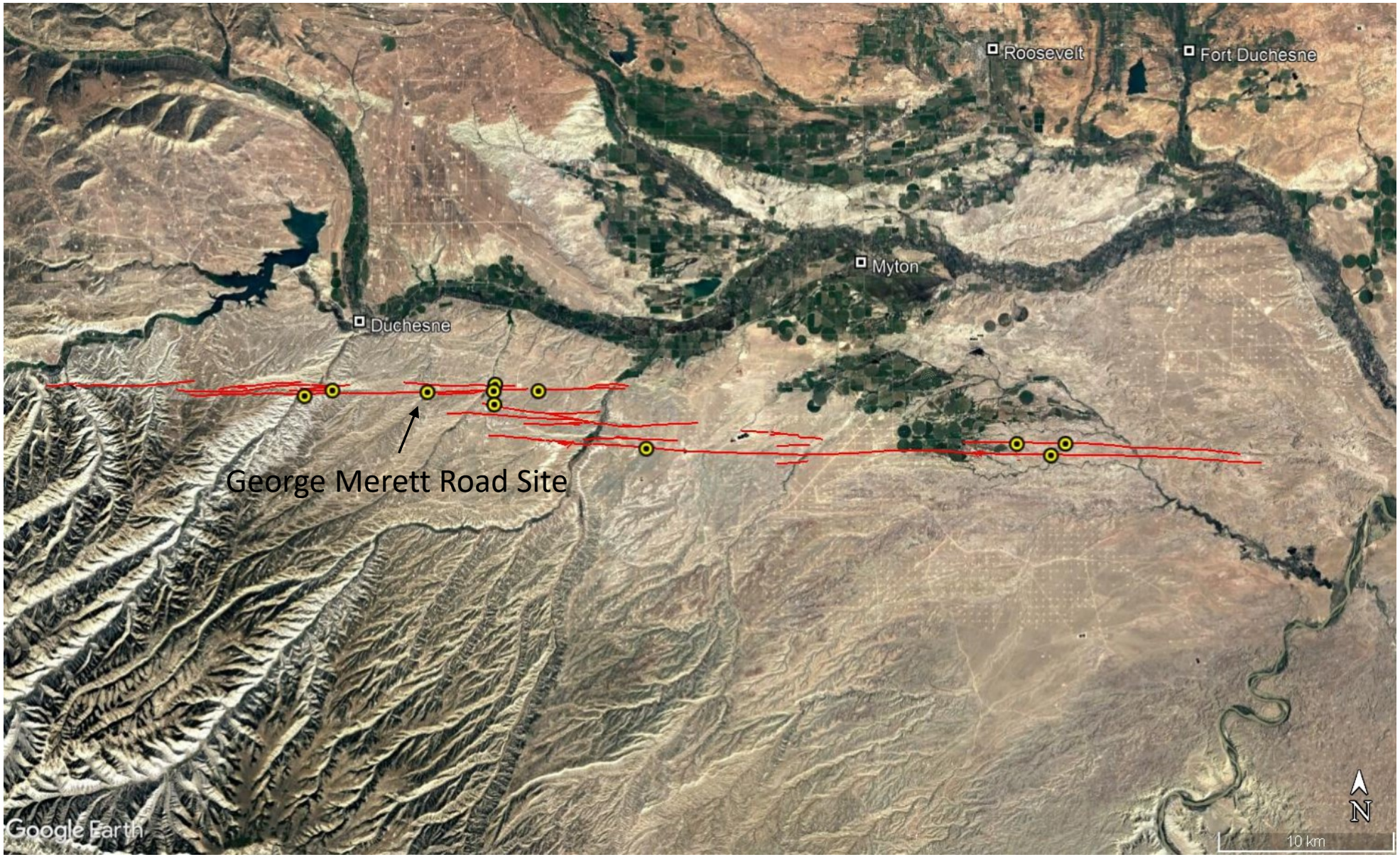


Geologic Map of the Duchesne Fault Zone Study Area



- The Duchesne fault zone (DFZ) is a 40-mile-long left-stepping en echelon fault system that forms a series of grabens
- The DFZ cuts mostly members of the Green River Formation in the western part and Uinta Formation in the eastern part
- The DFZ forms a linear topographic escarpment of as much 20 feet

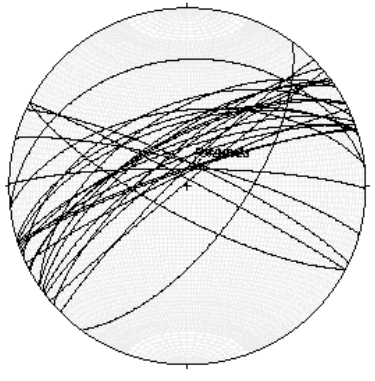
The Duchesne Fault Zone



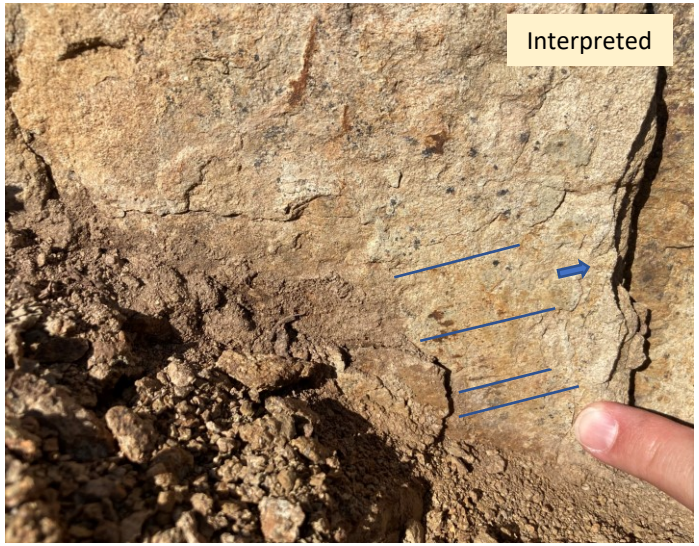
- Satellite imagery of the Duchesne fault zone (DFZ), in red, Uinta Basin, Utah
- The east-west DFZ forms an en echelon, left-stepping graben system
- Yellow dots are kinematic data sites
- Widespread oil & gas development both north and south of the fault zone

George Merett Road Site

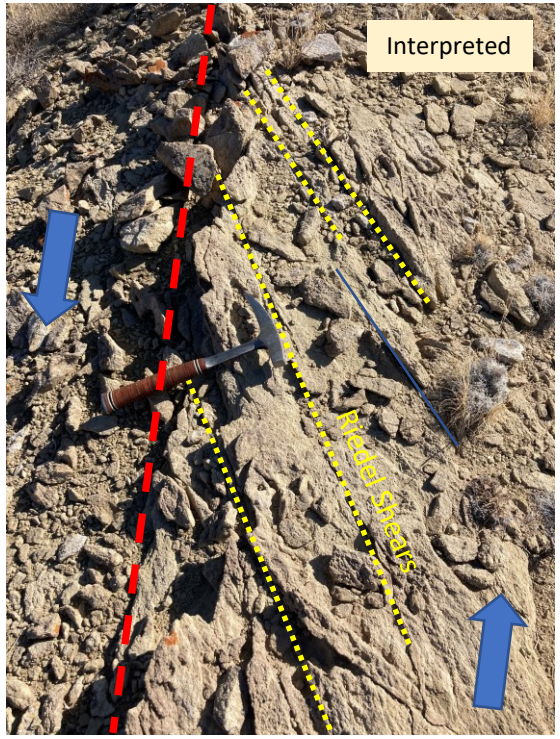
- Green River Formation (sandstone-limestone facies)
- Collected 27 dip direction and dip measurements
- Dip direction
  - Maximum = 354°
  - Minimum = 1°
  - Average = 335°
- Dip
  - Maximum = 89°
  - Minimum = 30°
  - Average = 71°
- Slickensides were mostly dip-slip with some oblique slip

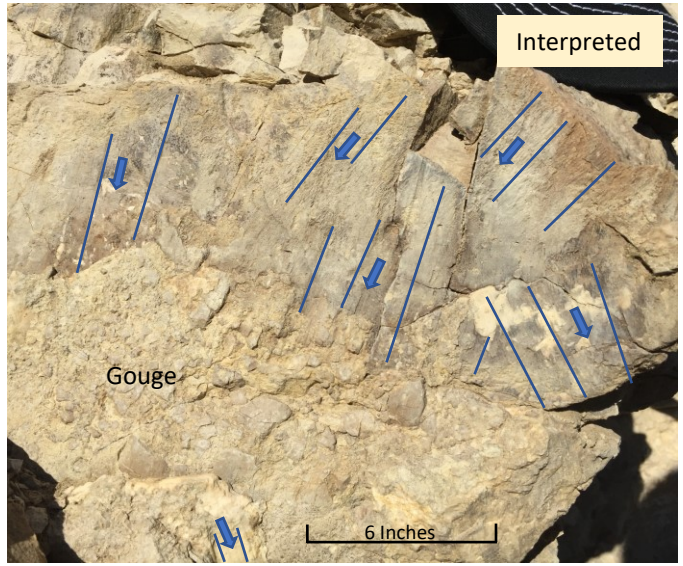


Fault Surfaces

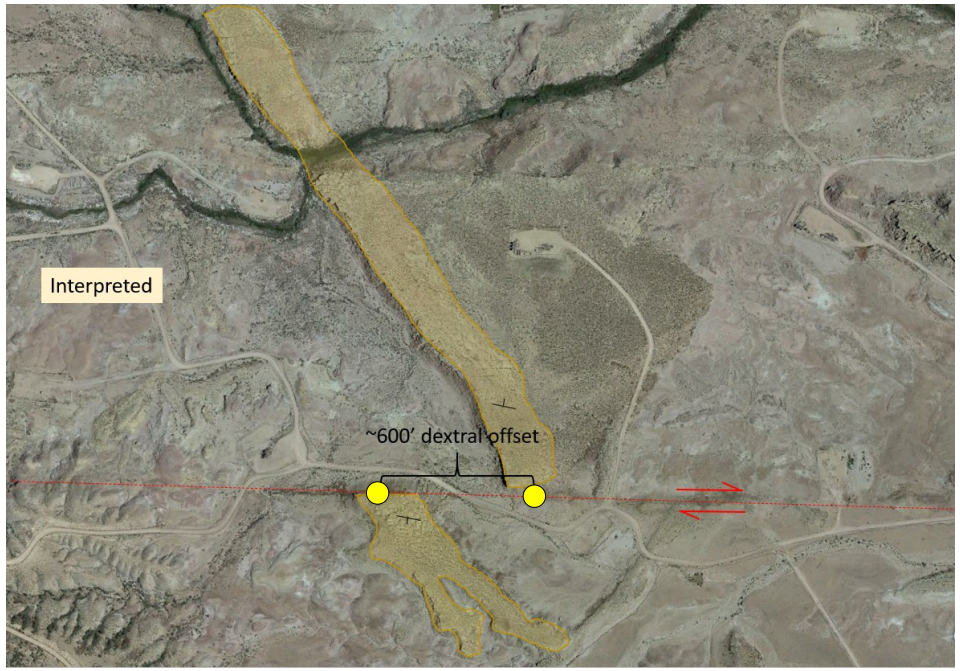


- Most of the surviving slickensides from fault traces in the DFZ record dip-slip movement from the latest phase of fault relaxation during Neogene extension
- However, slickensides preserved at some locations have horizontal and oblique orientations that indicate an early phase of strike-slip and oblique-slip motion
  - Interpreted and uninterpreted photos of a fault surface showing nearly horizontal slickensides created from lateral fault movement
  - Other slickenlines show dextral slip, then overprinting
- Nice examples of Riedel shears are visible on the fault's transpressional ridge
  - The shears are ~30° off the direction of the fault and point in the direction of motion of the block they reside in



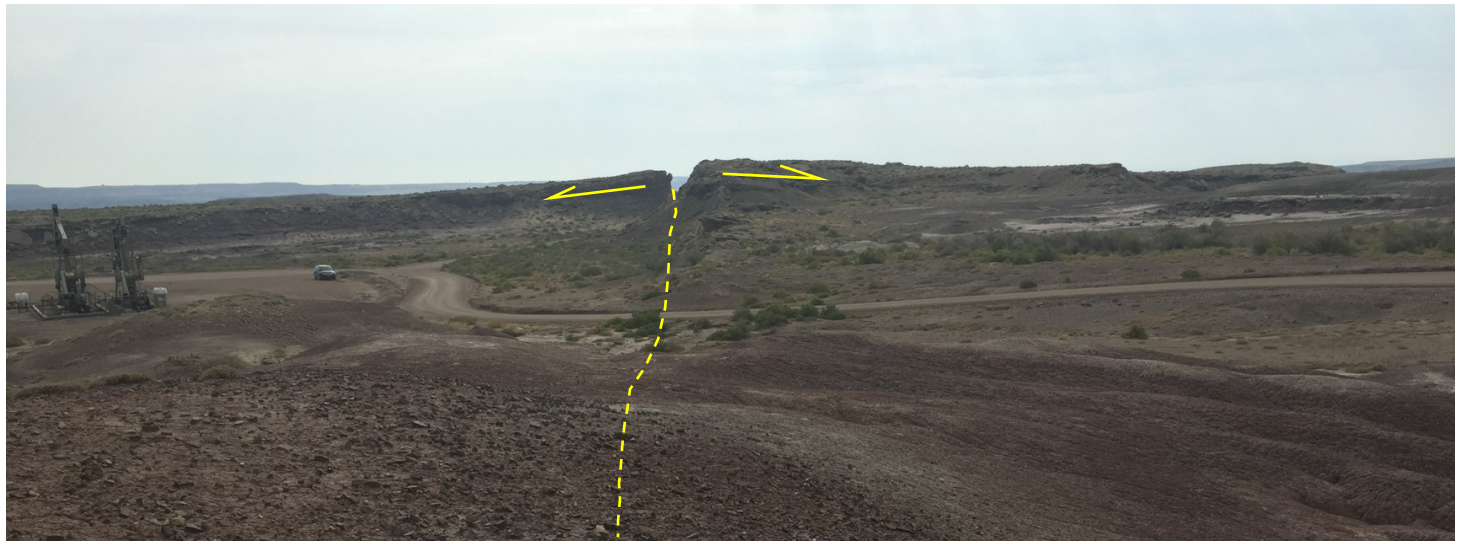


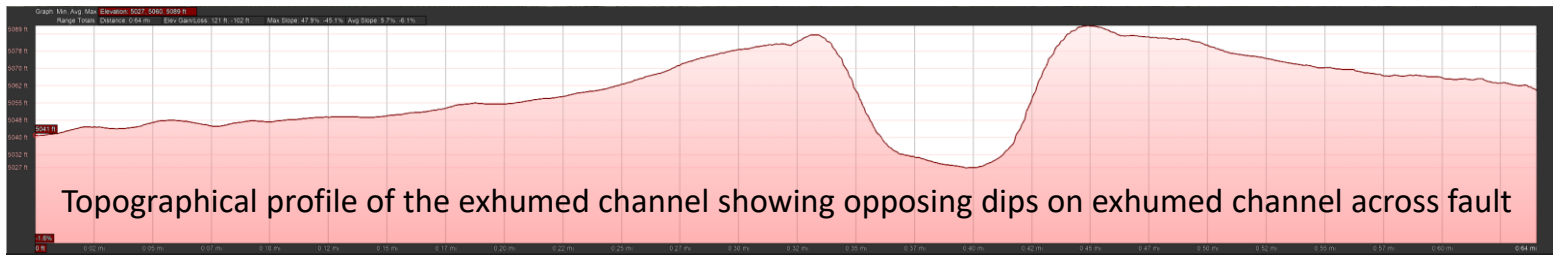
Pin Points



1,000 Ft

- A right-lateral (dextral) movement along the fault segment with the offset of an exhumed channel in the Eocene Uinta Formation
- The laterally offset features, called “pin points” by structural geologist, allow us to measure fault offset
- This fault offset the exhumed channel ~600 ft
  - The roads and cleared areas are oil well pads within the Greater Monument Butte field
- A change in structural dip is also observed across the fault zone, with the basin-ward side of the DFZ dipping steeply into the basin





Topographical profile of the exhumed channel showing opposing dips on exhumed channel across fault

Characterizing the DFZ Fault Traces

Malachite Deposits

- The DFZ consists of a complex series of fault segments that underwent strike-slip, oblique and then dip-slip deformation
- Variable fluids flowed through the fault zone overtime
  - Active springs and oil seeps are commonly found

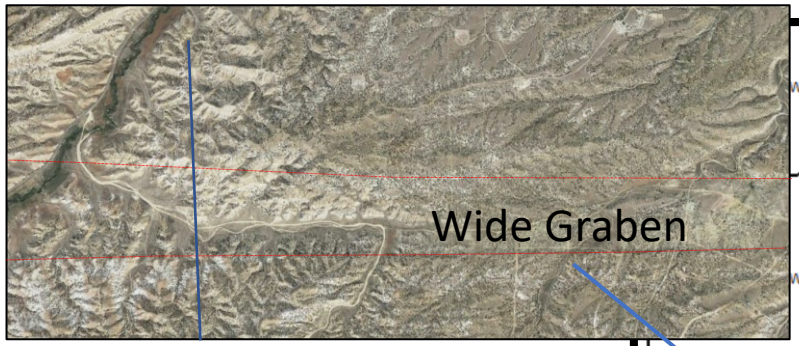
Tar Sand Deposits

Gouge that has been heavily altered

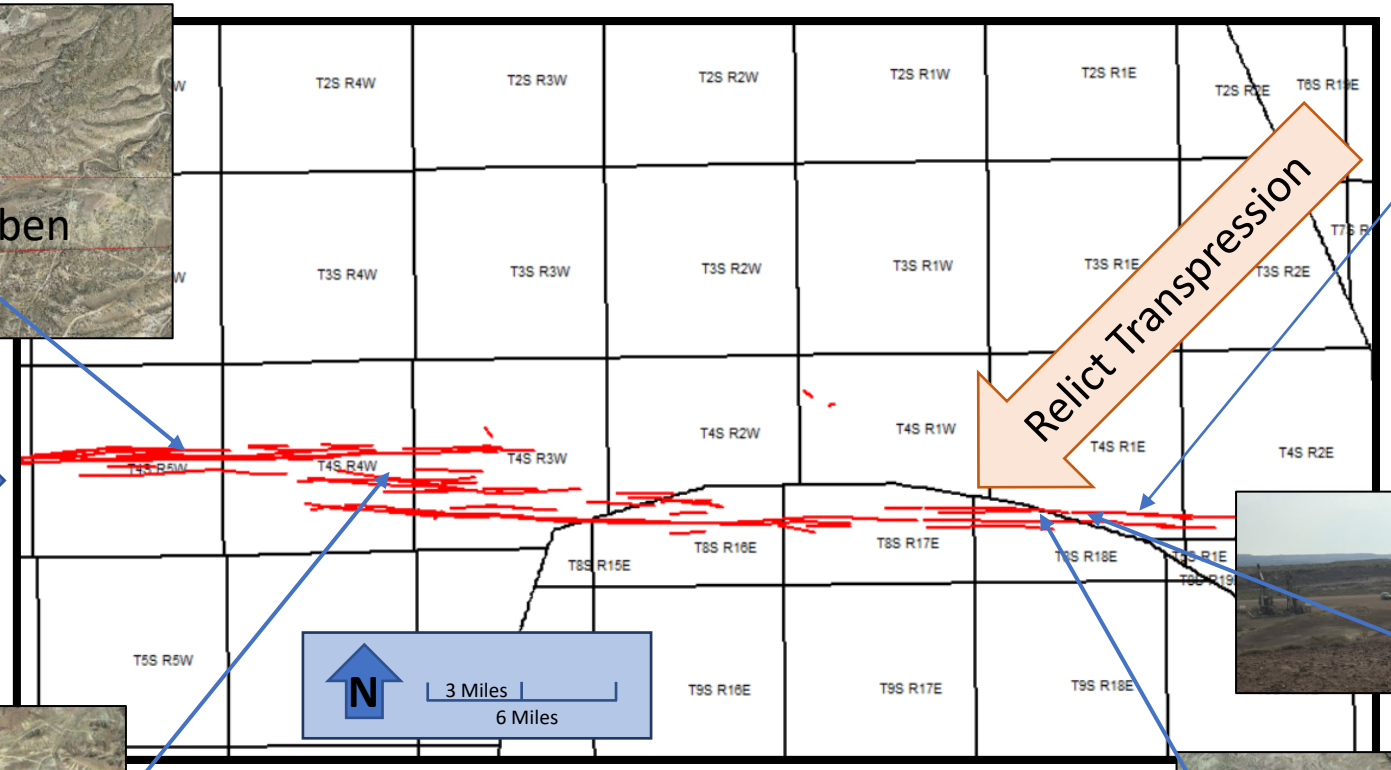
Springs Along DFZ

Gilsonite Deposits

Changes from East to West

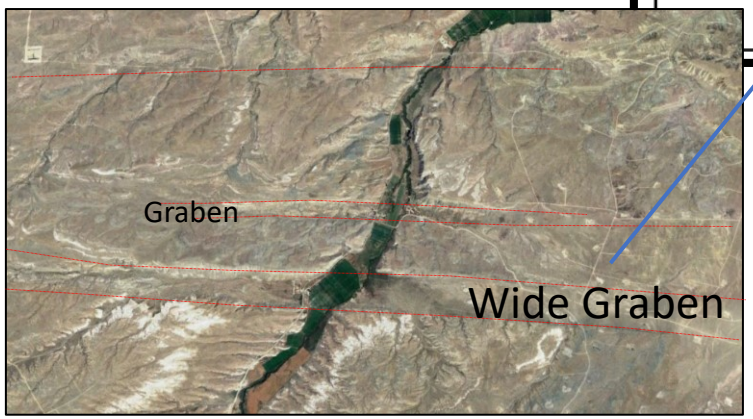


Widely Extended

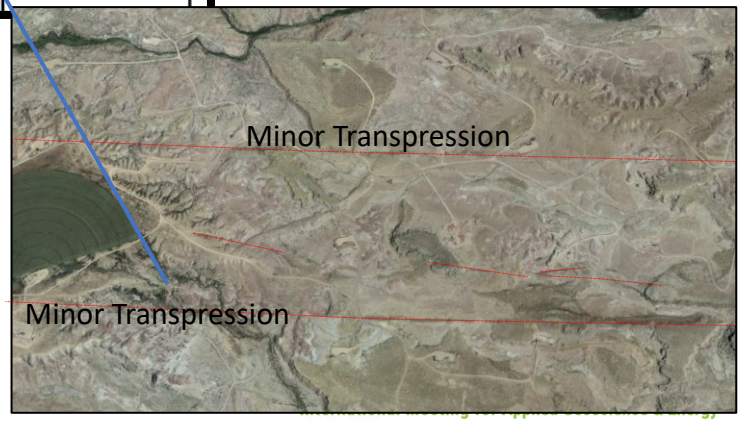


Relict Transpression

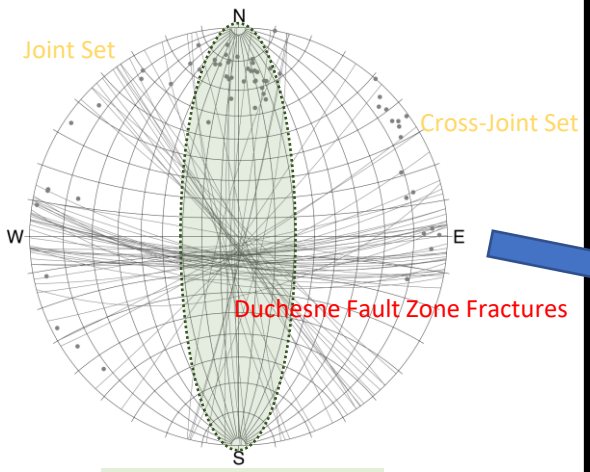
Transpressional Ridge



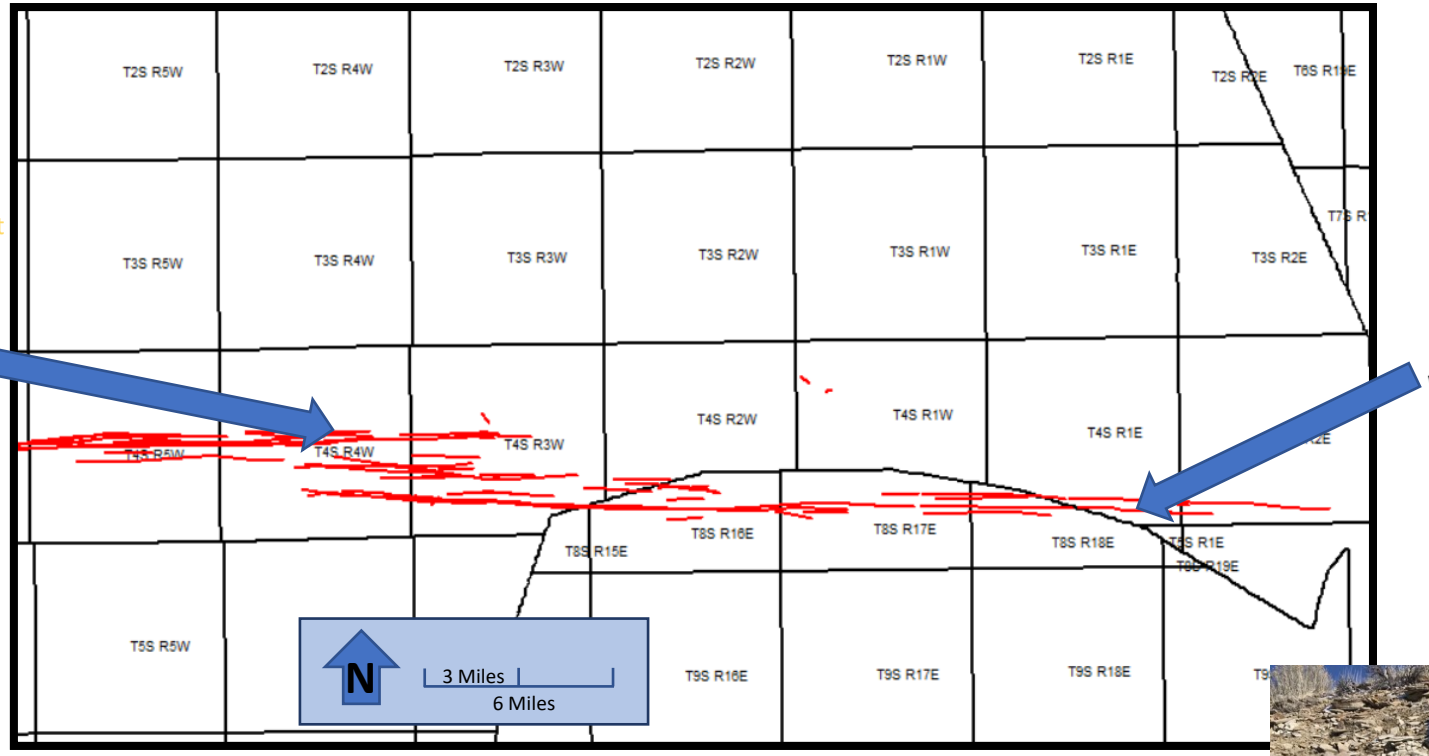
- The western half of the DFZ consists of wide grabens, which become progressively narrower and finally disappear to the east
- The eastern half of the DFZ consists of anticlines and tranpressional ridges

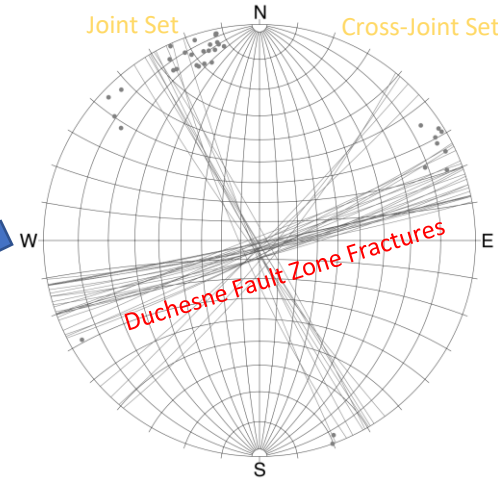


Fractures



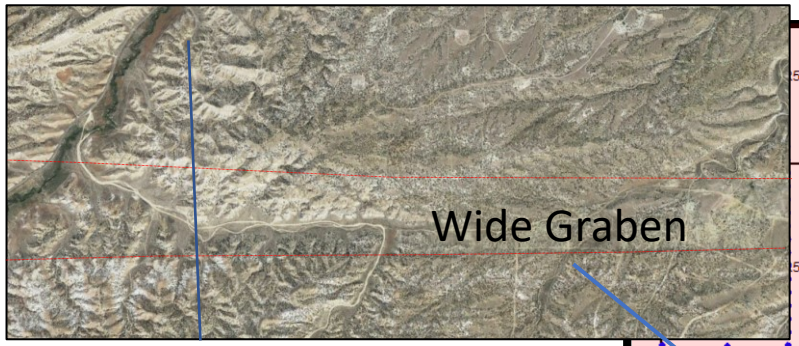
North-South Set from east-west extension

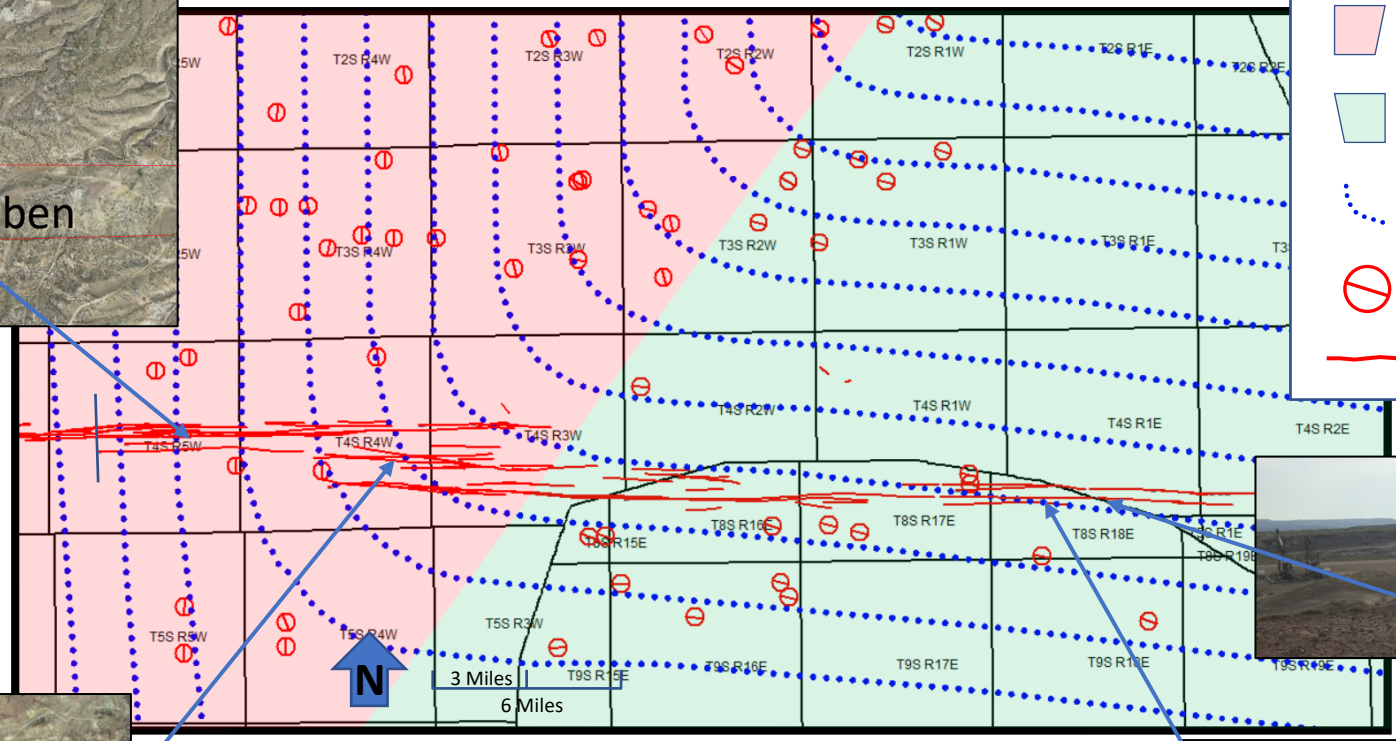




- Fractures within the fault zone tell a complex story of localized and regional stress fields that changed over time
- The newest fractures (in cemented Pliocene and Pliestocene gravels) record east-west extension on the western portion of the DFZ

Modern Stress Field and the DFZ





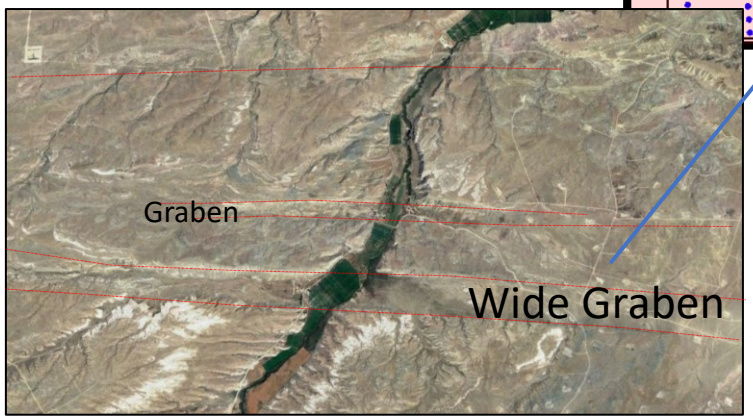
Part of the Uinta Basin experiencing east-west extension

Portion of the Uinta Basin experiencing relict-Laramide compression

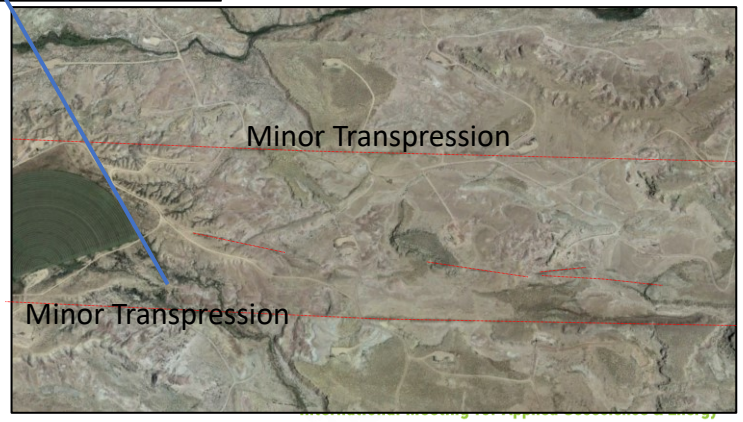
Maximum horizontal stress contours

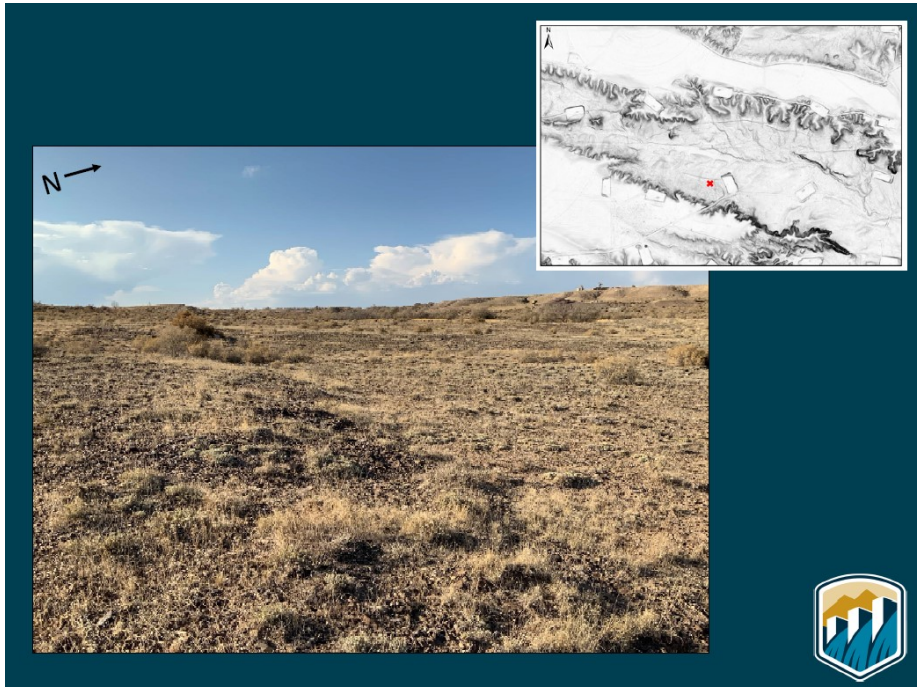
Maximum horizontal stress data point and direction indicator from well bores

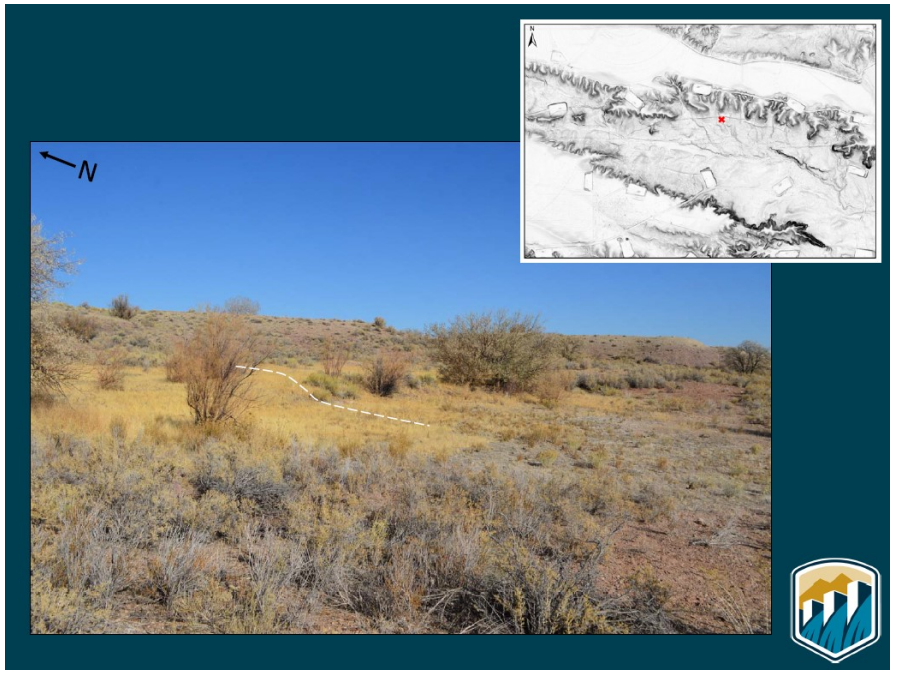
Duchesne fault zone surface trace



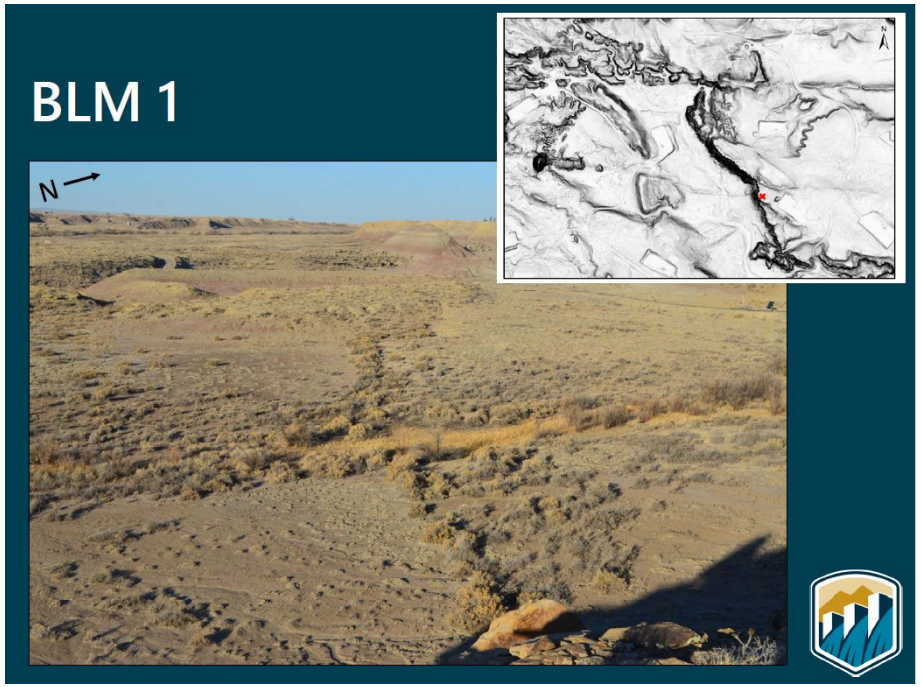
The western side of the Uinta Basin and the DFZ are experiencing extension related to Basin & Range tectonics, resulting in a change in the stress regime across the Basin







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.

SEG | AAPG image
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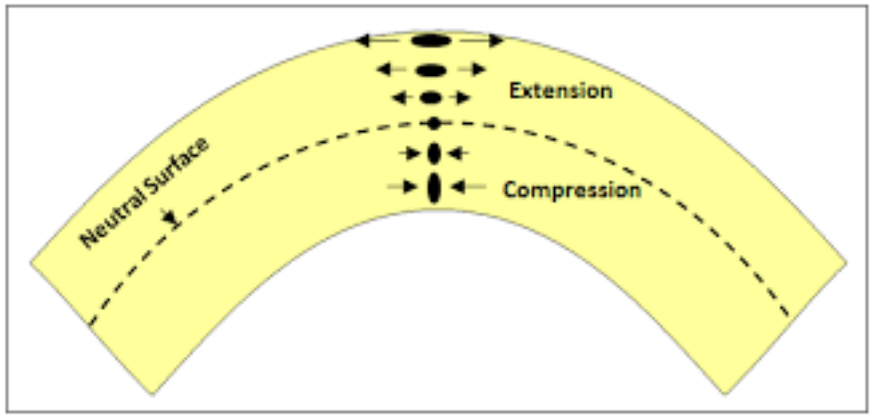
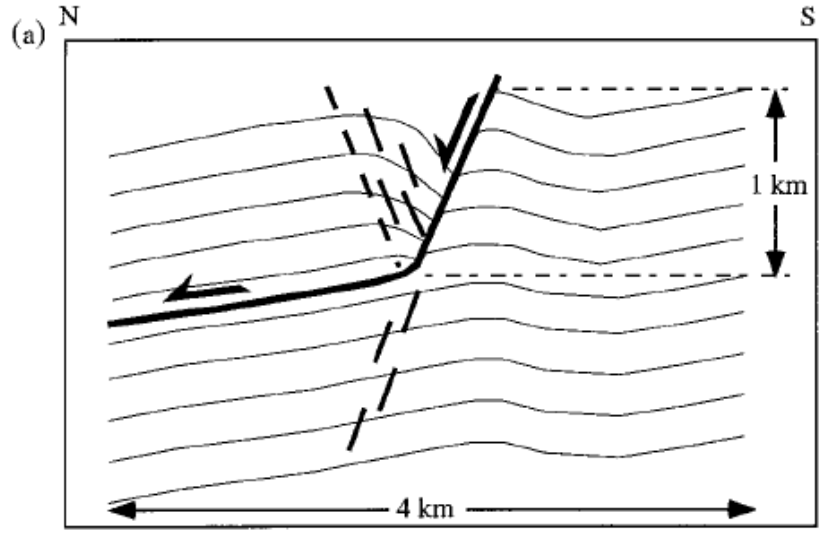
Recent Extension on the West Side of the Basin

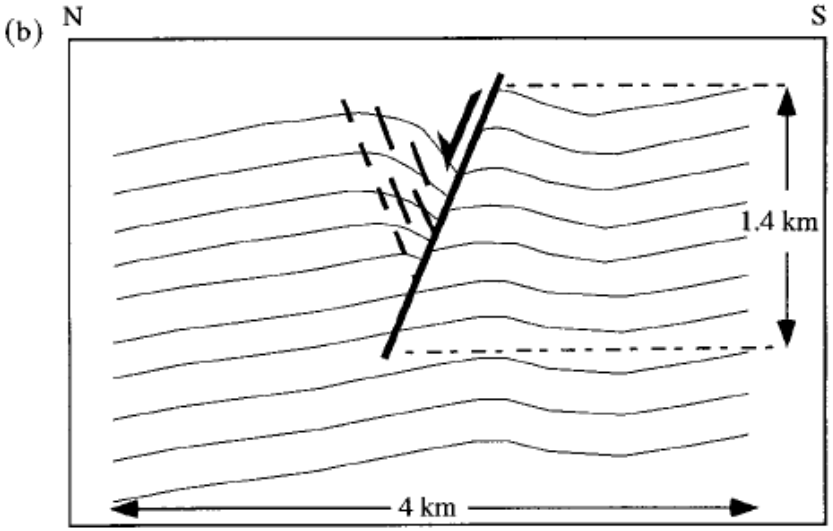
- The Tonawata Flat graben cuts Pliestocene aged glacial outwash sediments
- Together with modern deformation on the DFZ, these features are strong evidence for widespread extensive stresses on the western Uinta Basin

Shallow or Deep Deformation?

- Many investigators have shown that the faults seen at the surface lose throw downward
  - Groeger and Bruhn (2001) showed that almost all offset vertical offset ceased by ~3300 ft (1 kilometer)
- Our research shows that the DFZ is an ancient feature with significant deformation into basement rocks
  - The surface grabens relate to extension above the neutral surface of the Laramide aged folding related to the formation of the deep Uinta Basin







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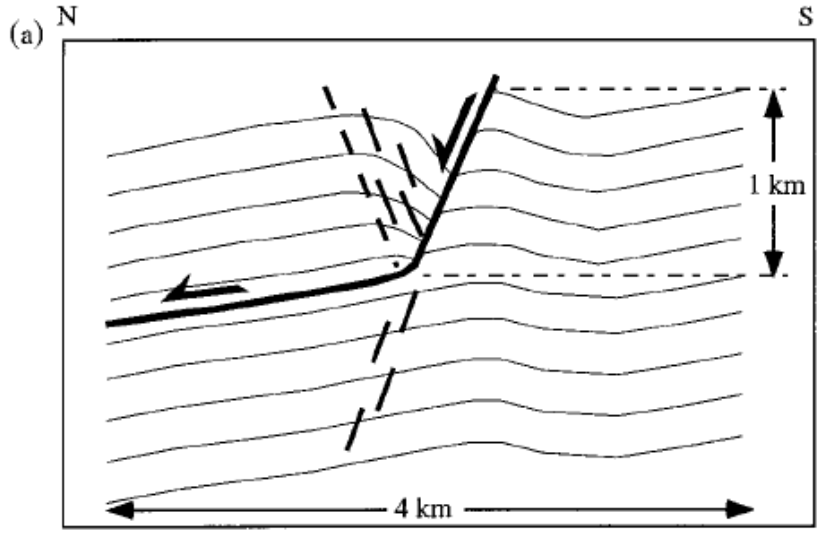

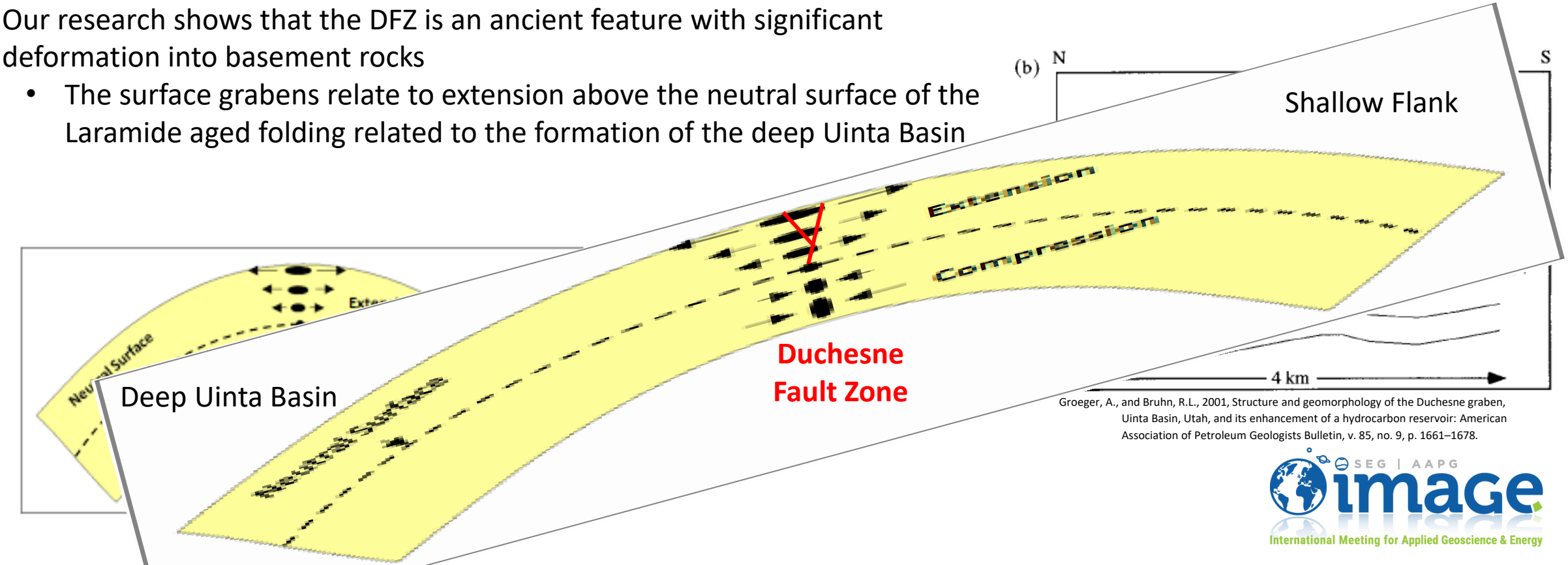

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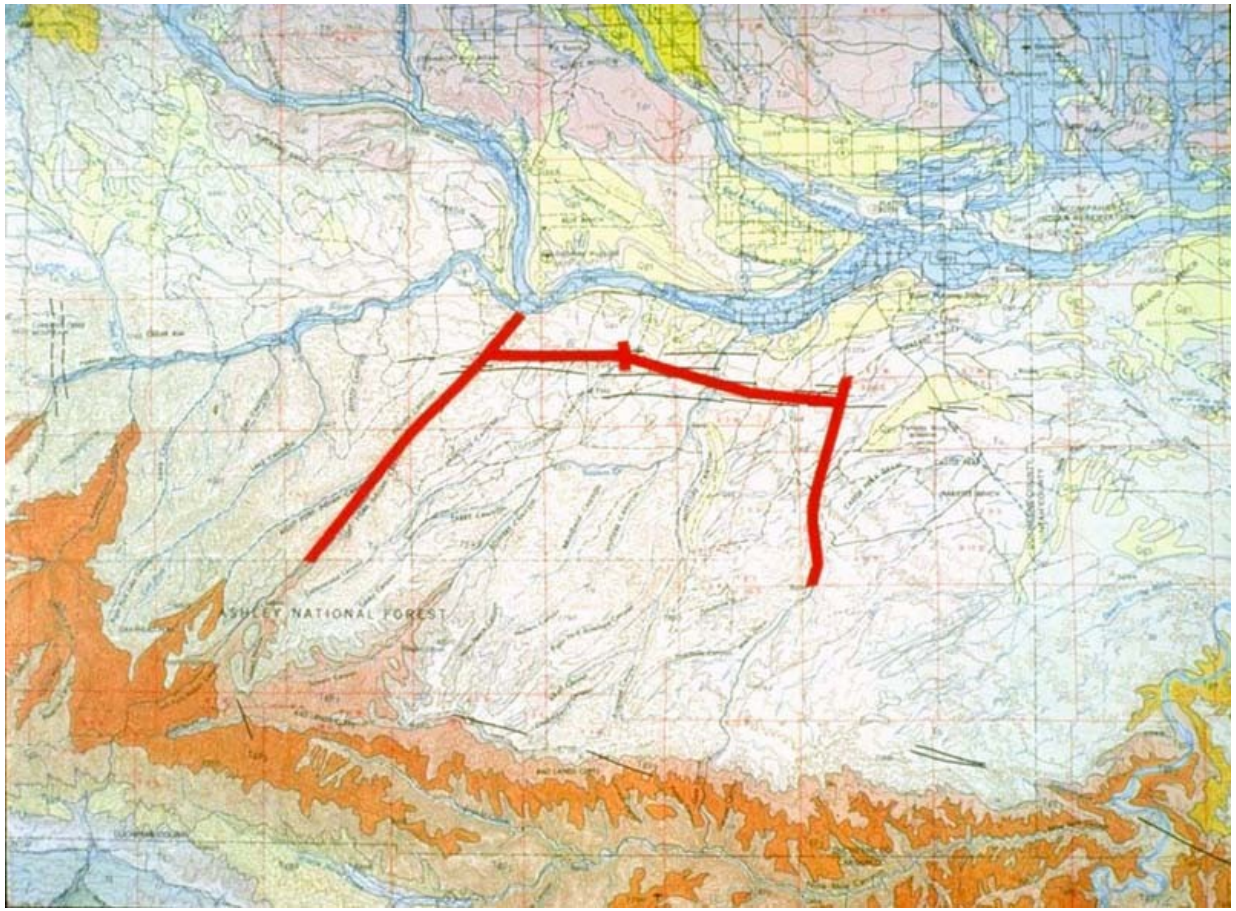
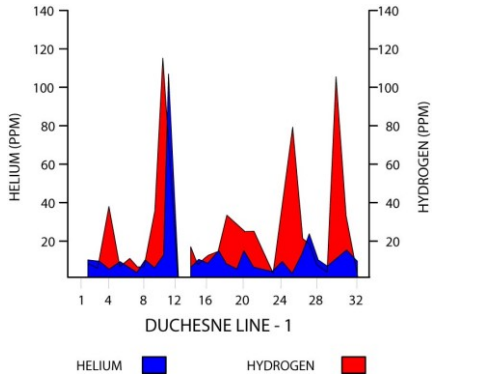
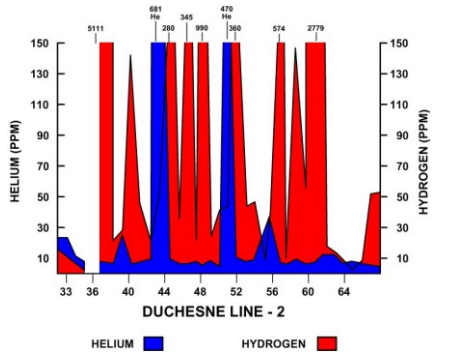
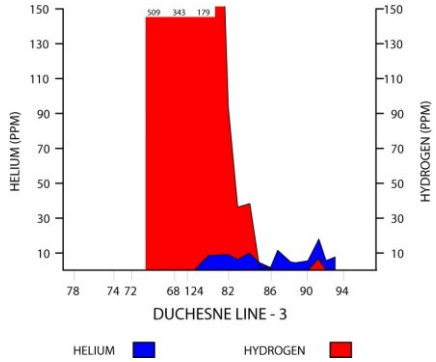
Helium-Hydrogen Soil-Gas Profiles



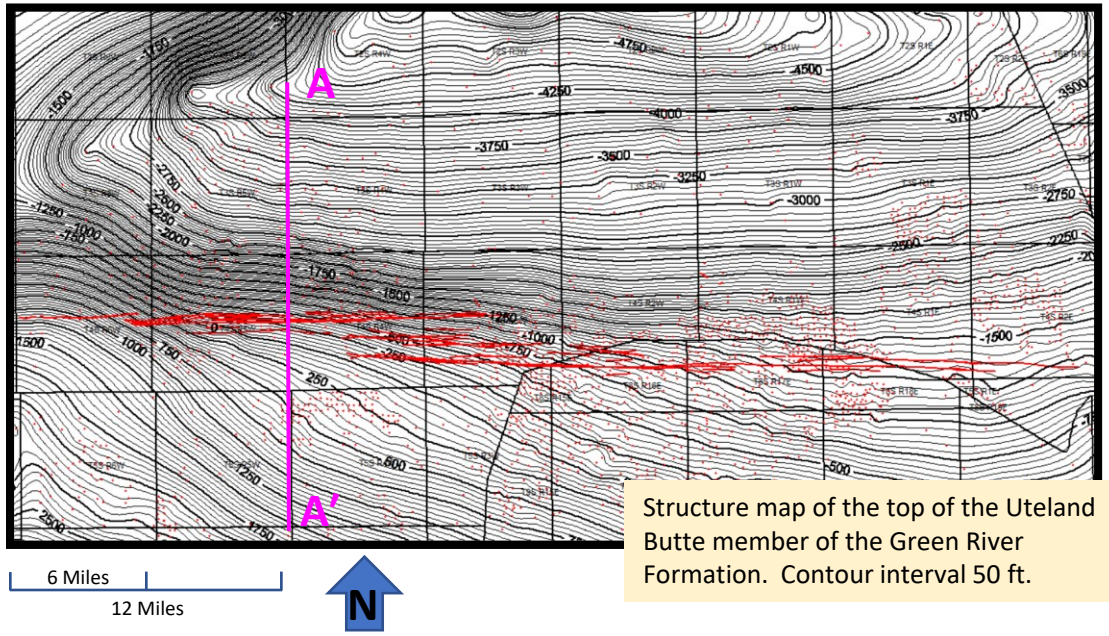




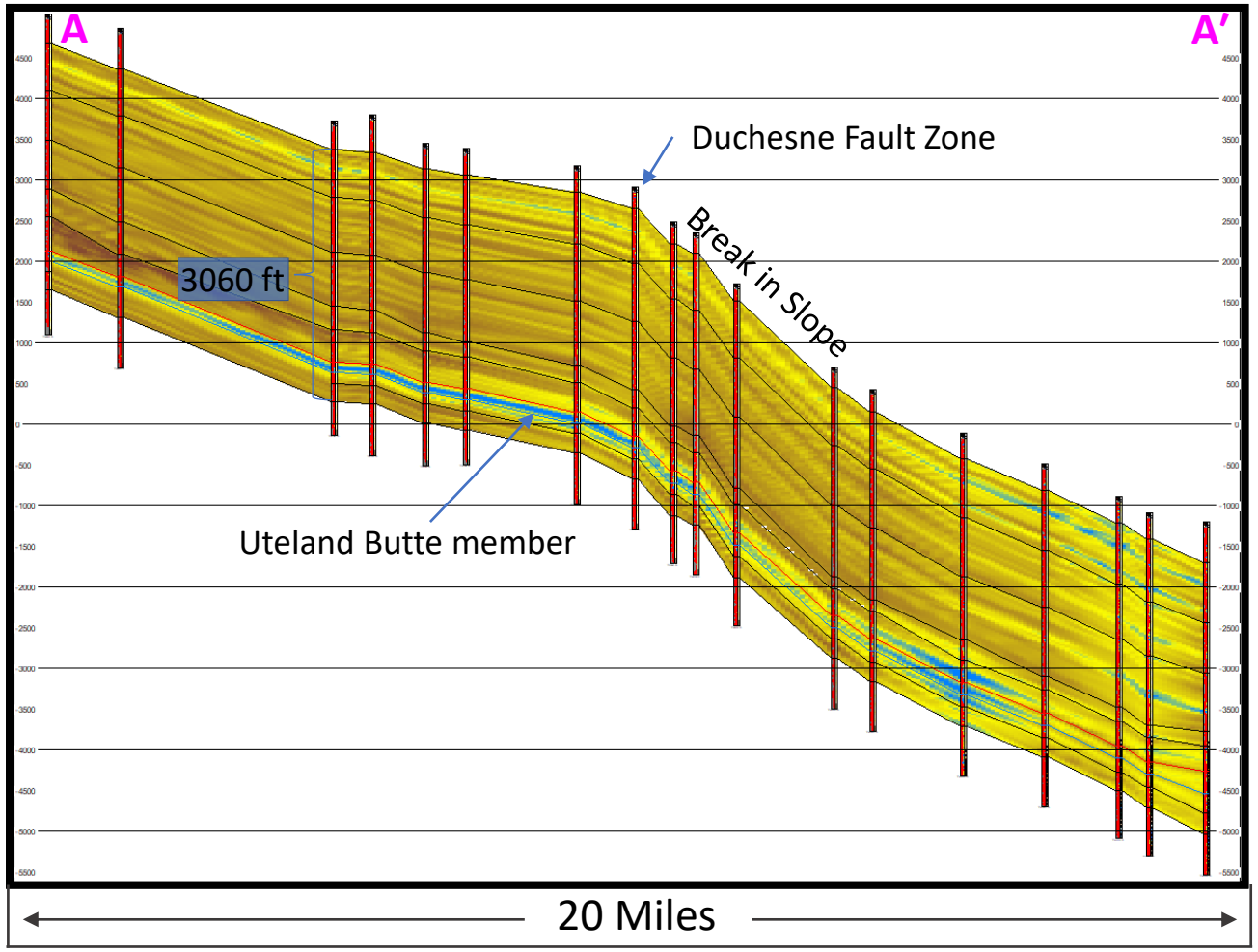


- Helium and hydrogen soil-gas profiles indicate high values along traces of the DFZ
- This suggest the DFZ is a deep-seated fault that cuts Precambrian igneous and metamorphic basement

Slope-Break



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



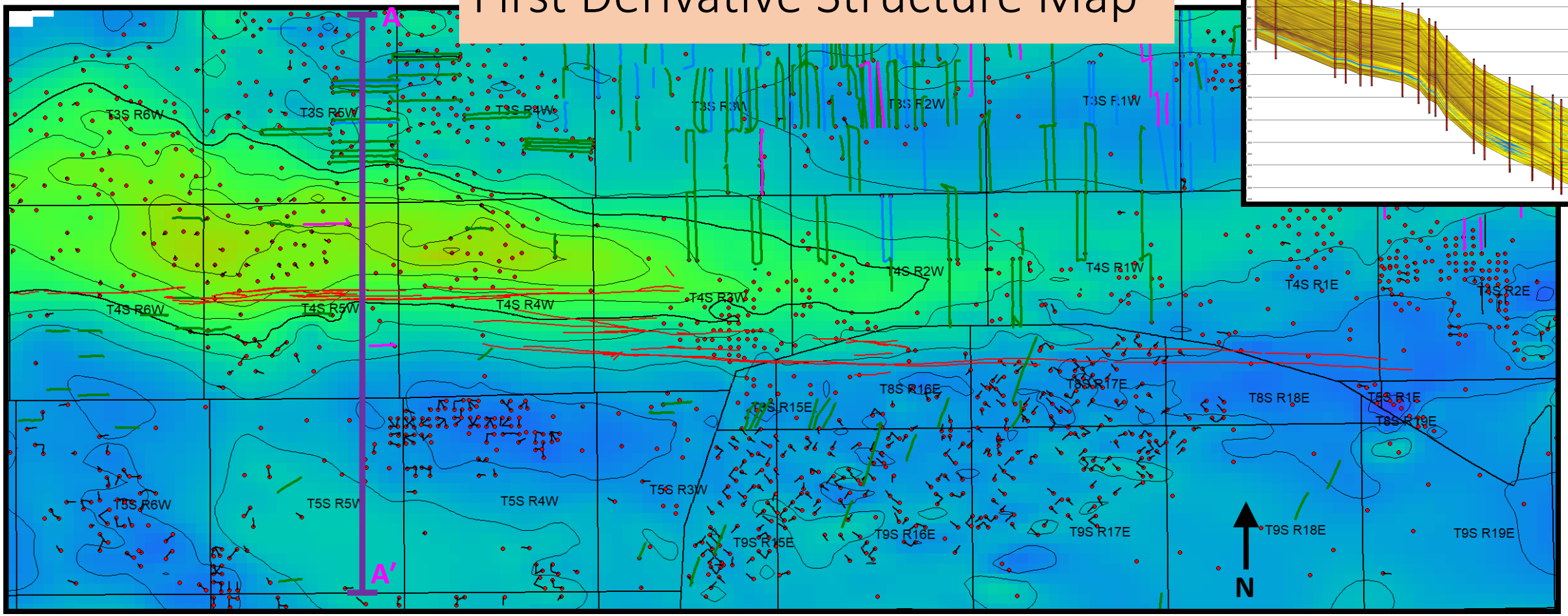
Subsea-true-vertical-depth (SSTVD) structure contour map on the top of the Uteland Butte member of the Eocene Green River Formation

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

First Derivative Structure Map



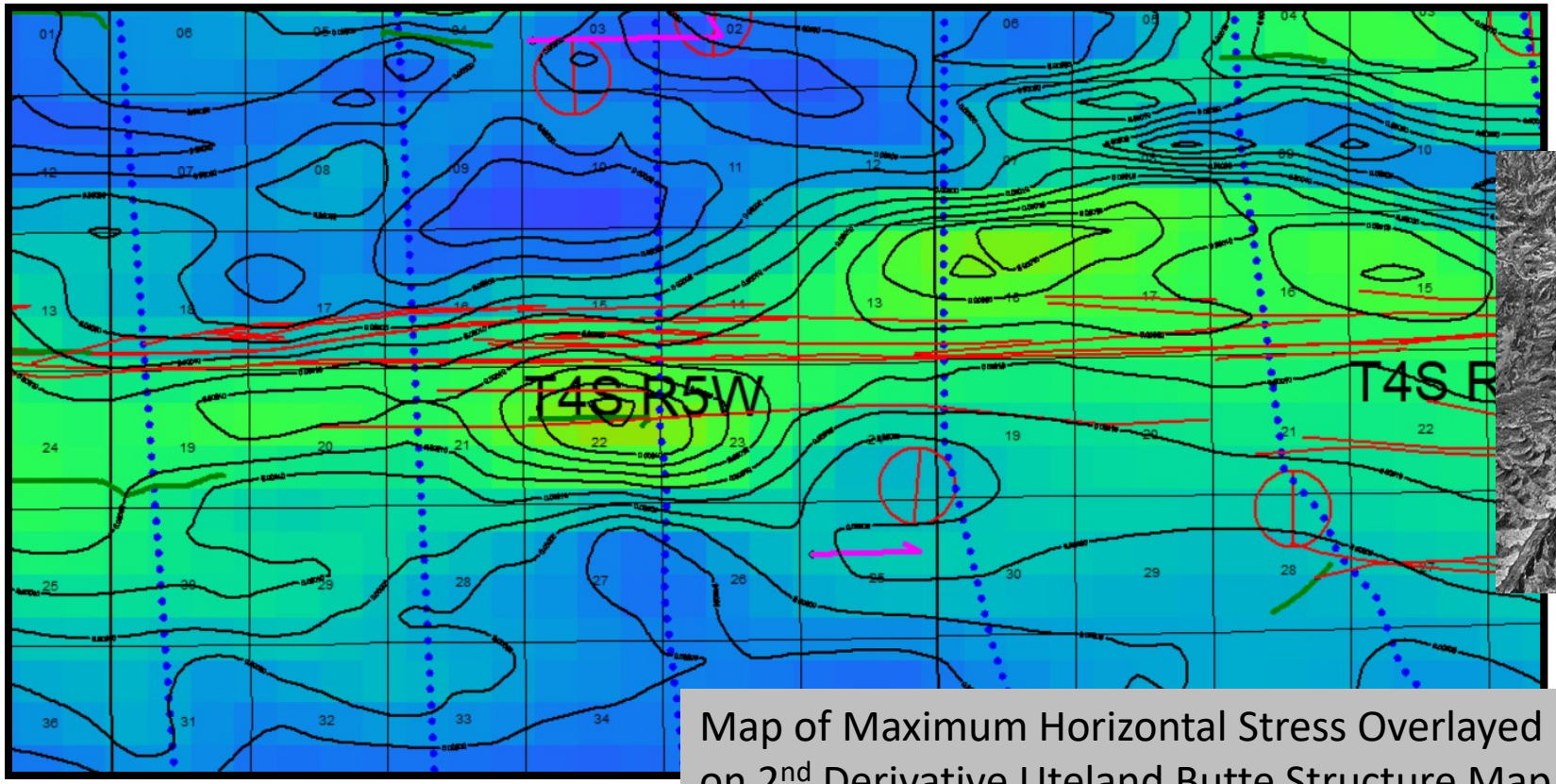
Uteland Butte
Wasatch
Castle Peak
Douglas Creek

12 Miles

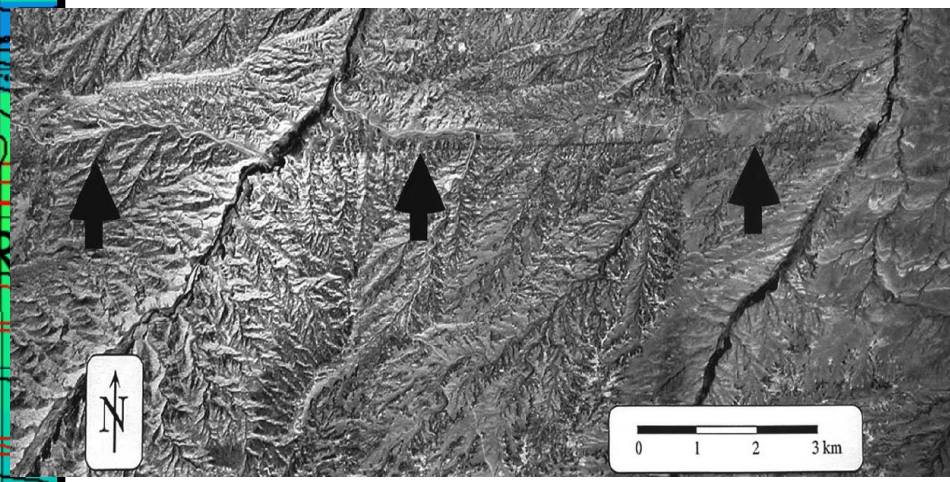
First-derivative structure contour map on the Uteland Butte member showing the portions of the basin with the steepest dips

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

Second Derivative Structure Map



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



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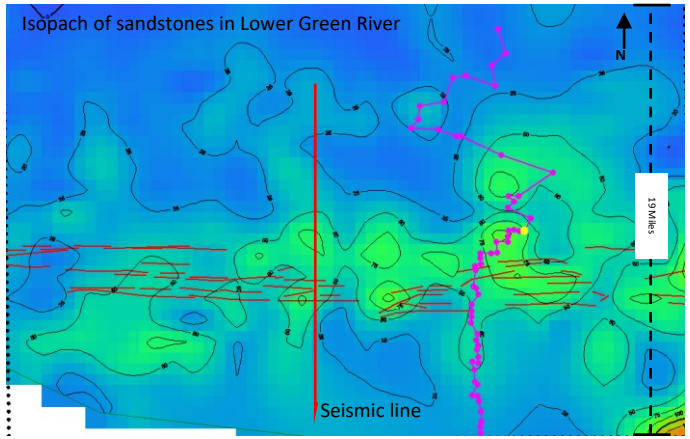
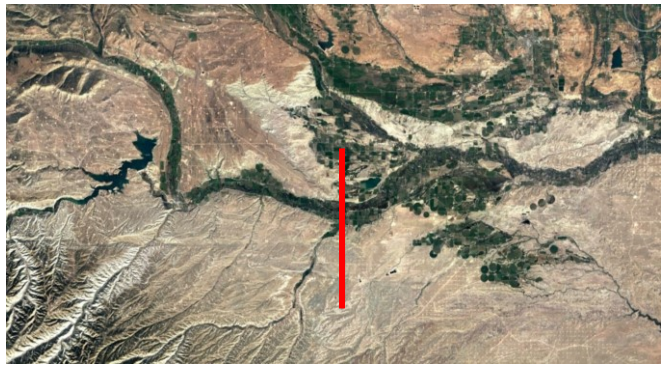
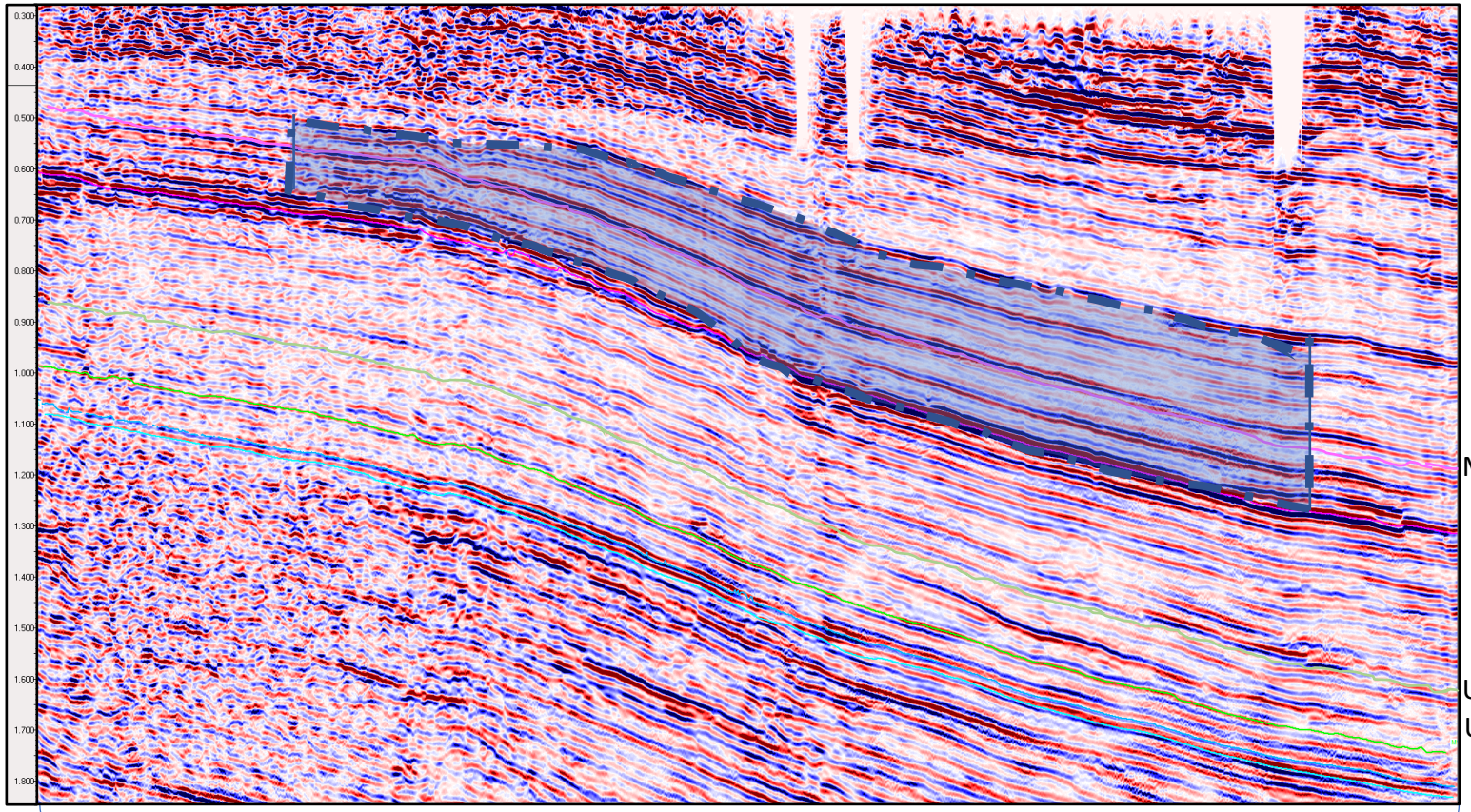
- Second-derivative structure maps highlight where the highest *change* of stratigraphic dips occur
- Note how well the 2nd-derivative maps correlate with the surface grabens

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

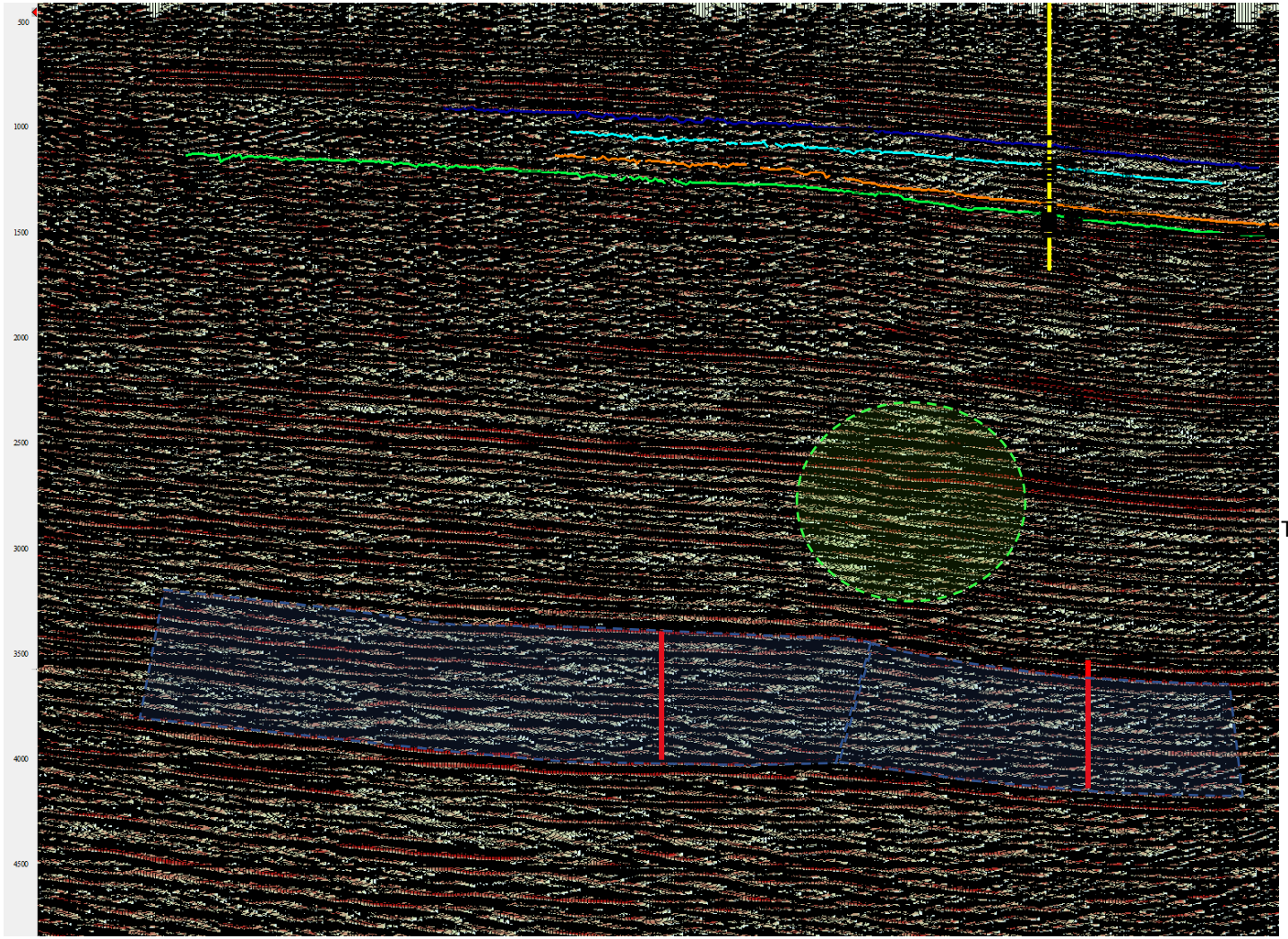




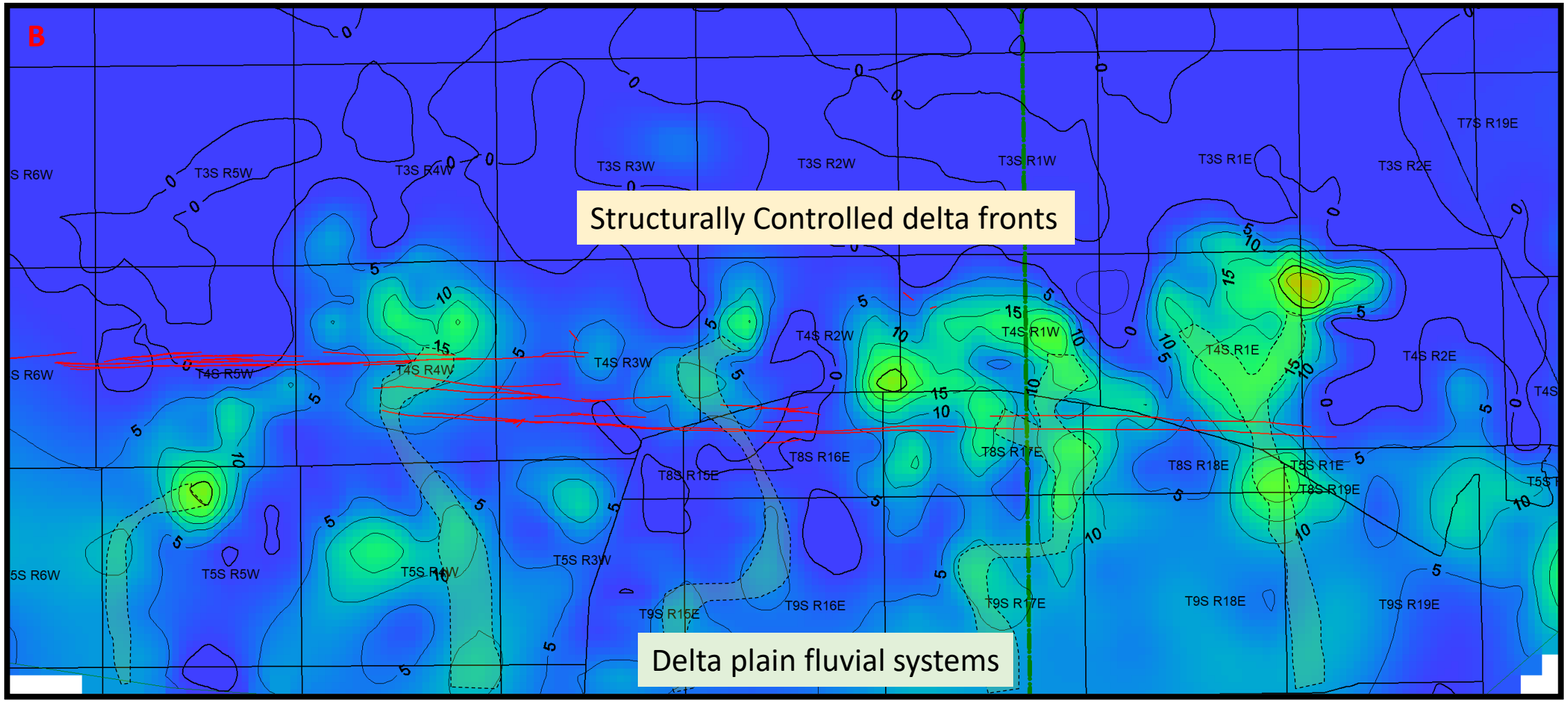


Modified from Brinkerhoff and Woolf - 2019

Ancestral Rockies and Sevier Aged Deformation? (Recurrent Movement)

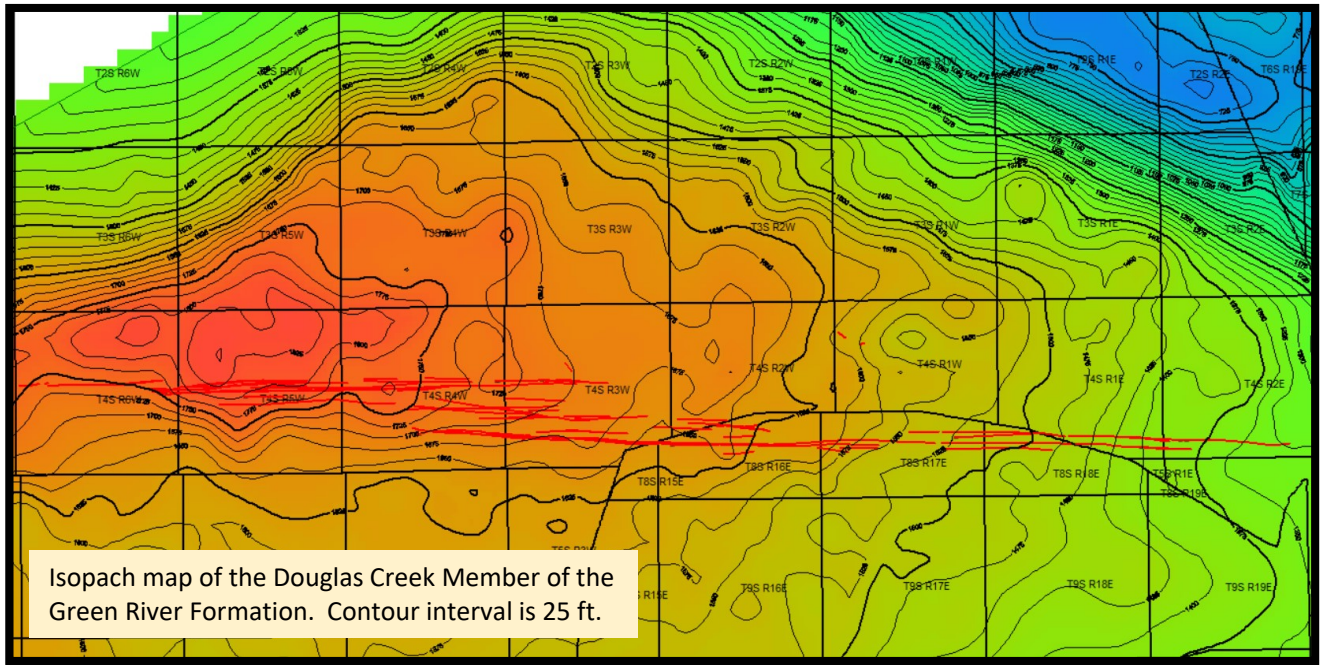


- Ancestral Rockies aged stratigraphy shows thinning on the basin side block
  - Possibly indicating a structural inversion on the DFZ?
- Sevier aged stratigraphy shows significantly more deformation than the overlying Laramide aged stratigraphy
  - Suggesting reactivation in Sevier time?

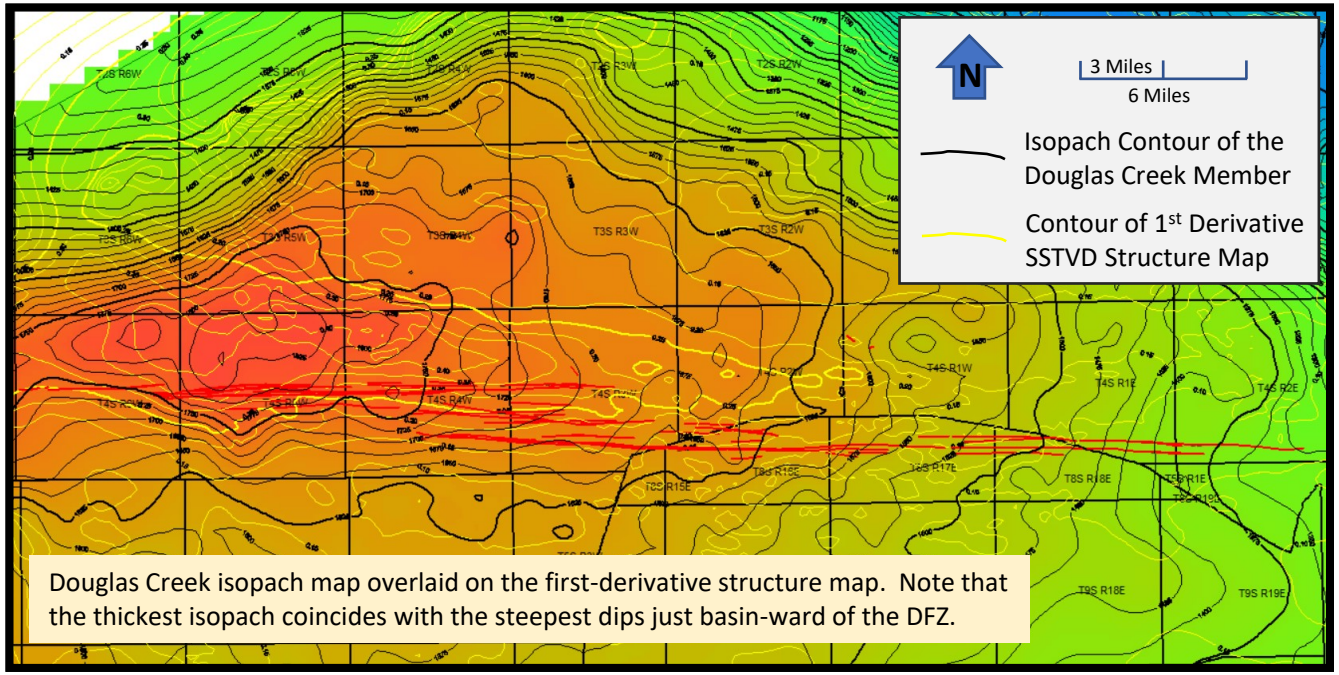


- The more rapid subsidence of the basin north of the fault created greater accommodation, resulting in much thicker stratigraphic thicknesses just basinward of the fault

Stratigraphic Effects



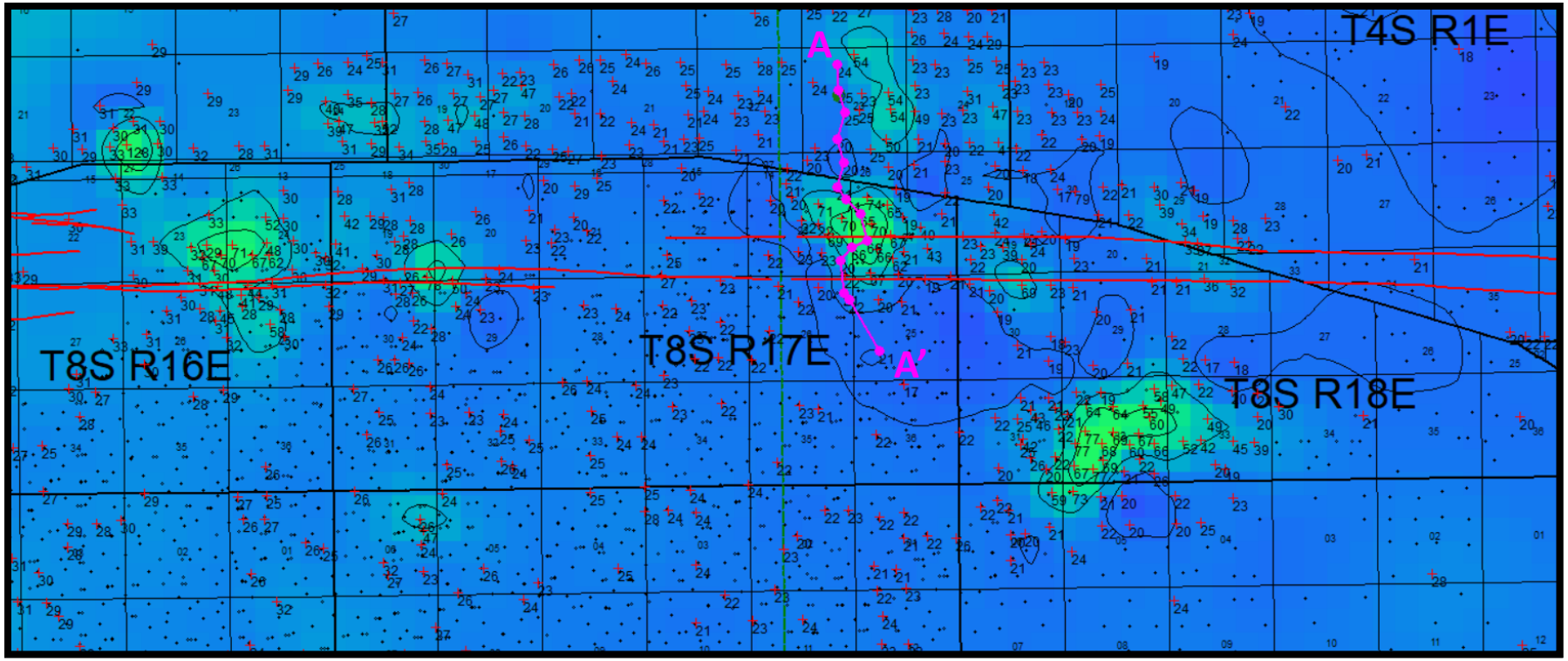
Isopach map of the Douglas Creek Member of the Green River Formation. Contour interval is 25 ft.



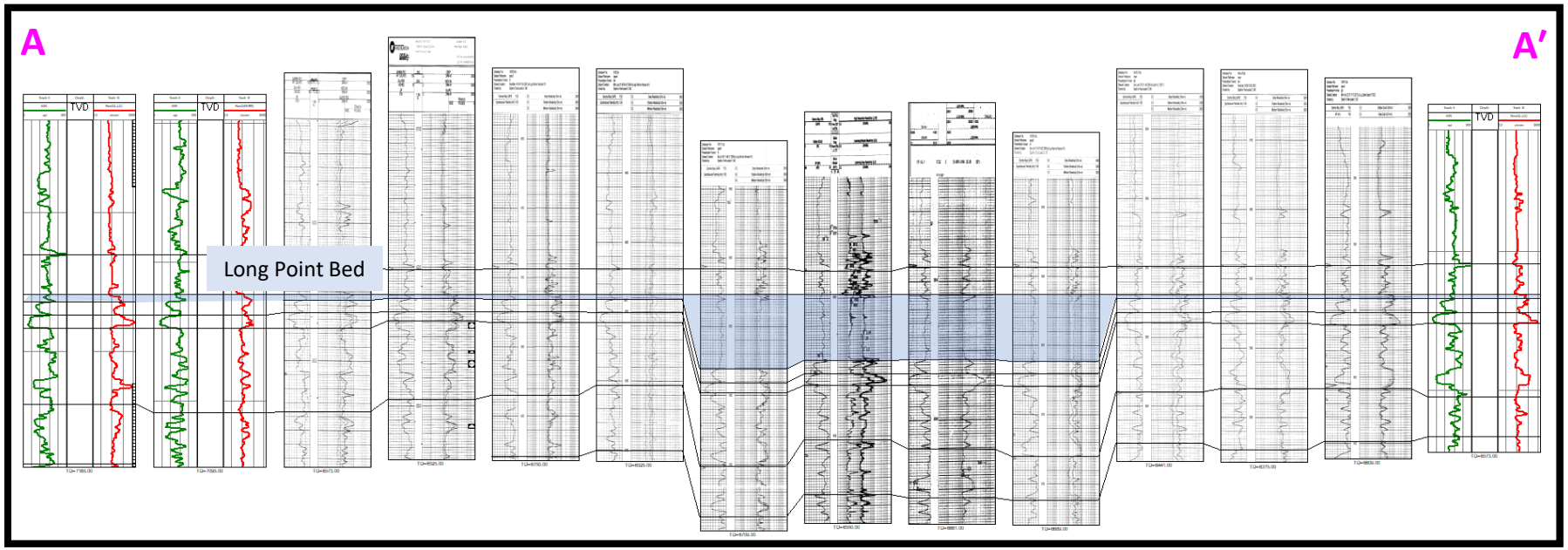
Douglas Creek isopach map overlaid on the first-derivative structure map. Note that the thickest isopach coincides with the steepest dips just basin-ward of the DFZ.

- 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.

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

SEG | AAPG image
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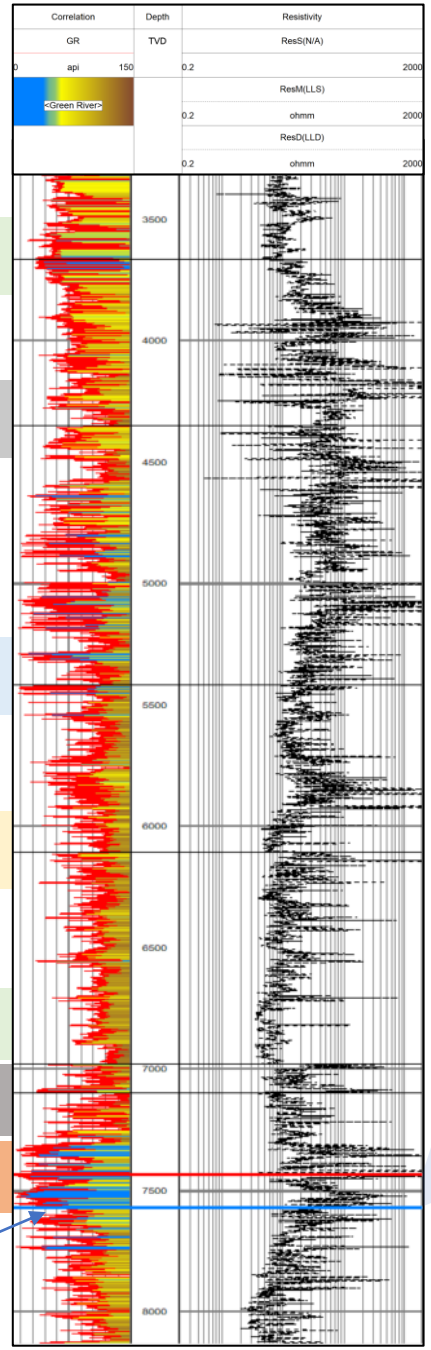
Timing of Deformation



Top Green River

Mahogany Bench

TGR-3

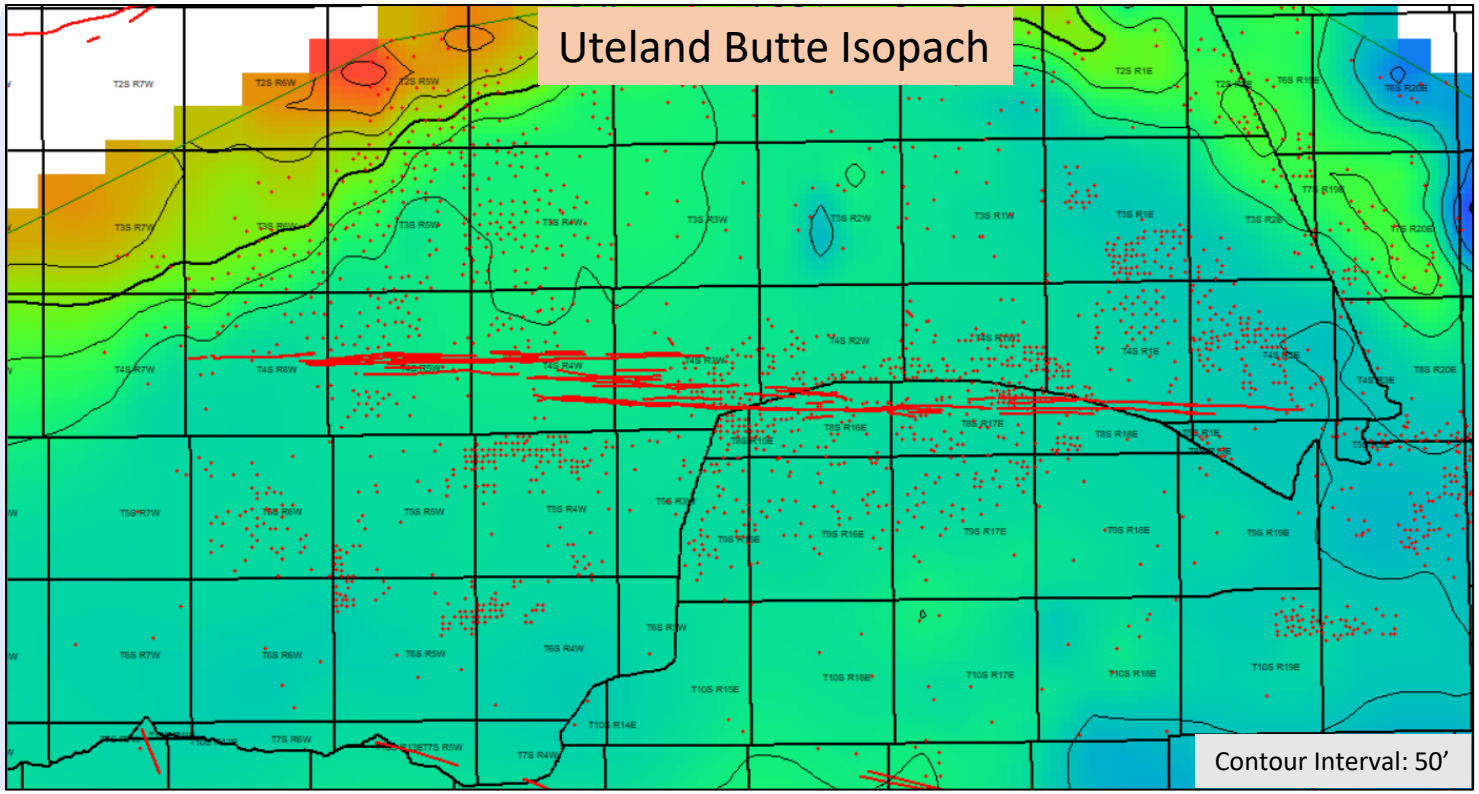
Douglas Creek

Lower Black Shale

Castle Peak

Uteland Butte

Wasatch



- No significant thickness changes across the fault zone
- Predates major structural movement on the DFZ

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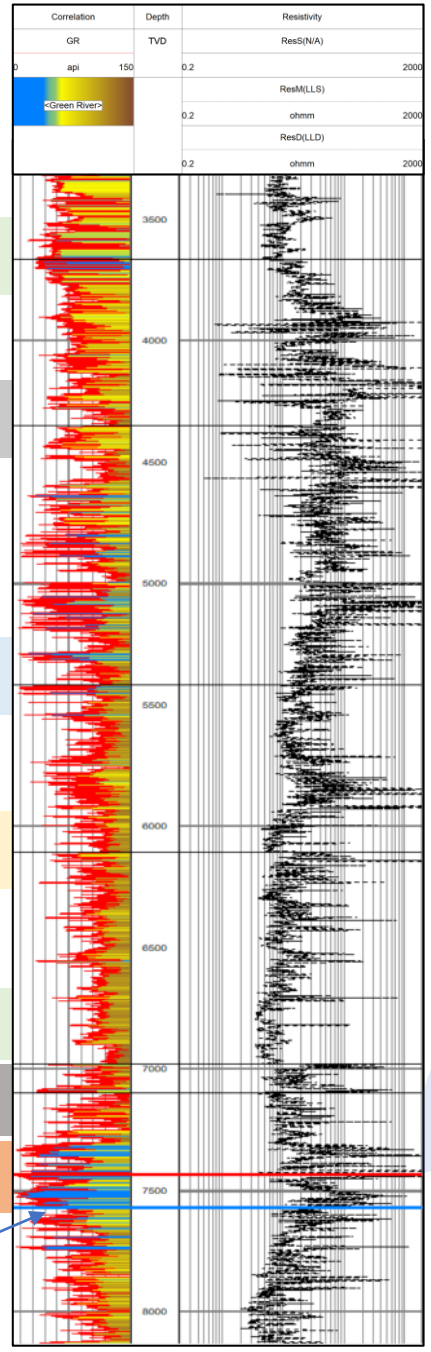
Timing of Deformation



Top Green River

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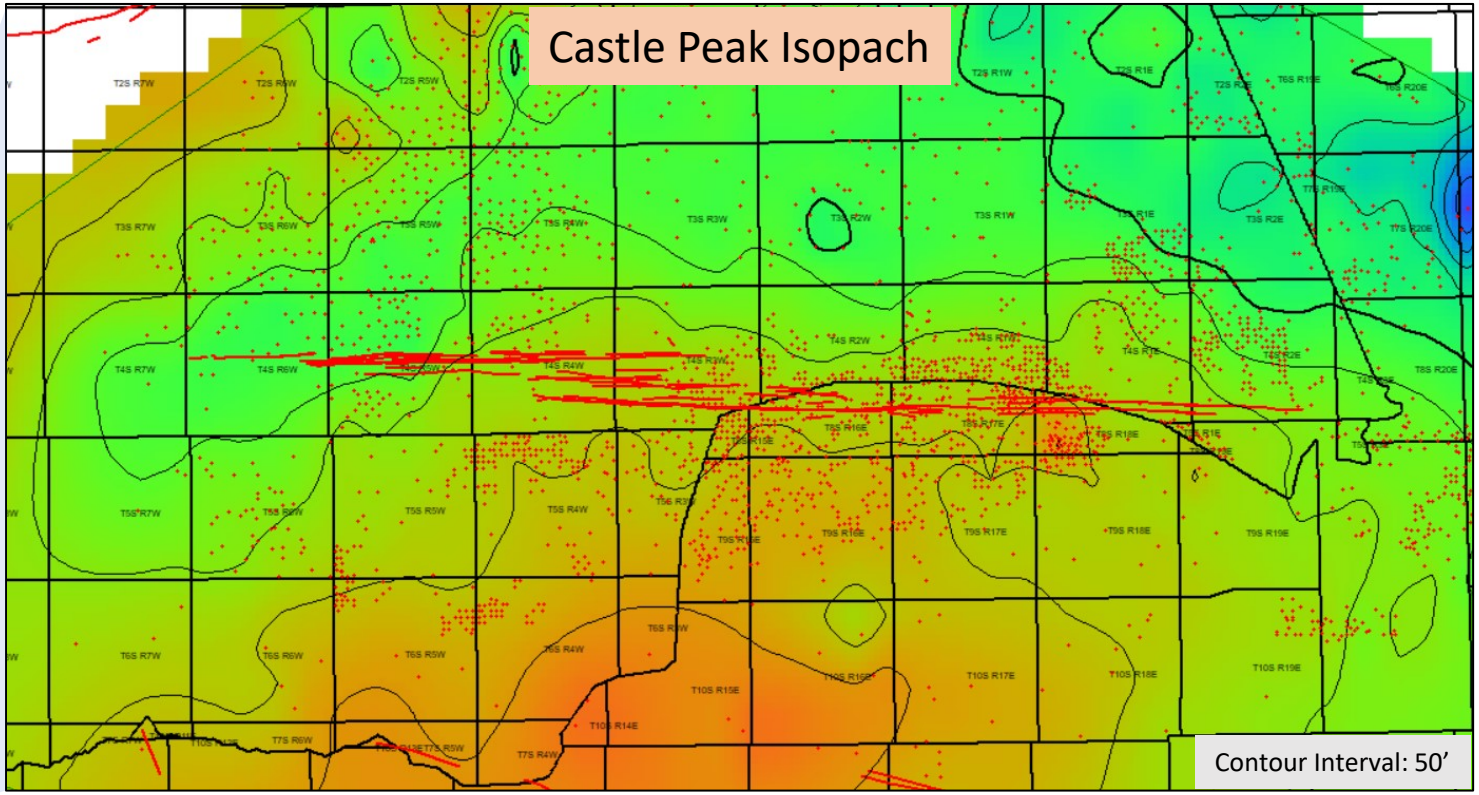
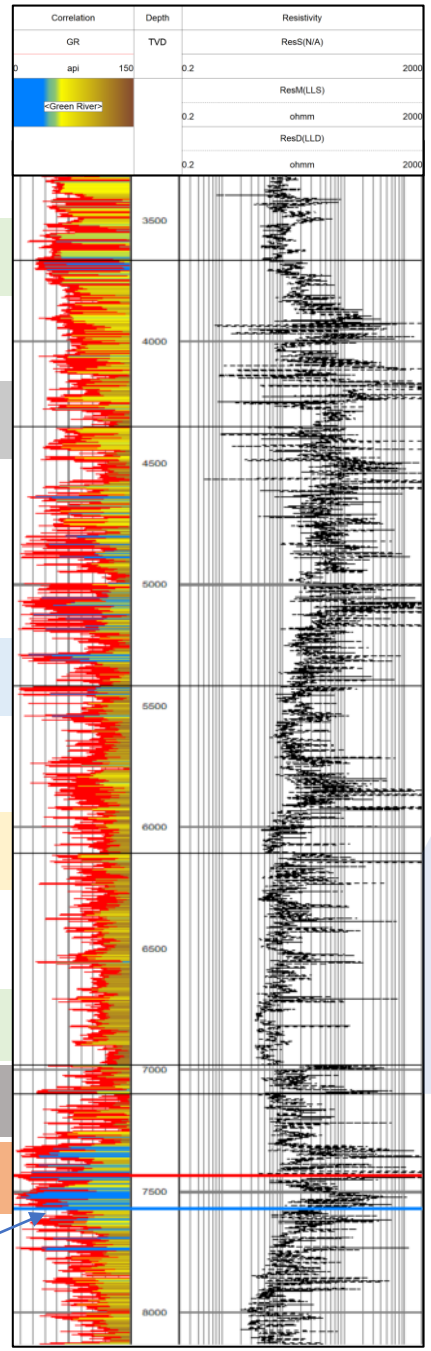


- Clastic deltas terminate at the DFZ, leading to thickening south of the fault zone
- Castle Peak sediments record the onset of major structural movement on the DFZ

Timing of Deformation



Top Green River

Mahogany Bench

TGR-3

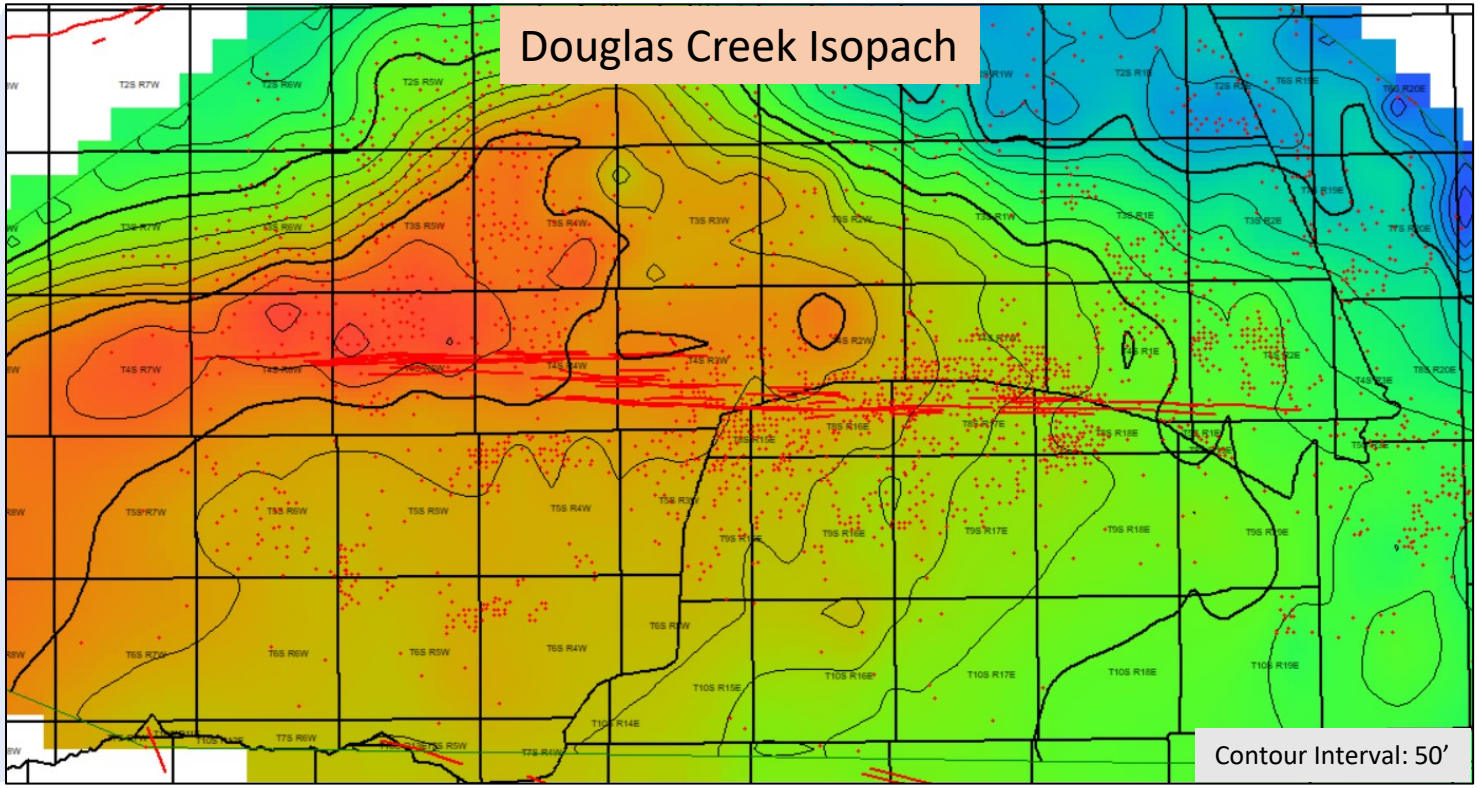
Douglas Creek

Lower Black Shale

Castle Peak

Uteland Butte

Wasatch



- Thickest intervals are just basinward of the fault zone
- The Douglas Creek records the period of most rapid deformation on the fault zone

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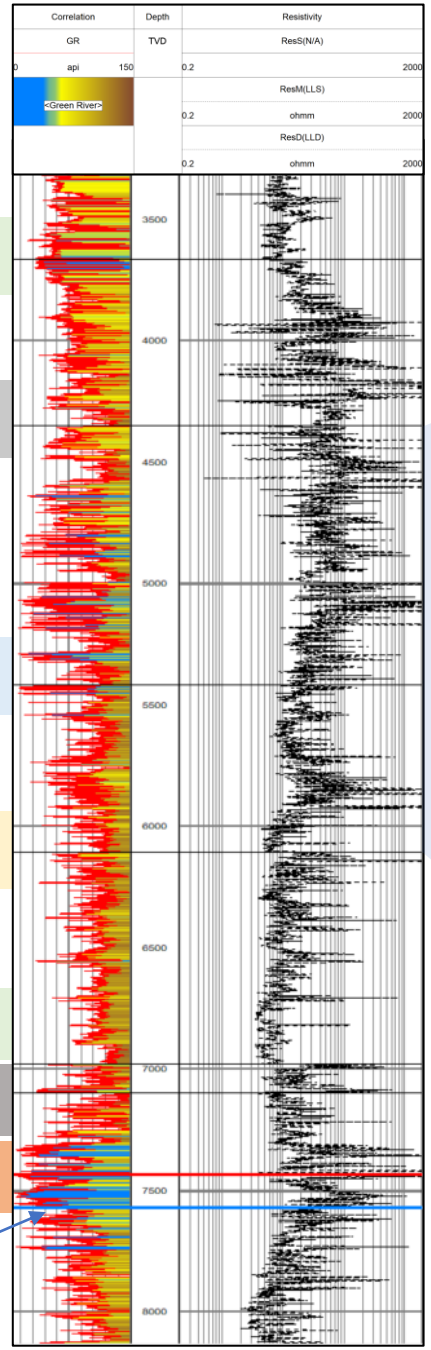
Timing of Deformation



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Douglas Creek

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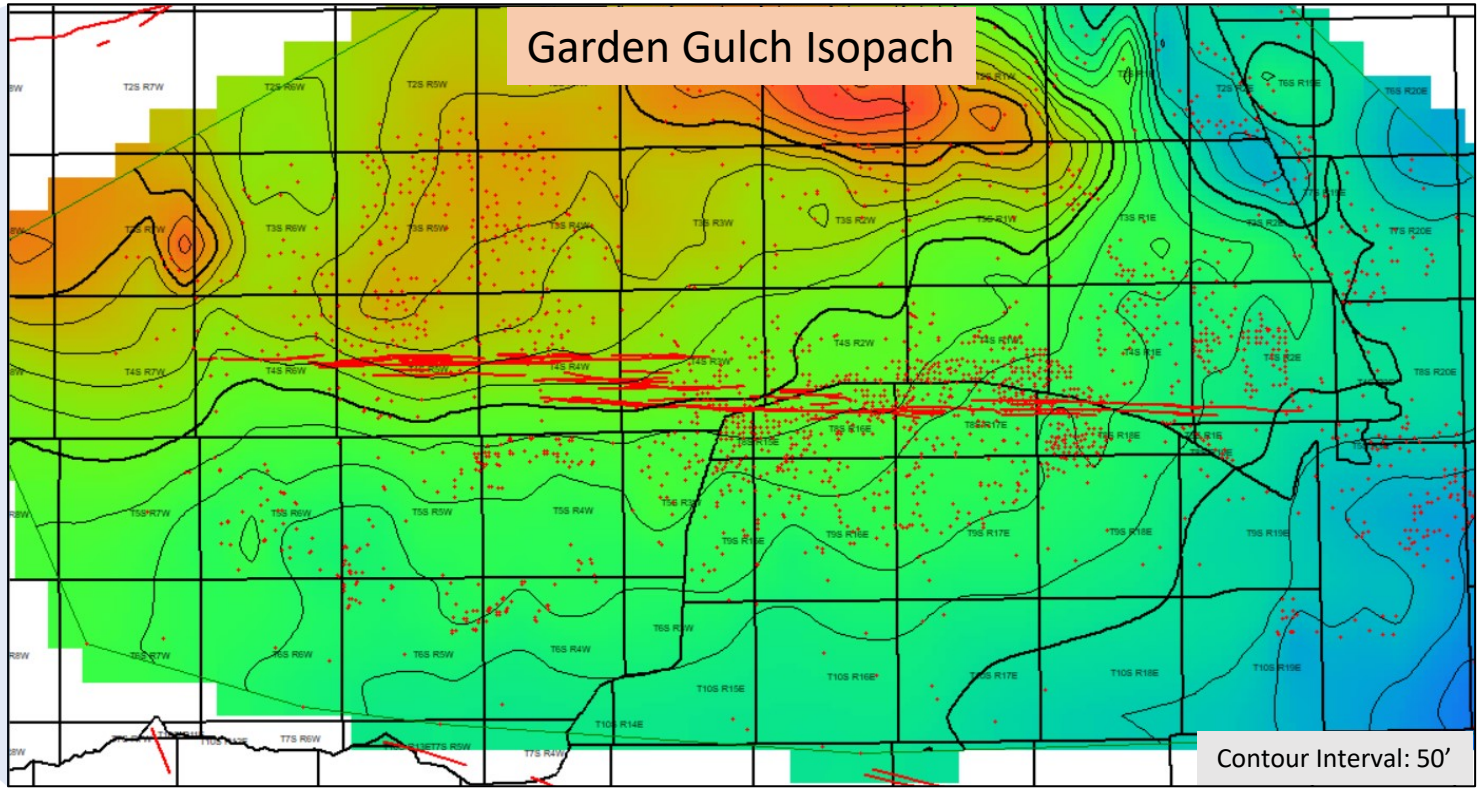

- Significant thickness changes across the fault zone, but less than the Douglas Creek
- Rate of deformation is beginning to decrease

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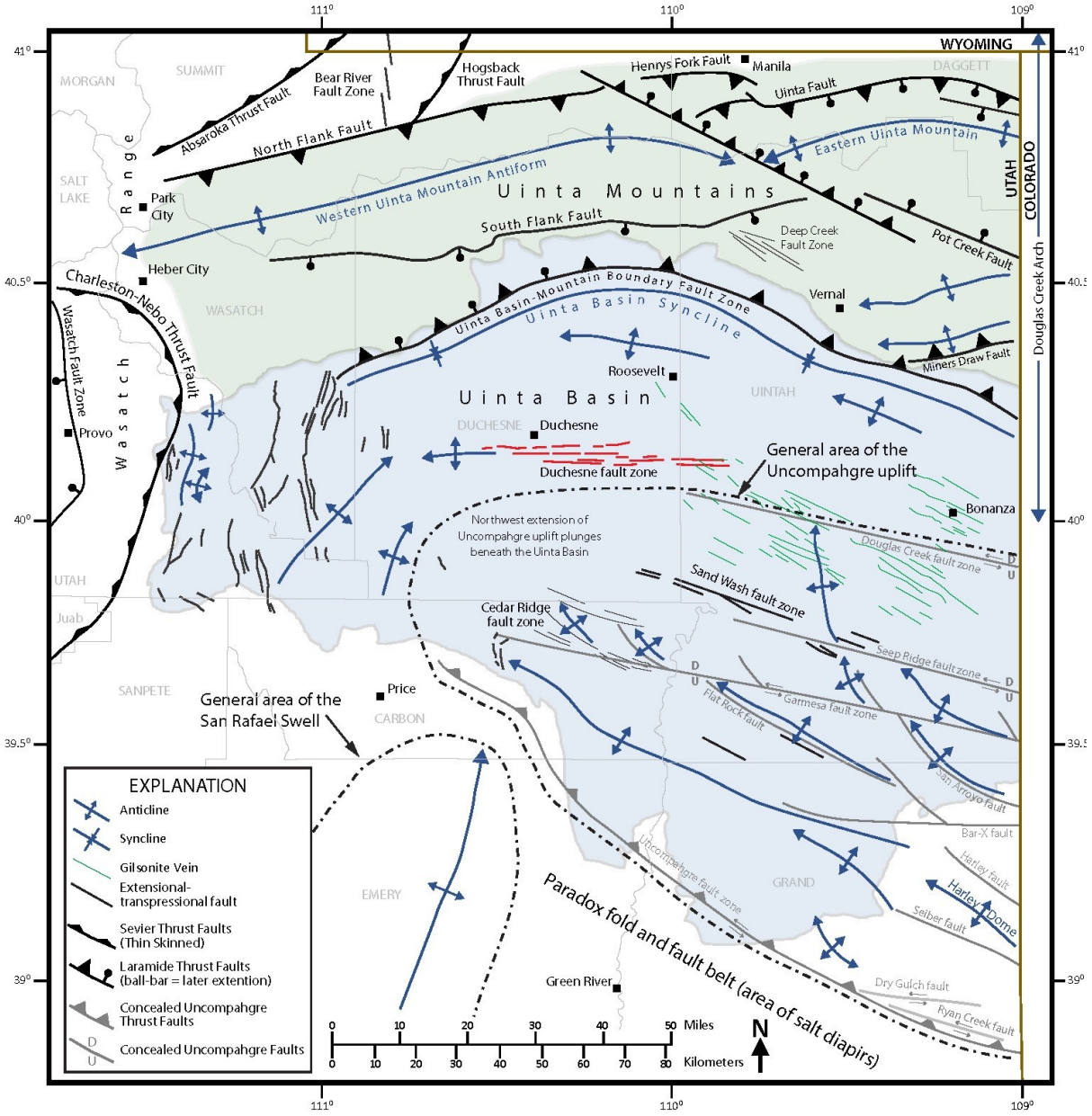
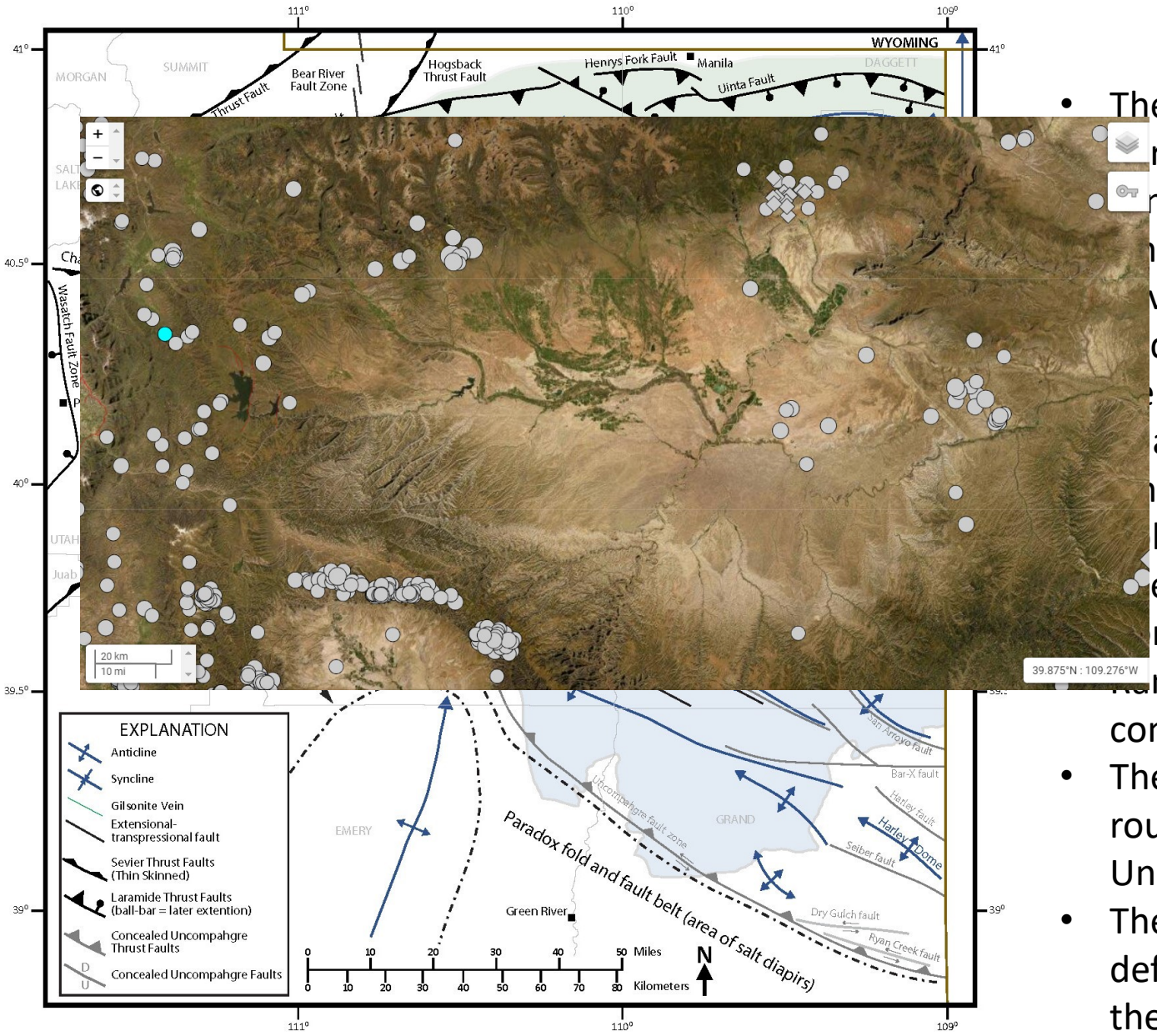
Tectonic-structure map of Uinta Mountains-Uinta Basin Colorado



- 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
- General orientation may be related to it position relative to the buried Uncompahgre uplift
- 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
- The hinge point within the Green River formation roughly parallels the northwest flank of the buried Uncompahgre uplift
- The Uncompahgre was likely active during Laramide deformation, which may be related to the location of the DFZ and the Green River Formation hinge point

Tectonic-structure map of Uinta Mountains-Uinta Basin Colorado



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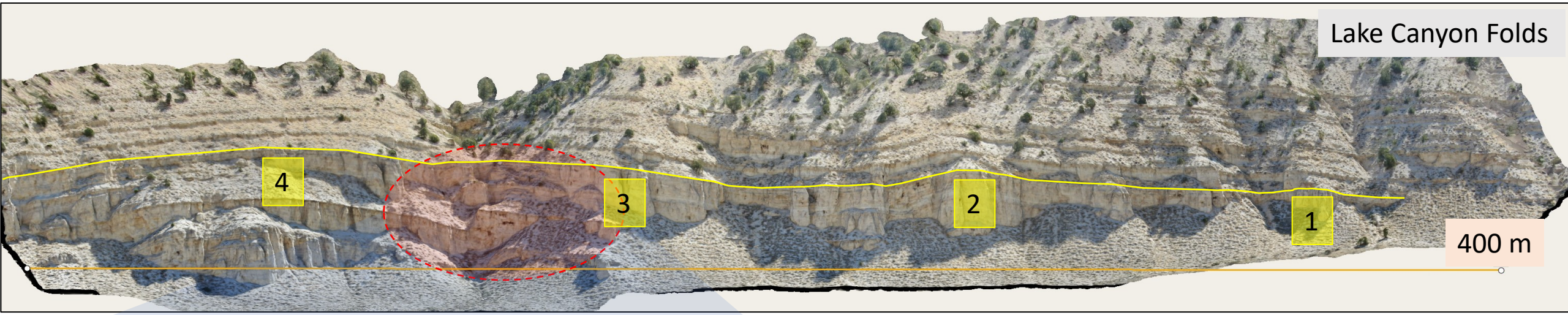
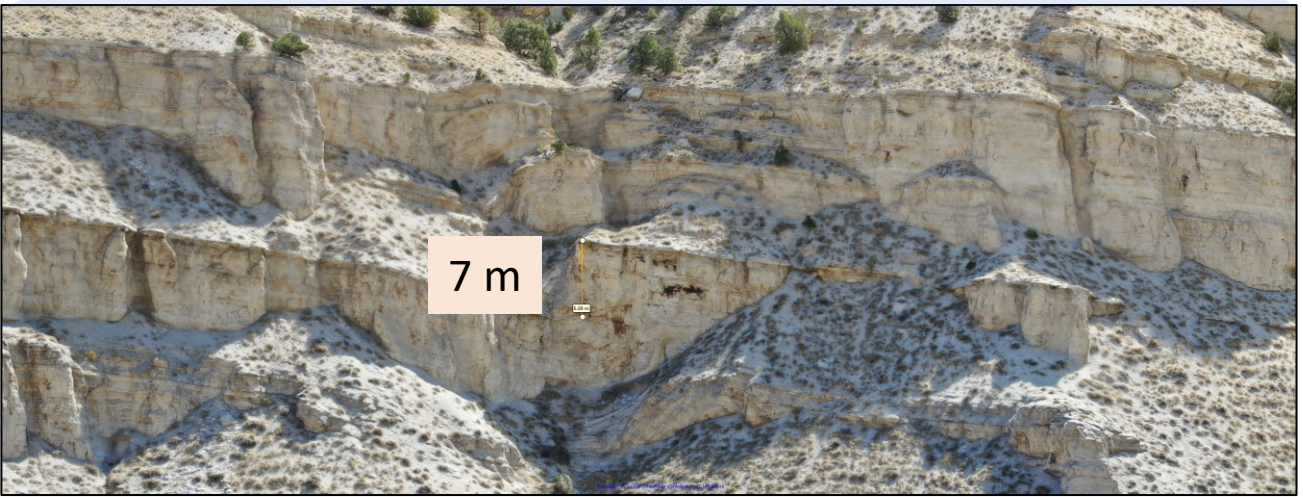
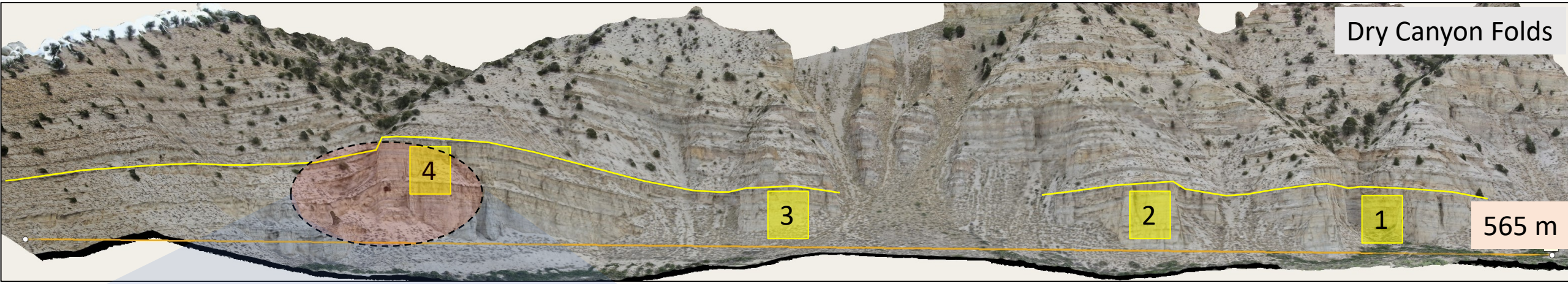
Laramide Thrusts and Folds





- Folds and small thrusts on the far western side (structurally below the grabens) demonstrate Laramide-aged compression on the DFZ
- Various intervals are overturned in the cores of the fold, with significant shortening across the entire outcrop

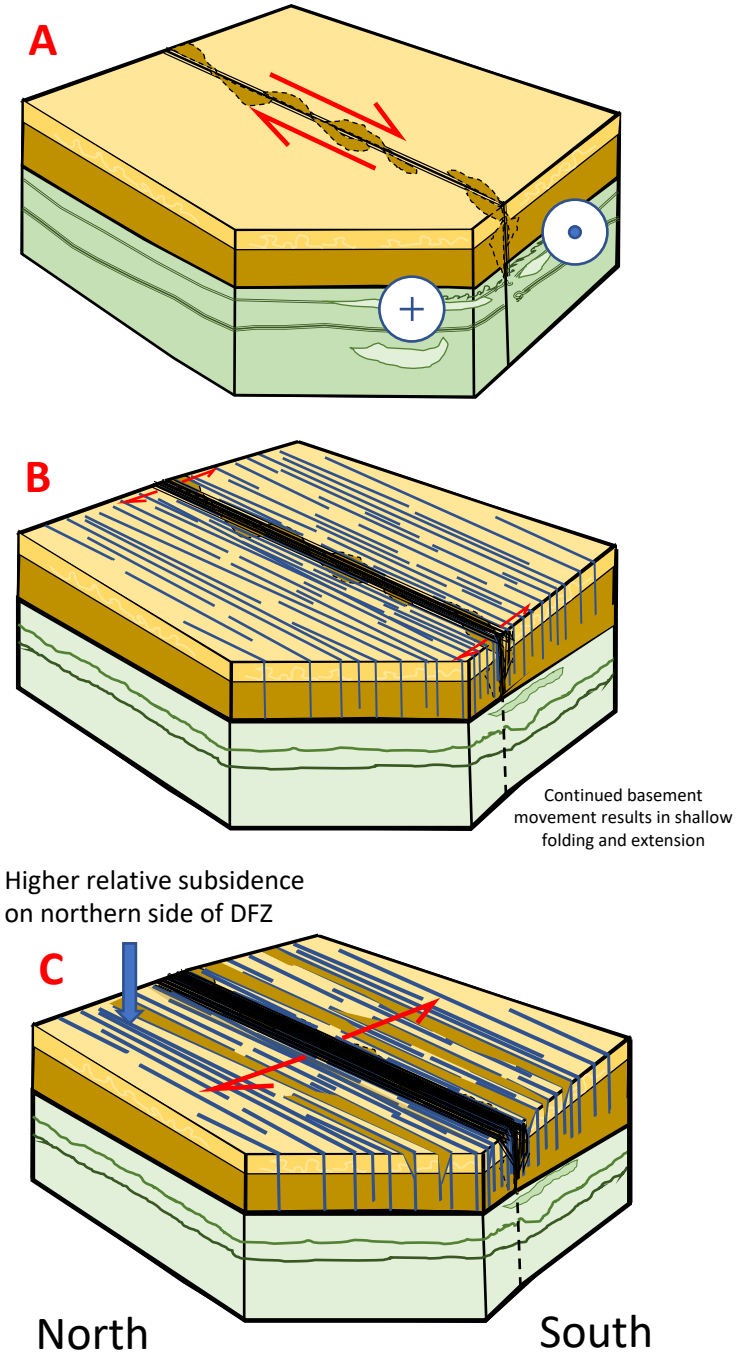
Thrust Relationships on the Western Margin



- Folds increase in amplitude toward the main DFZ fault trace

Models

All models are wrong, but some are useful
George E.P.Box

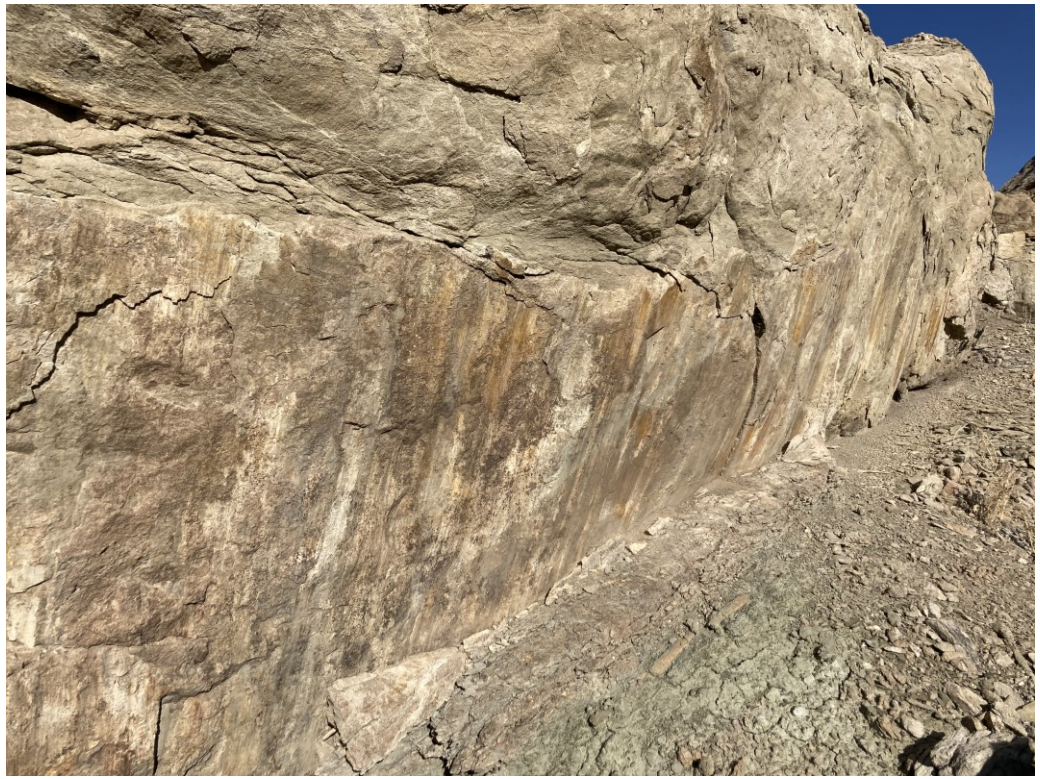


- Time A – Before lithification, no fractures could form, but the DFZ was active, moving in a right lateral sense and creating several small to medium sized sag basins

- 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

Conclusions



- The Duchesne Fault Zone is an ancient feature that extends into basement rocks
- It has experienced various types of deformation depending on contemporaneous stress fields
- In Laramide time this included early compression, transpression and extension above the neutral surface of a larger fold
- During the formation of the Uinta Basin, the DFZ acted as a hinge-point between the Uncompahgre block to the south and the rapidly subsiding deep Uinta to the north
- It is an active fault zone today with Holocene displacement