Post-Laramide Thrust Backsliding and Arch Collapse: A Mechanism for Creating Intensely Fractured Trends and High Off-Structure Production, Wind River Basin, Wyoming*

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Abstract

The mechanisms and timing of fracturing are important parameters in predicting intensely fractured trends with enhanced formation permeability and production potential. Fracture analyses were used to test hypotheses for the structural development of the Wind River Basin in Wyoming. These hypotheses include: pre-Laramide regional compression or forebulge migration; syn-Laramide ENE-WSW horizontal compression and left-slip faulting; and multiple post-Laramide hypotheses: 1) elastic strain release following Laramide shortening; 2) near-surface mechanisms; 3) regional extension due to transtensional plate interactions or epierogeny; and/or 4) localized extension due to backsliding on thrust faults during collapse of basin-bounding arches. Fracture data from Cambrian to Eocene strata throughout the basin included 1900 joints and minor faults measured at 45 outcrop stations and 14,775 previously interpreted fractures from 39 micro-resistivity image logs. Inferred stress axes, calculated using eigenvector analysis, show two distinct clusters indicating two stages of deformation: syn-Laramide ENE-WSW horizontal shortening followed by post-Laramide extension consistent with variation in the modern stress. Post-Laramide fractures in the basin parallel NW-SE striking joints observed across the Rocky Mountain foreland, except in the vicinity of E-W-trending, basin-bounding arch margins, where these fractures closely parallel arch-bounding thrust faults. Fracture analyses and seismic data indicate localized extension in proximity to basin-bounding thrust faults and backsliding on these thrusts that is probably due to arch collapse. Recently completed wells at Frenchie Draw gas field probably intersected off-structure, intensely fractured trends that parallel the margins of what appears to be a collapsed anticline. These wells have uncommonly high production rates.

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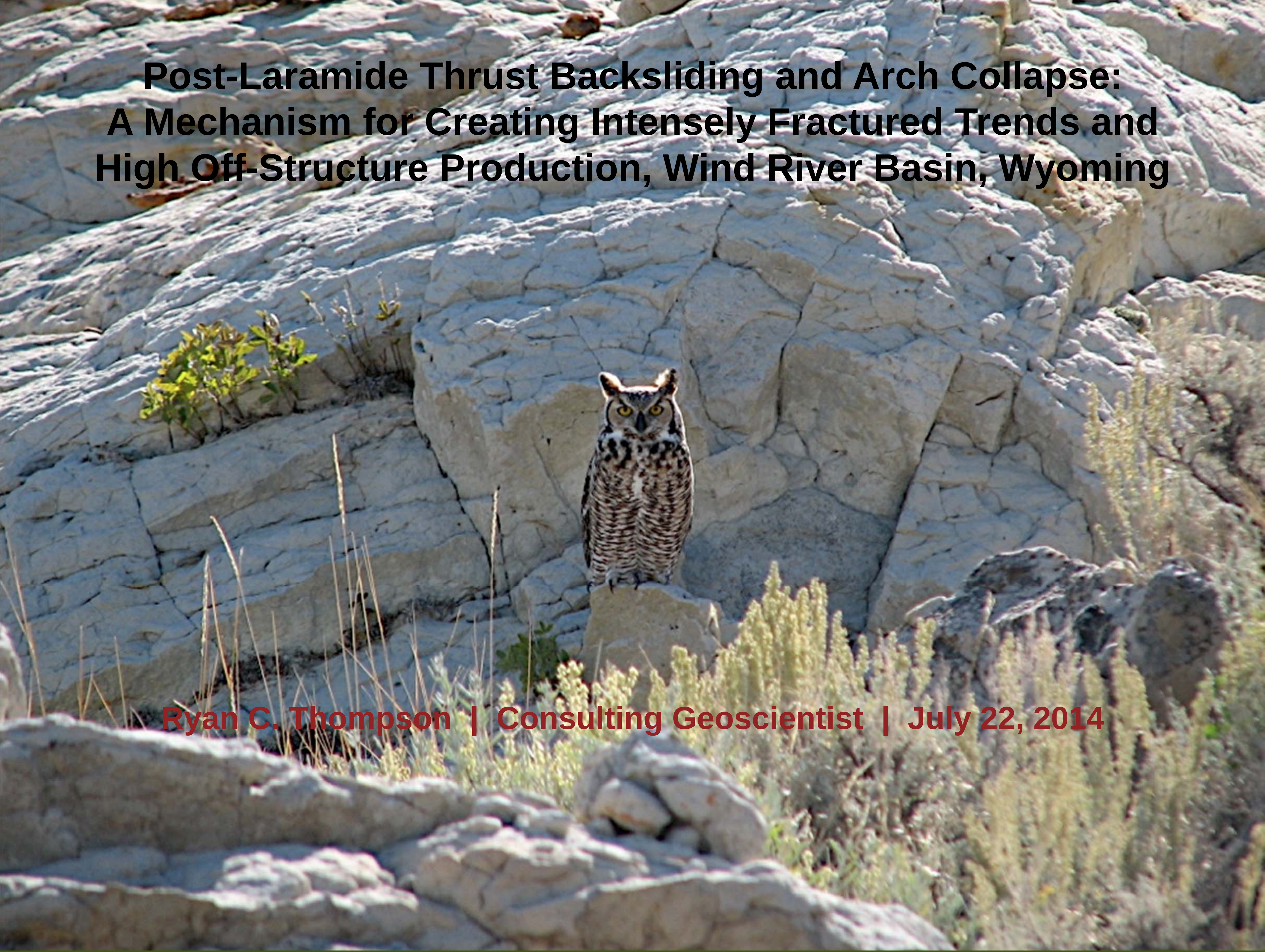
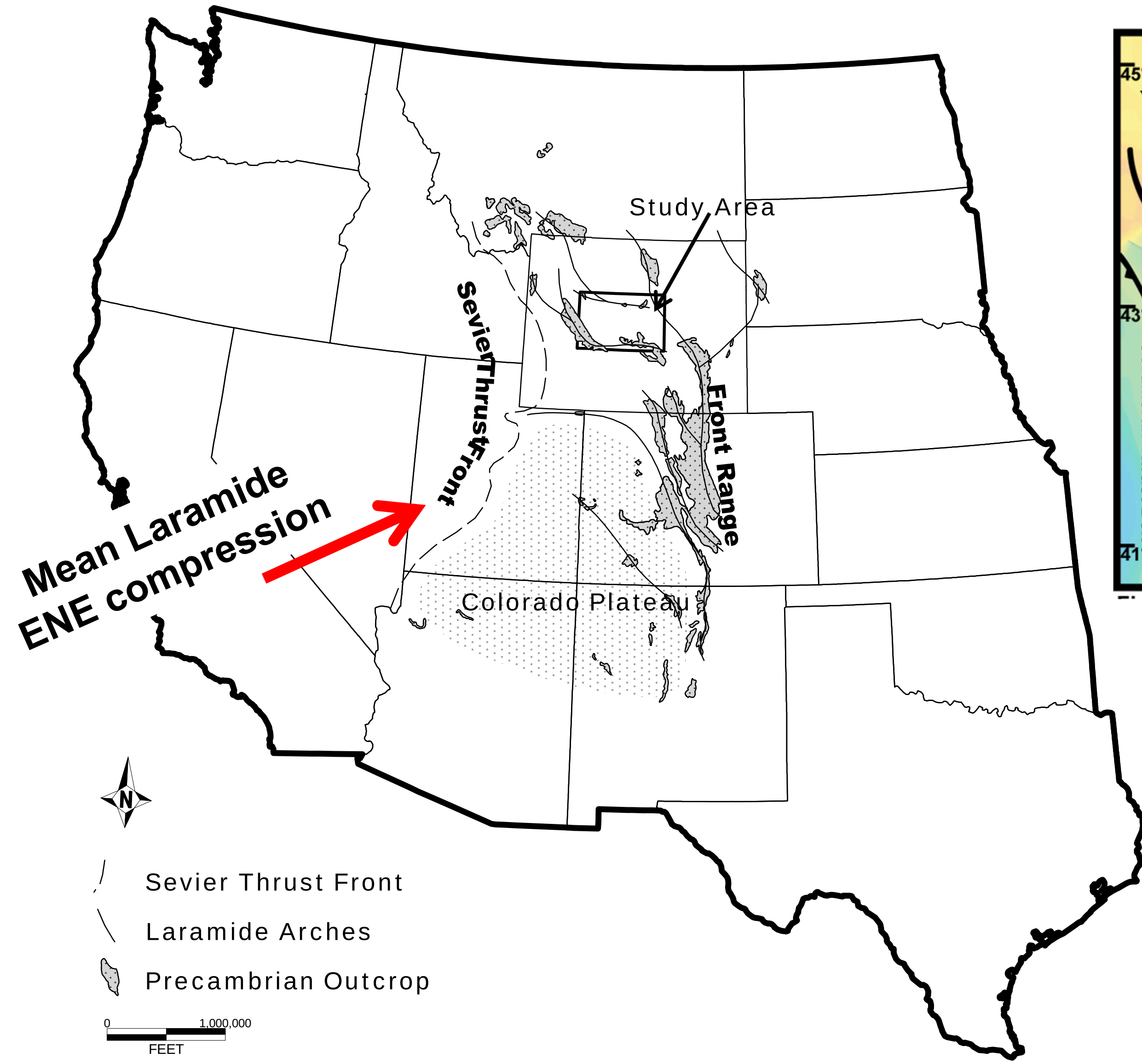
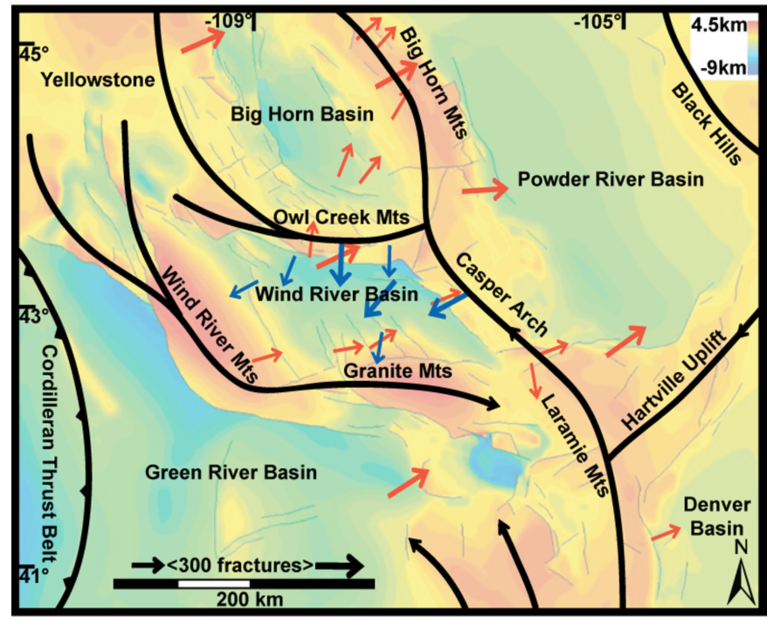
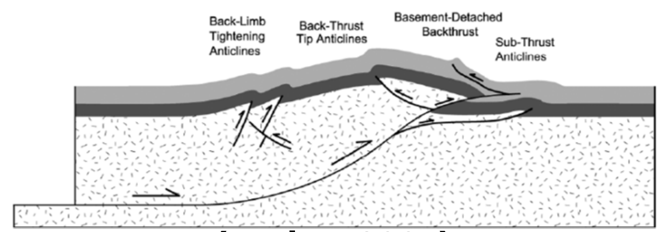


Ryan C. Thompson | Consulting Geoscientist | July 22, 2014

Regional Laramide Shortening







(Erslev, 2005)

Regional Post-Laramide Extension

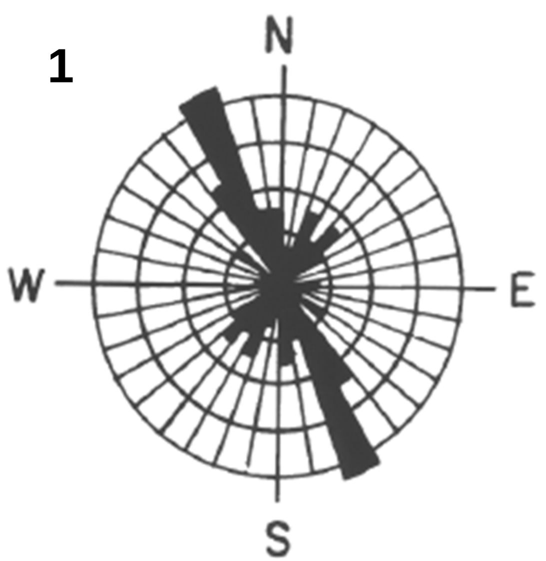
1. Eocene Green River Fm, Uinta Basin, UT (Narr, 1982)

2. Oligocene White River Fm, Casper Arch, WY (Hamlin, 2010)

3. Miocene Brown's Park Fm, NW Colorado (Detring, 2009)

& many other studies…

1



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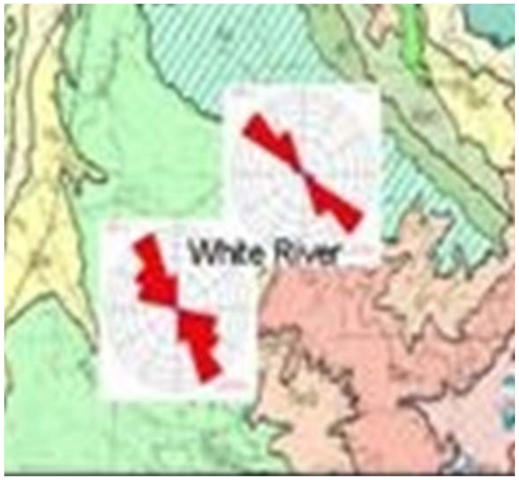

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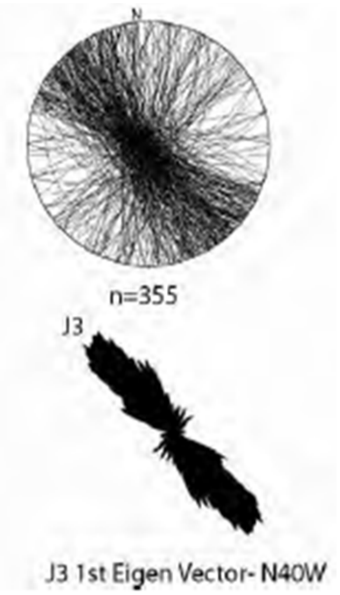
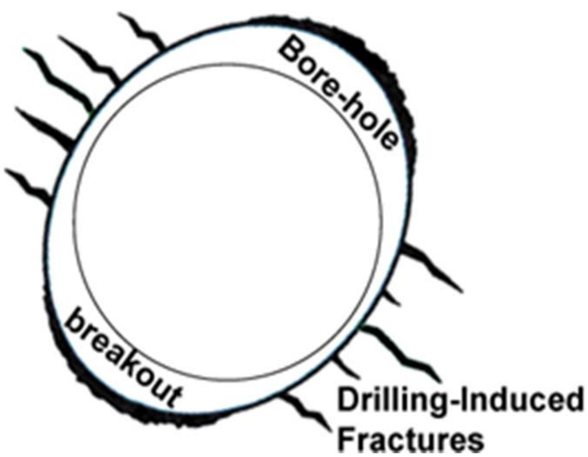


Relative Timing of Extension

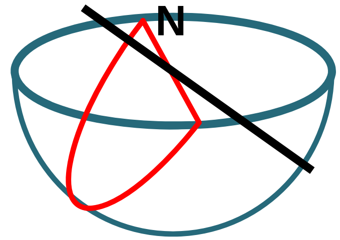
- Miocene/Pliocene collapse of the Granite Mtns (Bauer, 1934; Scott, 2002)
- Miocene mafic dikes in NW Colorado (Thompson *et al.*, 1989)
- Miocene & younger opening of the Gulf of California & Basin and Range extension (Bird, 2002)
- Eocene-Miocene collapse of the Cordillera (Constenius, 1996)
- Eocene & younger Rio Grande rifting (Erslev & Koenig, 2009)



S. Granite Mtns Earthquake

May 17th, 2009
3.7 magnitude
Focal mechanism calculated by Hermann, 2009

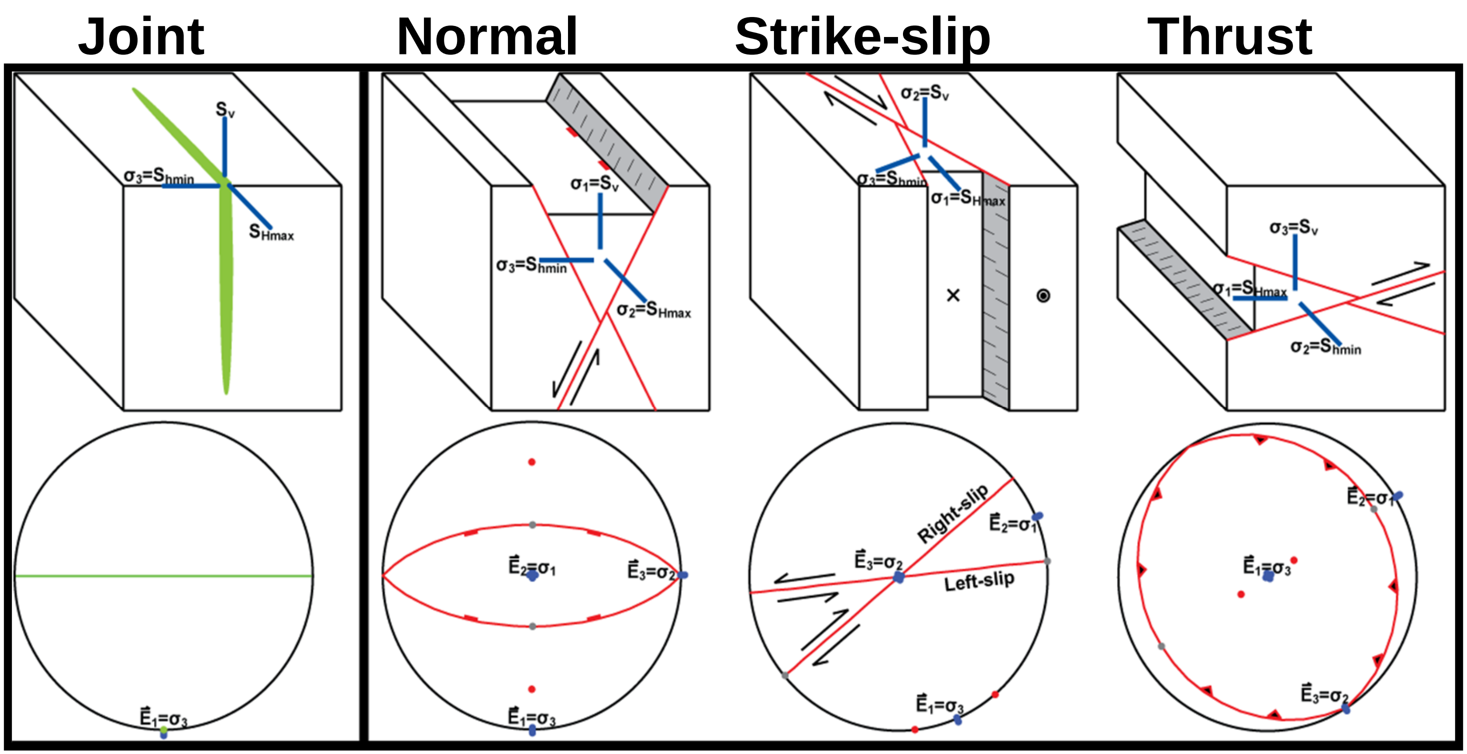
Methodology & Data



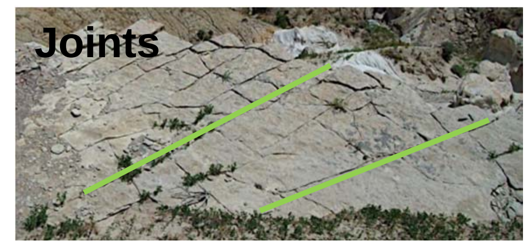
- Fractures are caused by stress
- Fracture geometry is related to the stress orientation
- Eigenvector analysis gives mean fracture orientation

1,900 outcrop fractures measured & described (45 stations)

14,775 subsurface fractures previously interpreted from image logs (39 wells)

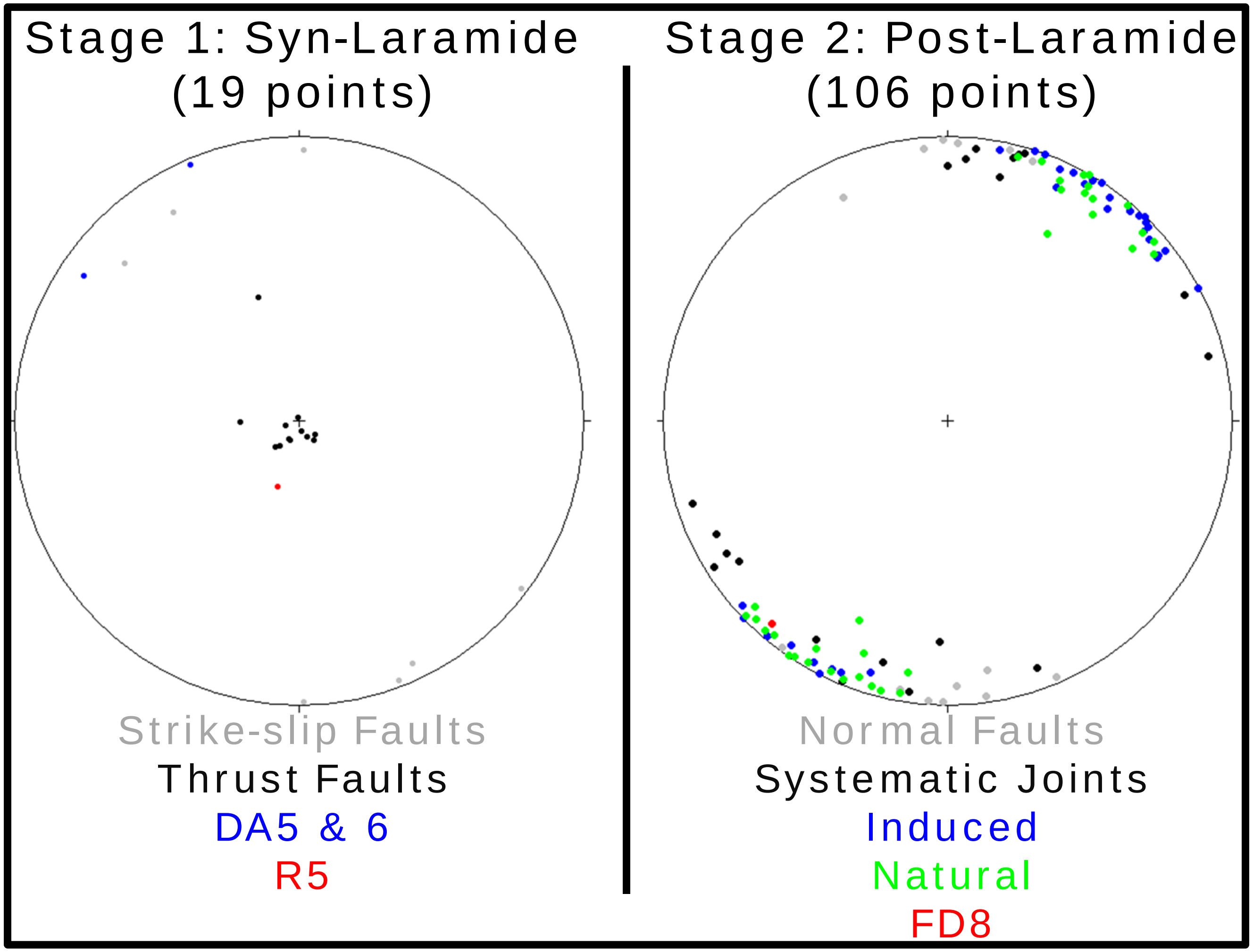


Fracture type classification after Anderson (1951)

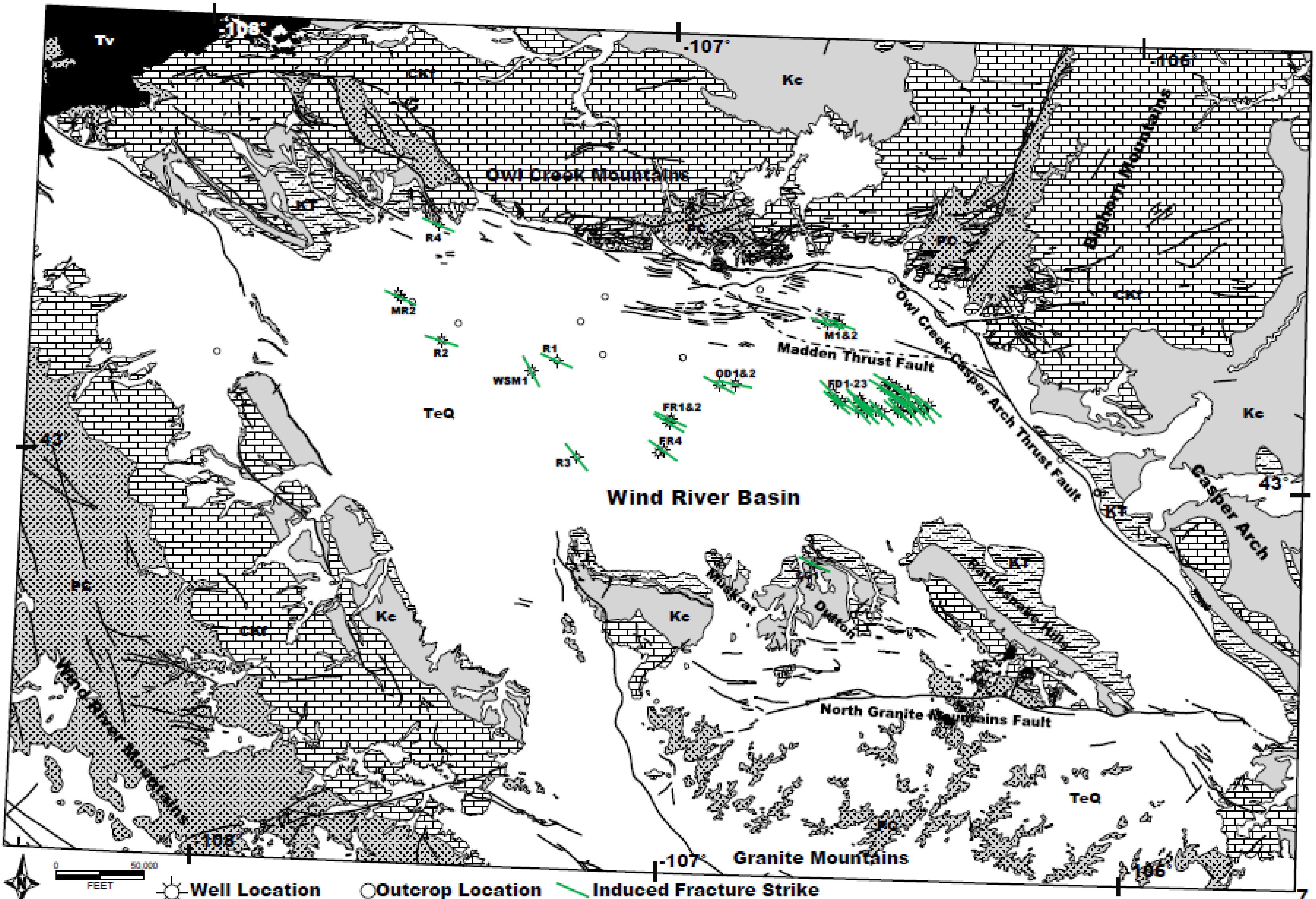


Inferred σ_3 Axes

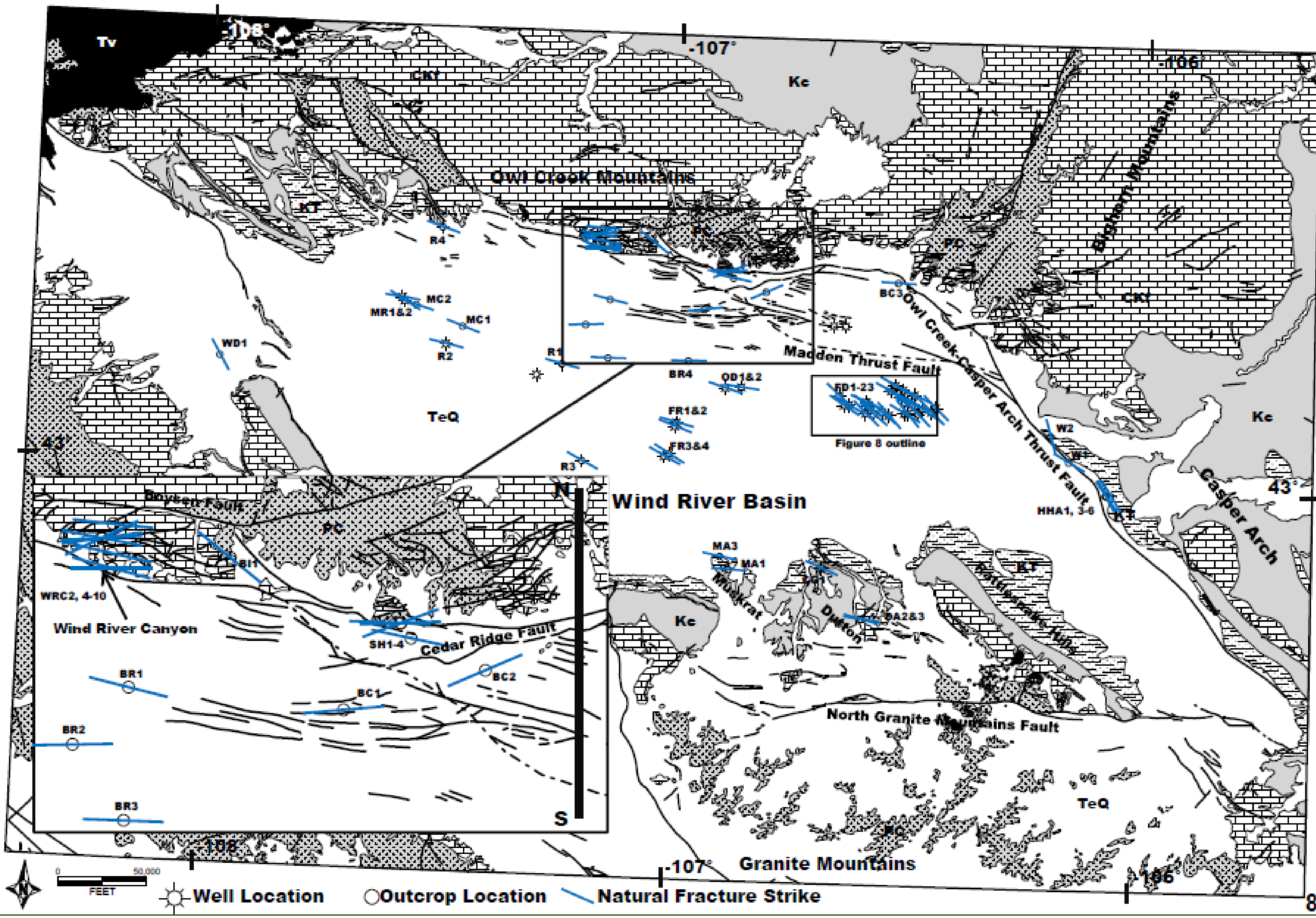
- **Strike-slip and thrust faults observed have σ_3 axes consistent with Laramide N66°E-directed shortening as also observed by prior workers.**
- **Normal faults, systematic joints, and natural fractures seen in image logs plot in the same NE-SW quadrant as modern induced fractures, indicating they are post-Laramide.**



Induced Fracture Strikes

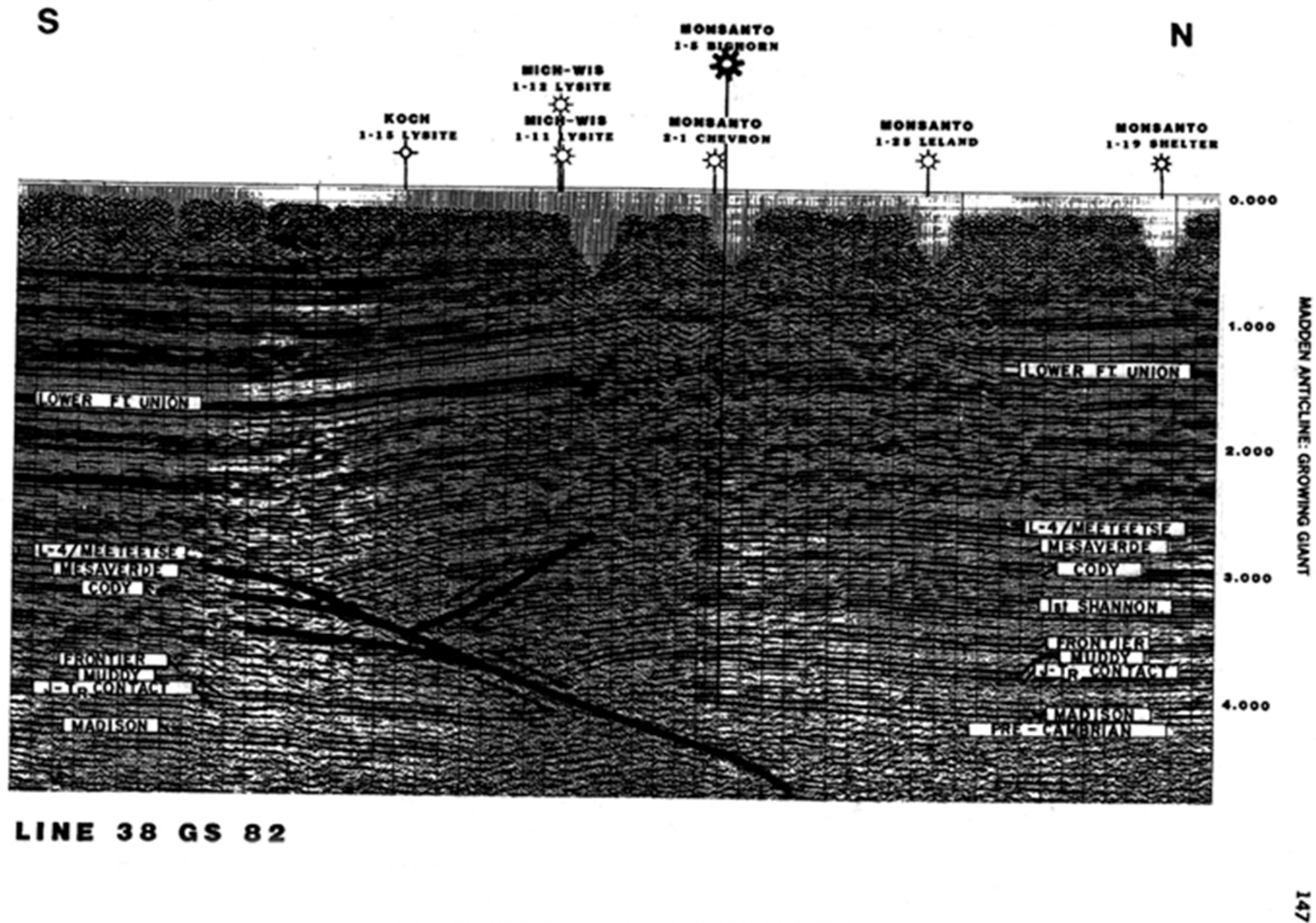


Natural Fracture Strikes



Seismic Observations

- Black lines indicate Laramide thrust faults at depth.
- Red lines (next image) indicate seismically ‘fuzzy’ zones associated with intense fracturing and extending upwards from the thrust limbs through the Lance & Fort Union formations.
- Orange line (next image) indicates flattened anticlinal crest.



(Dunleavy & Gilbertson, 1986)

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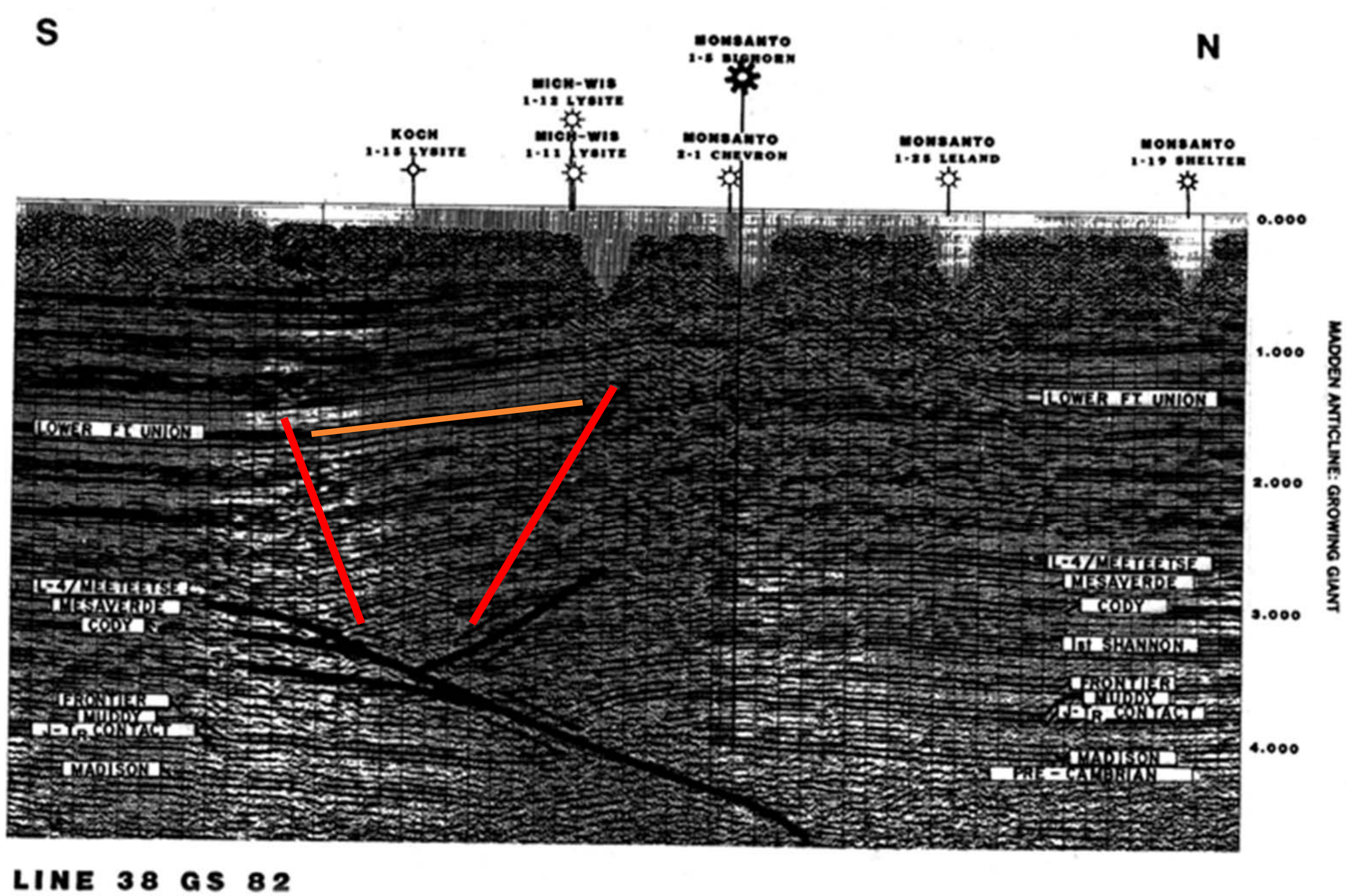
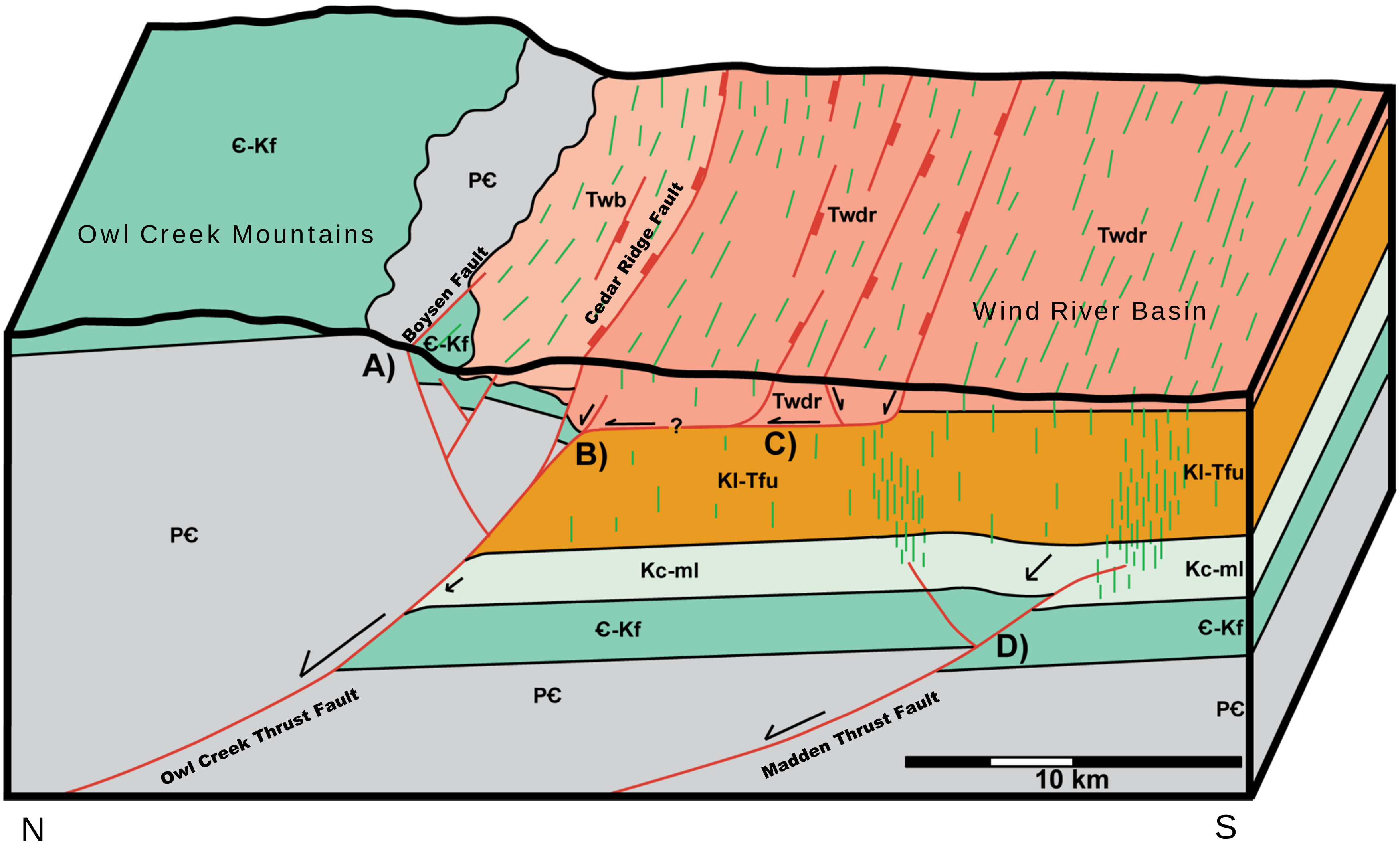


(Dunleavy & Gilbertson, 1986)

Backsliding & Collapse Model

A) "keystone" graben formation (Wise, 1963) typified by the Boysen fault; B) normal faulting terminating into the main thrust (Keefer, 1970; Blackstone, 1990) typified by the Cedar Ridge fault; C) basinal zone of normal faulting paralleling the main thrust showing hypothetical detachment; D) fracturing due to anticlinal collapse typified by the Madden and Frenchie Draw thrusts.



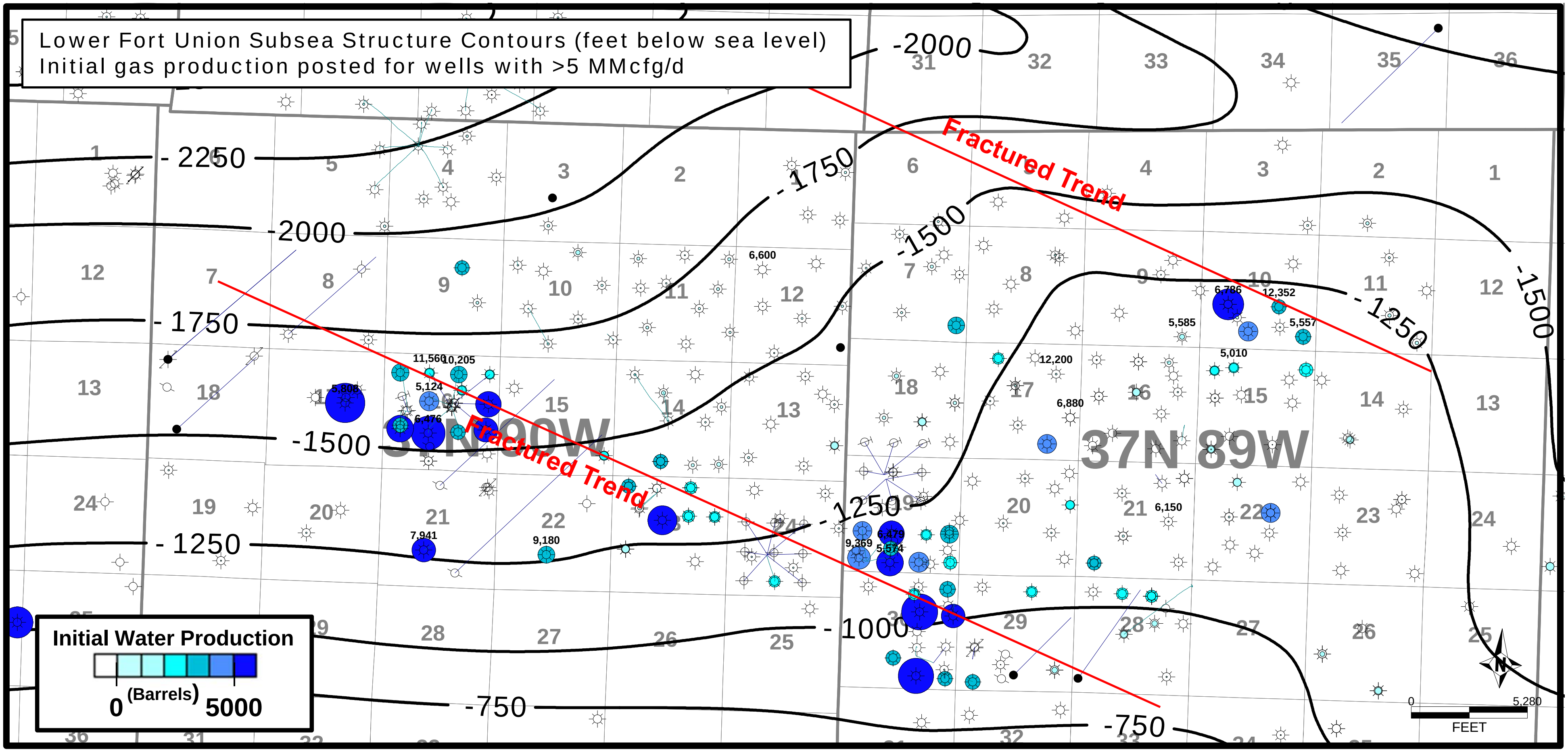
Frenchie Draw Production

230 productive wells since 1961: 5.3 MMBO, 250 BCFG

Recent deeper wells, pads, & horizontals drilled along fractured trends

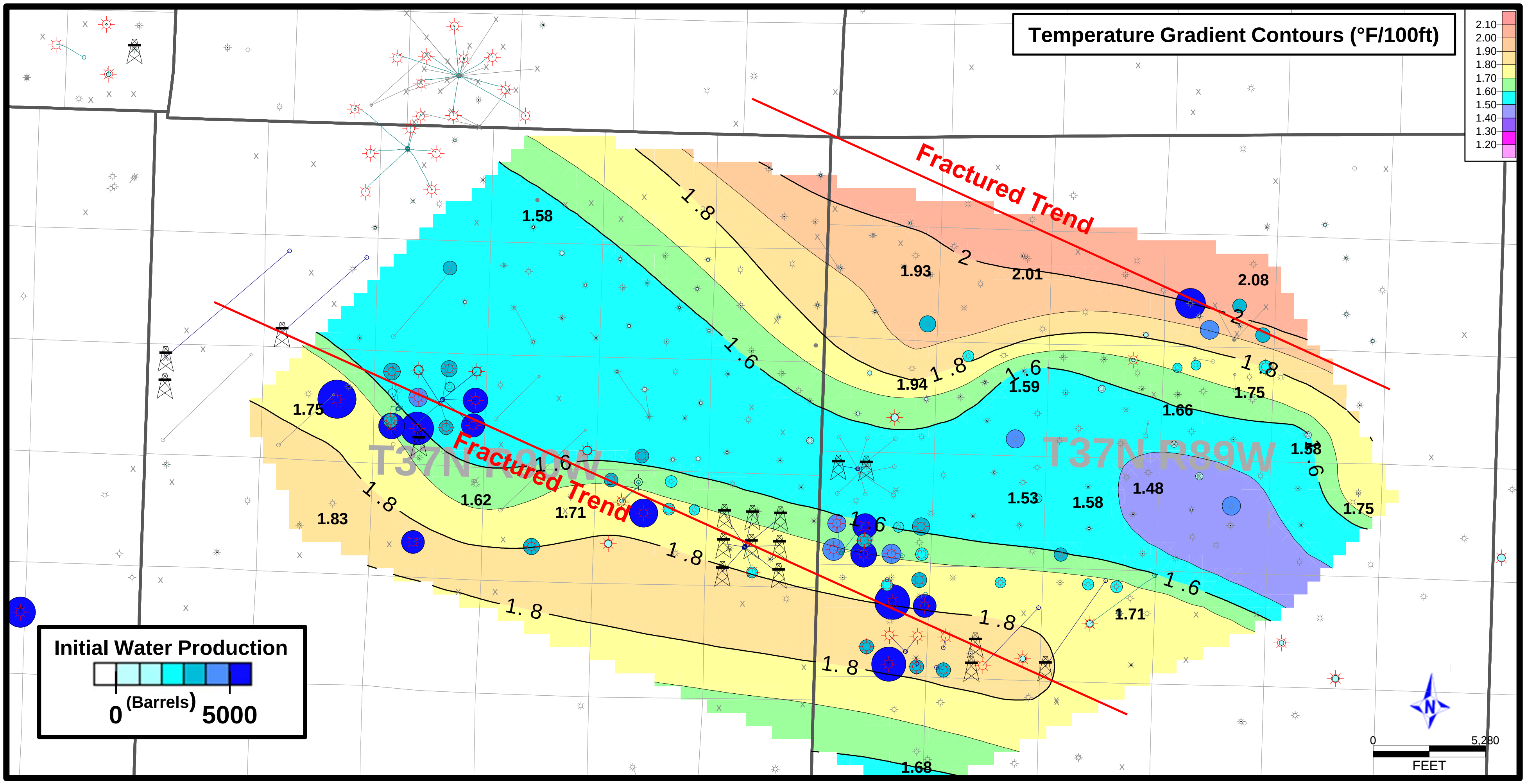
Most of the horizontals have had costly sidetracks

Horizontals have high initial rates with very steep declines

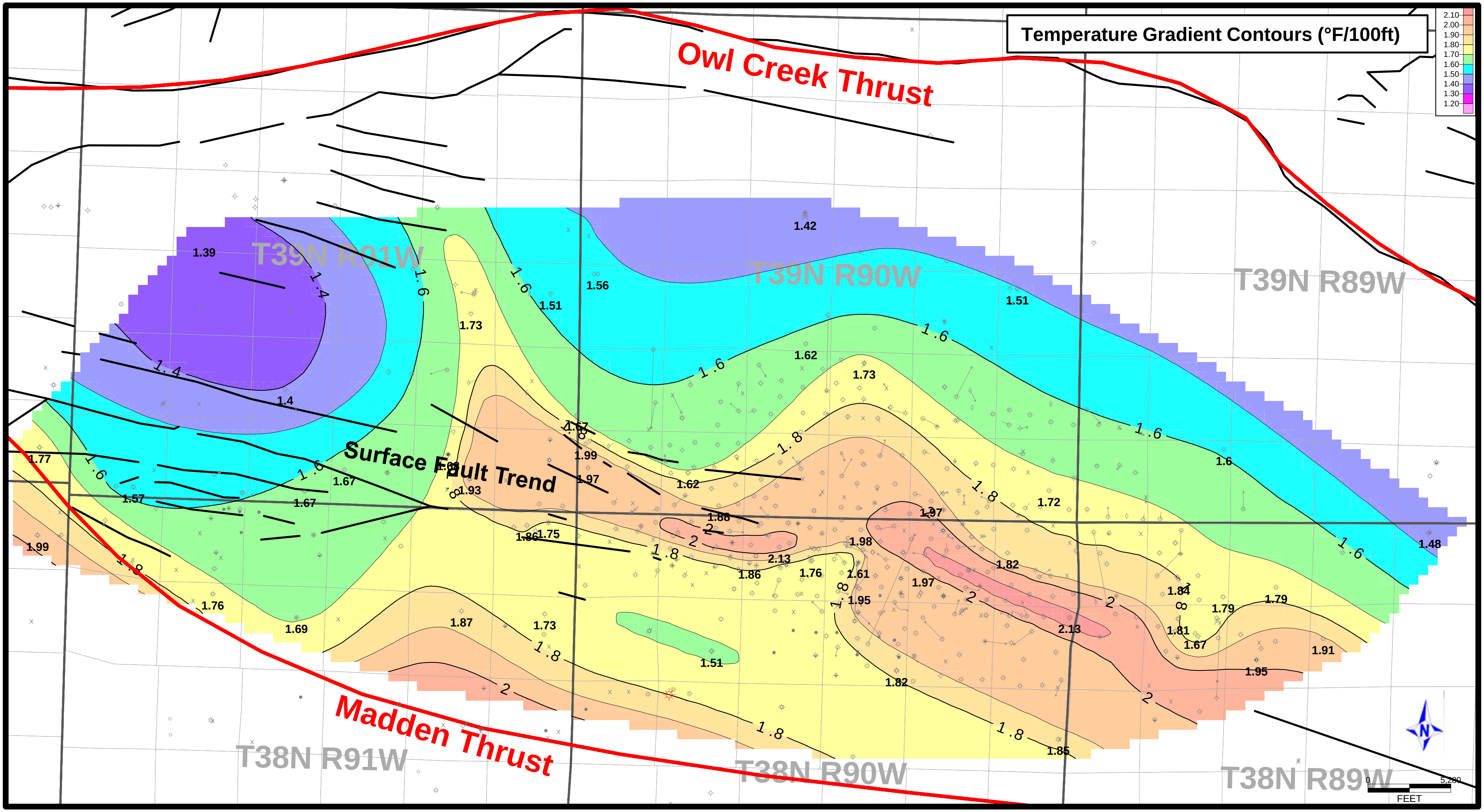


Frenchie Draw Temperature Gradient

Higher temperature gradients can be indicative of higher fluid flow associated with intense fracturing. At Frenchie Draw the higher gradients are along the margins of the field.



Madden Temperature Gradient



Conclusions

- Fractures from pre- to syn-Laramide strata indicate a single shortening direction resulting in orogenesis
- Fractures from post-Laramide strata indicate post-orogenic extension and collapse
- Fractured trends should be present along the margins of collapsed anticlines and be seismically identifiable
- Intensely fractured collapse trends will present drilling and completion difficulties
- Fractures increase the initial production rate significantly

Thank you!

Any Questions?

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Eric Erslev (thesis advisor), Dean DuBois (Encana), and many others whose comments were most helpful

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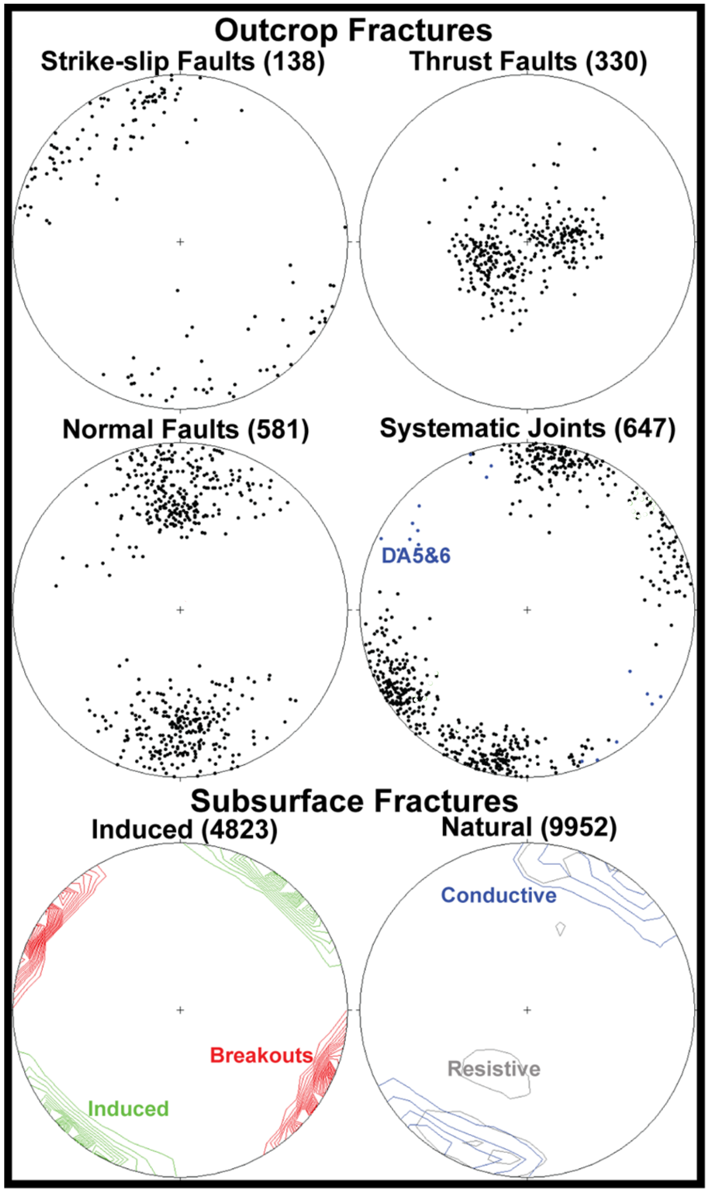
Complete Data Set



Additional Information

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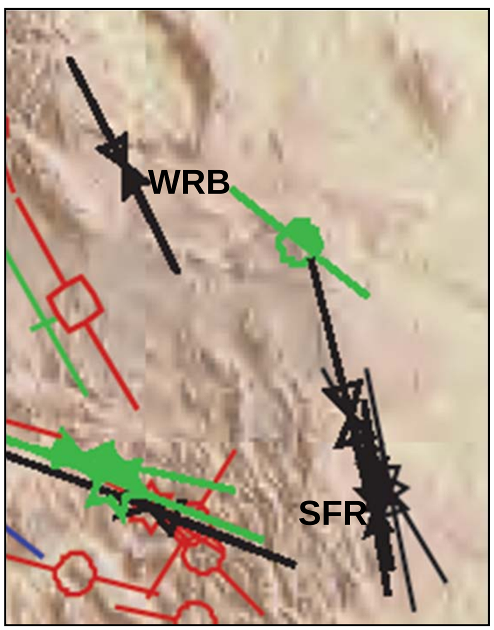
Other Potential Collapse: Southern Front Range

- **Also oblique to Laramide shortening, but N-S**
- **Induced fractures parallel arch margins (Heidbach *et al.*, 2009)**
- **Apatite Fission Track dating gives relative ages indicative of the margins of the SFR being structurally lower (Kelley & Chapin, 1997)**
- **Early mappers considered the SFR bounded by numerous normal faults (Richardson, 1915; Finlay, 1916)**
- **Sandstone dikes parallel Laramide, irregular arch-bounding faults (Harms, 1965)**



(Heidbach *et al.*, 2009)

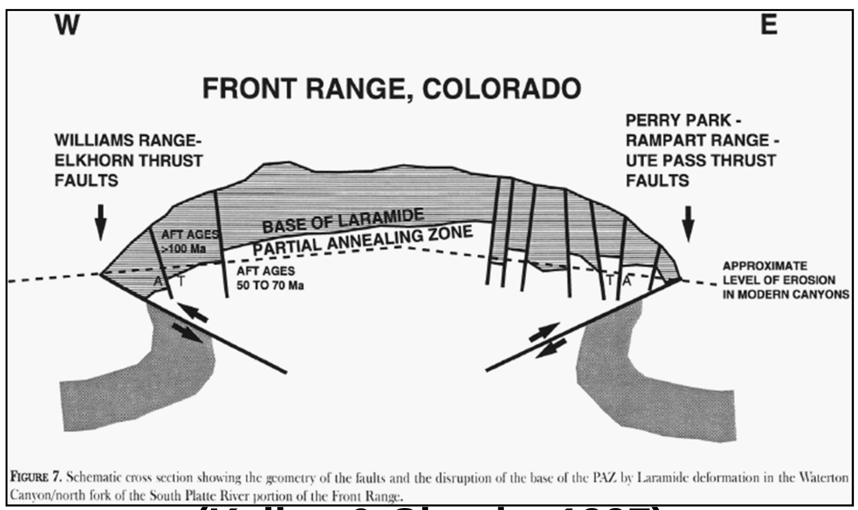
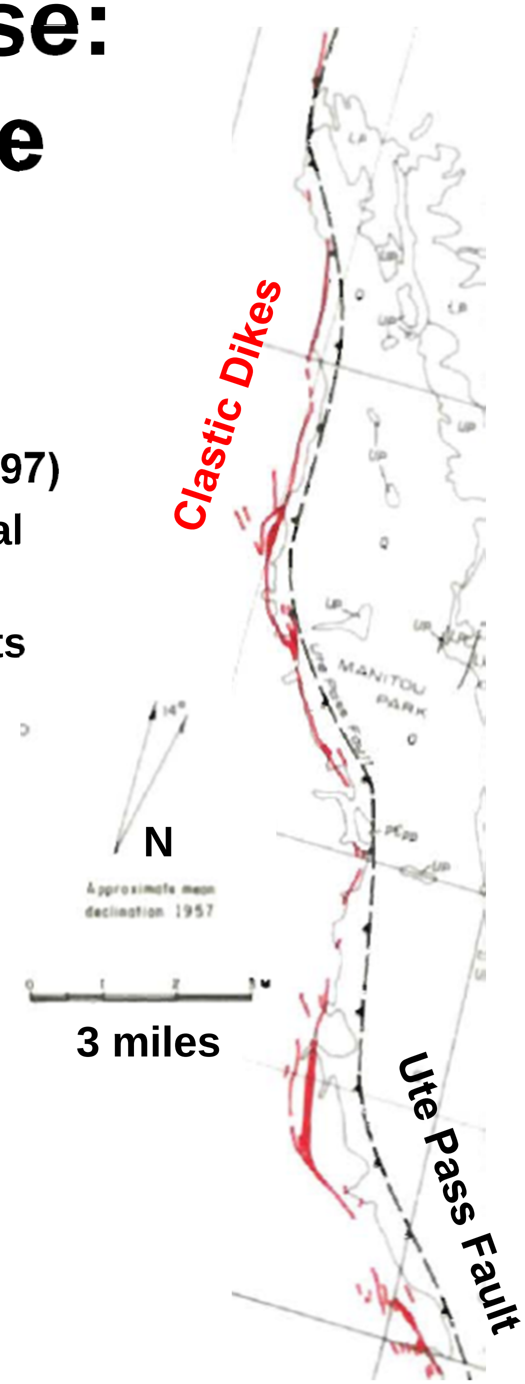


FIGURE 7. Schematic cross section showing the geometry of the faults and the disruption of the base of the PAZ by Laramide deformation in the Waterton Canyon/north fork of the South Platte River portion of the Front Range.

(Kelley & Chapin, 1997)



(Harms, 1965)