Kinematics of Laramide deformation and the influence of basement fabrics in the Black Hills uplift, South Dakota and Wyoming

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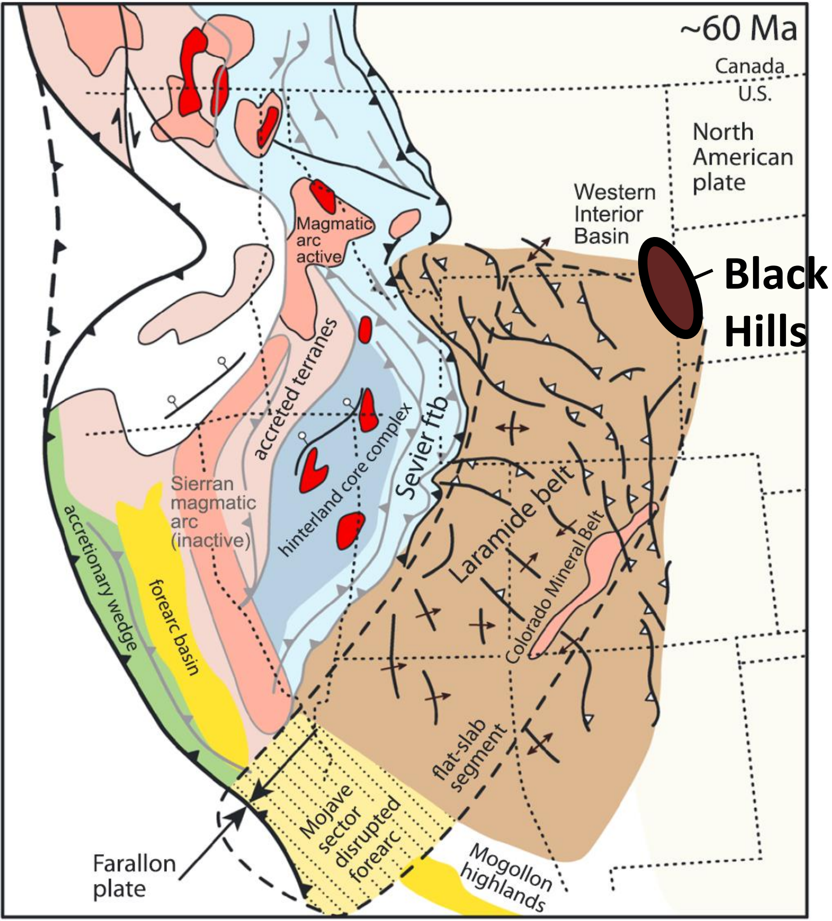
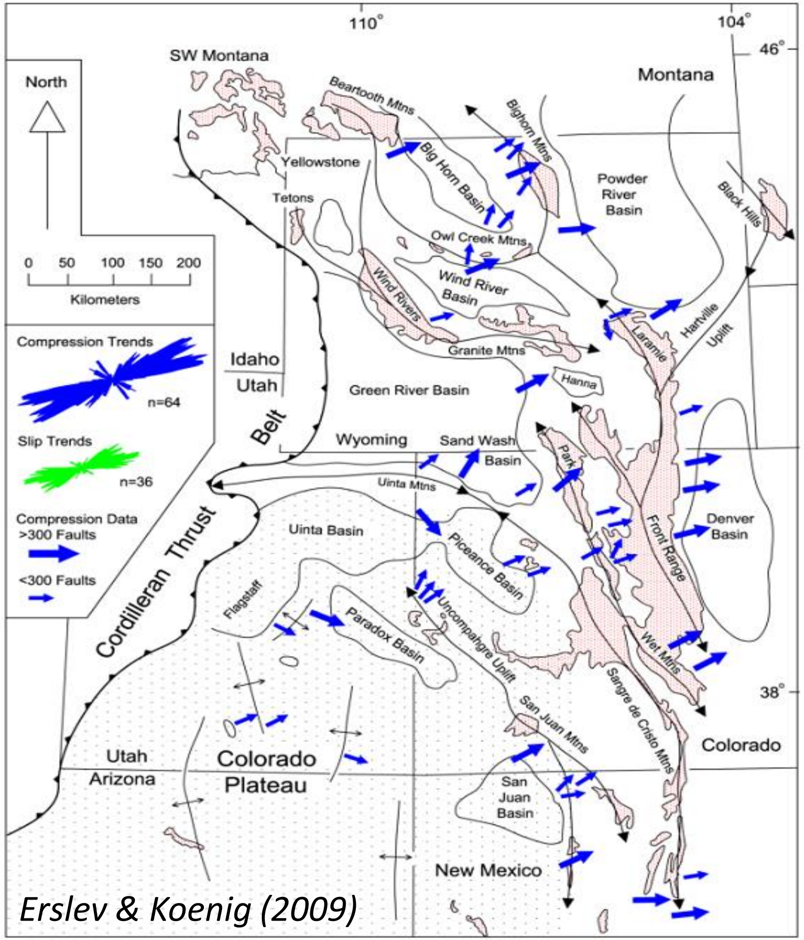
The Black Hills



Weil et al. (2016)

- NE-most basement-cored uplift, ~2000 km from trench!
- Phanerozoic strata overlying strongly deformed Precambrian metamorphic and igneous basement
- Basin sedimentation records initiation of uplift by 63-65 Ma, basement unroofing by 57 Ma, and a cessation of uplift by 37 Ma (Lisenbee and DeWitt, 1993).

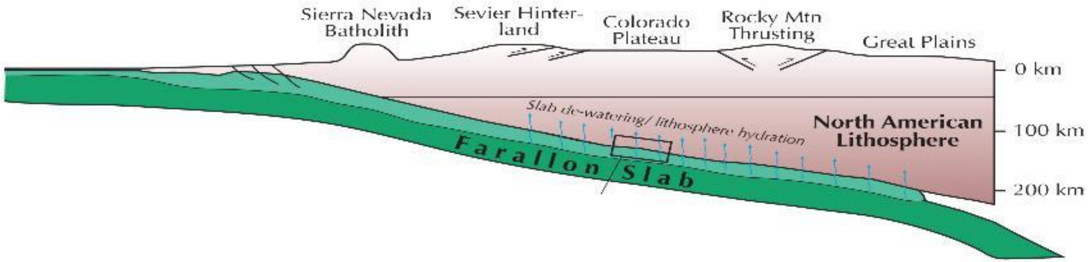
Project Introduction



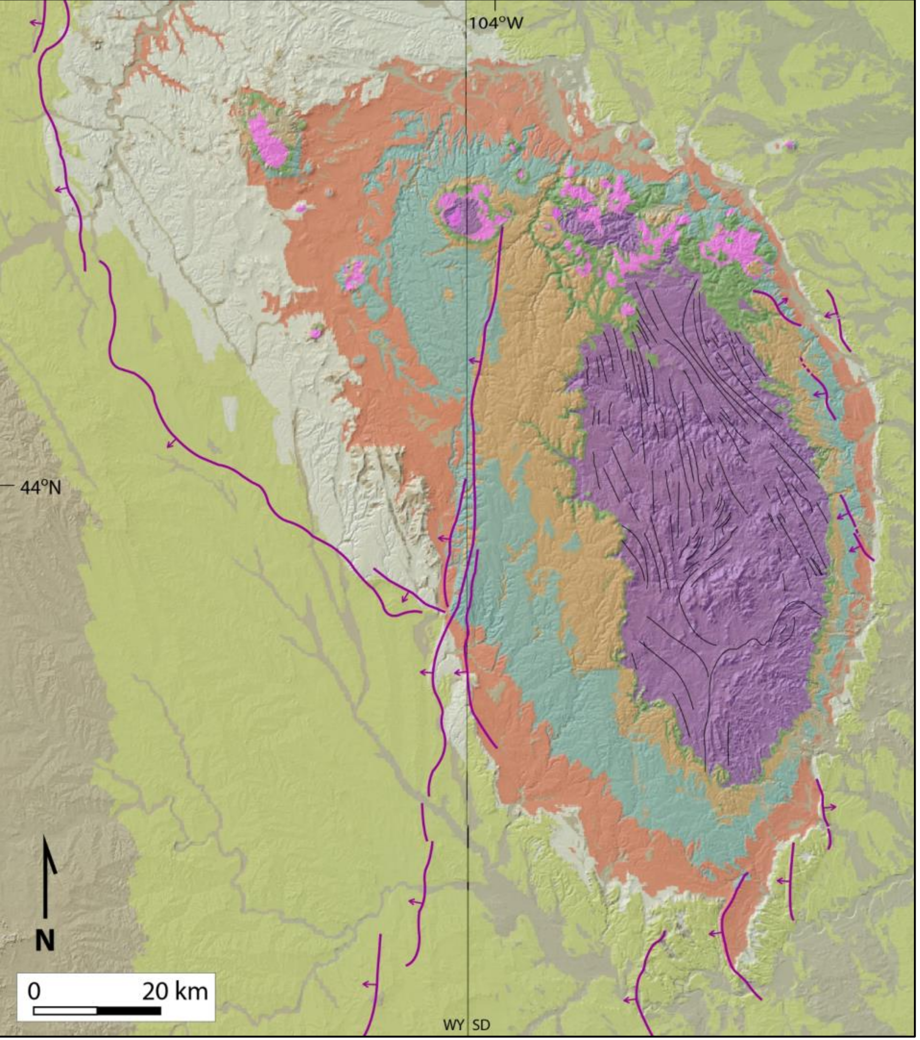
Erslev & Koenig (2009)

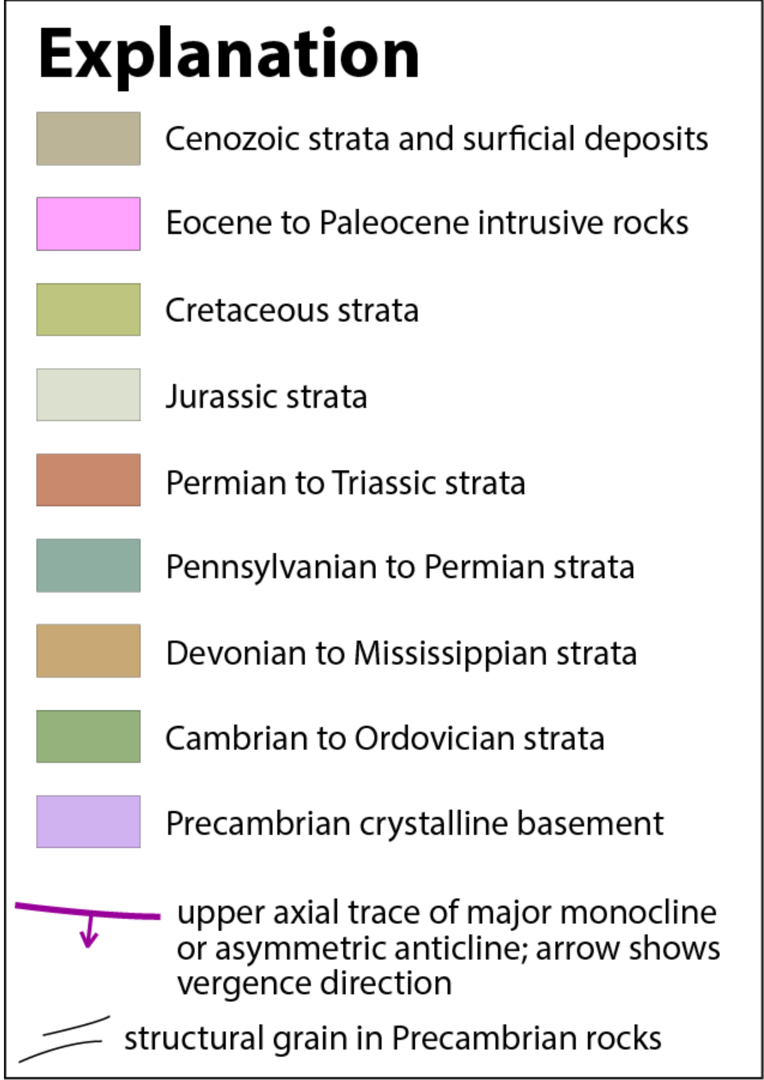
- Laramide flat slab subduction produced anomalous basement-cored uplifts far inboard of the trench

- Shortening directions across these uplifts are horizontal, NE-SW to E-W directed



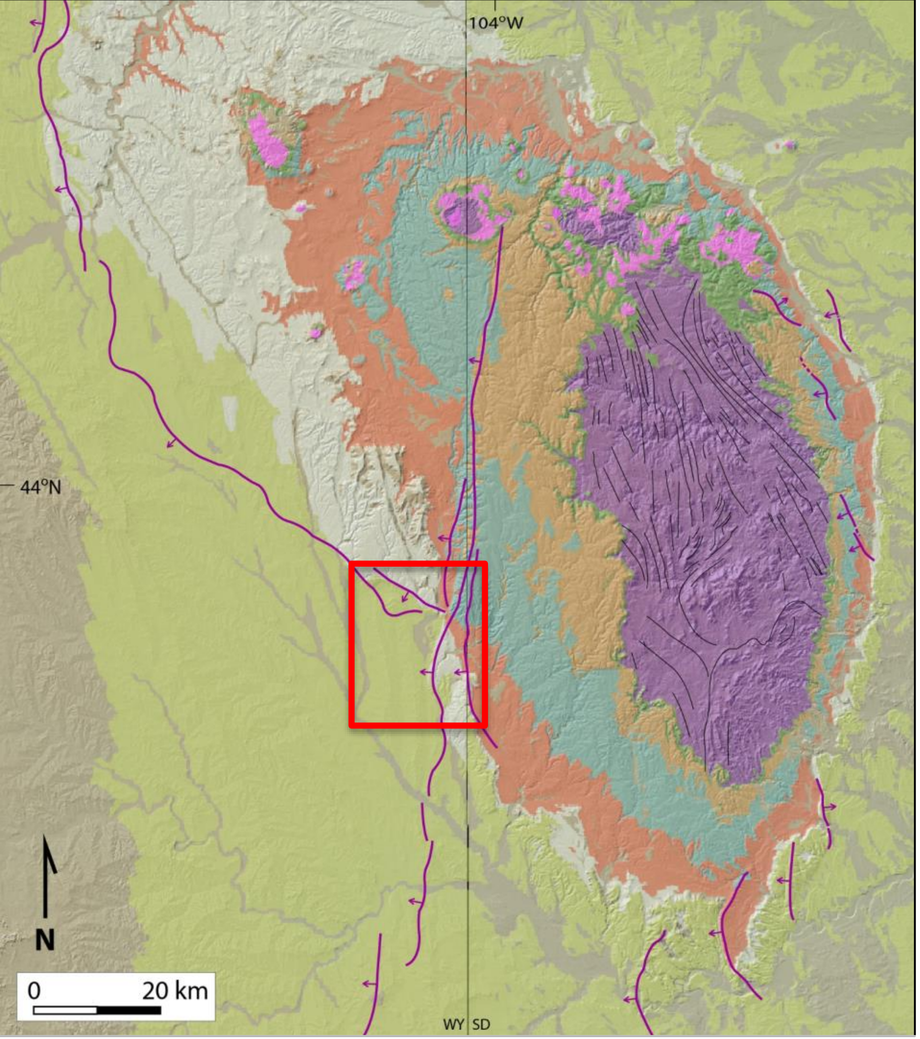
Humphreys et al. (2003)



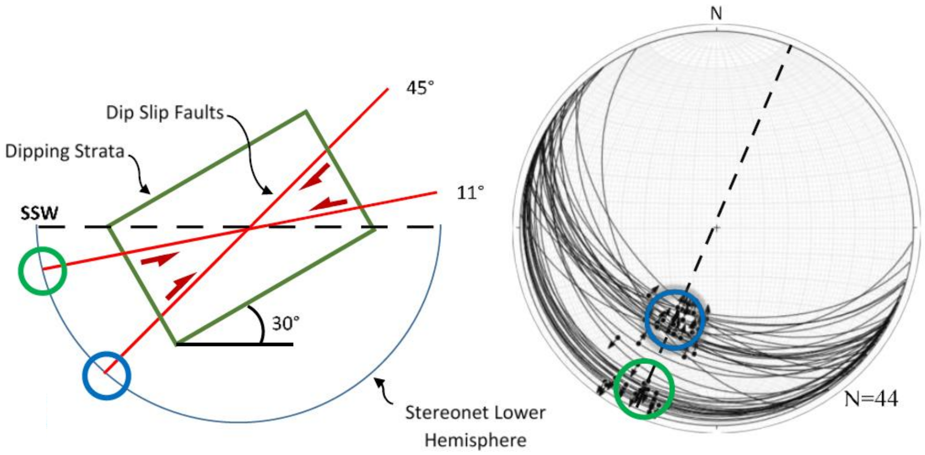


Simplified from Lisenbee (1985), DeWitt et al. (1989), and Redden and DeWitt (2008)

Previous Studies

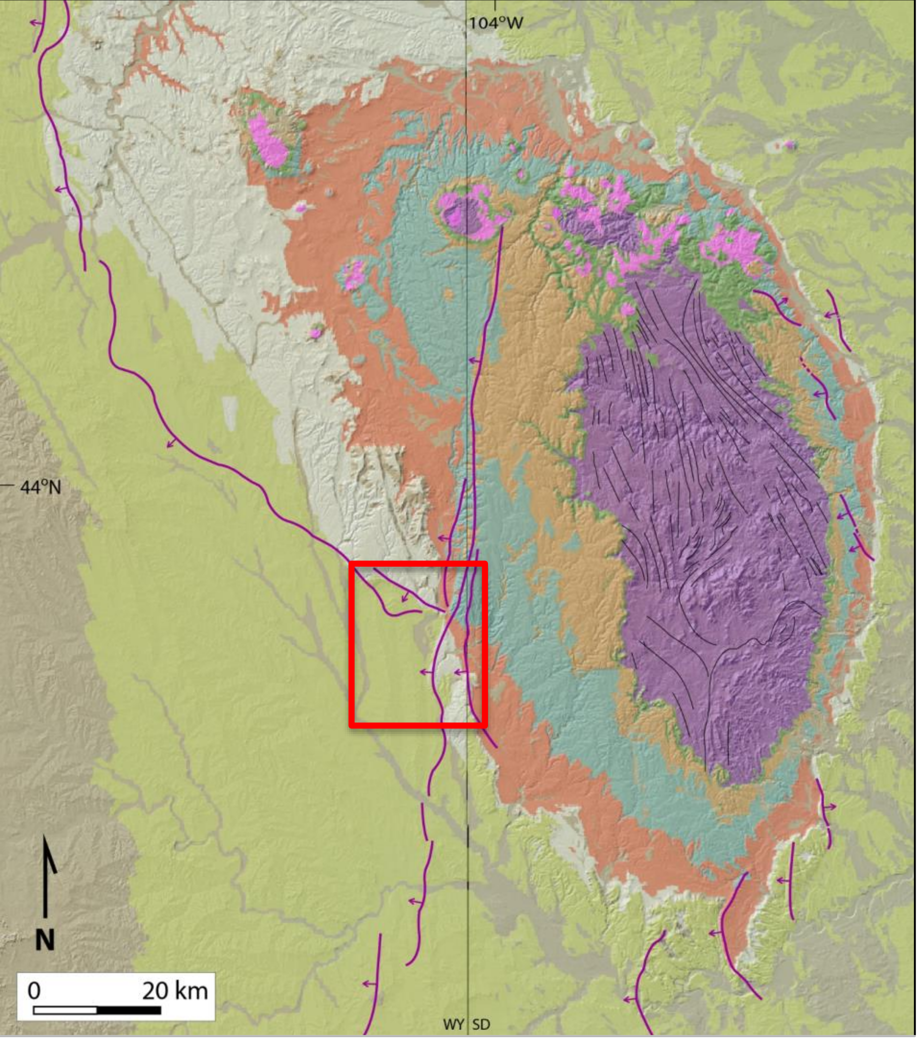


Simplified from Lisenbee (1985), DeWitt et al. (1989), and Redden and DeWitt (2008)

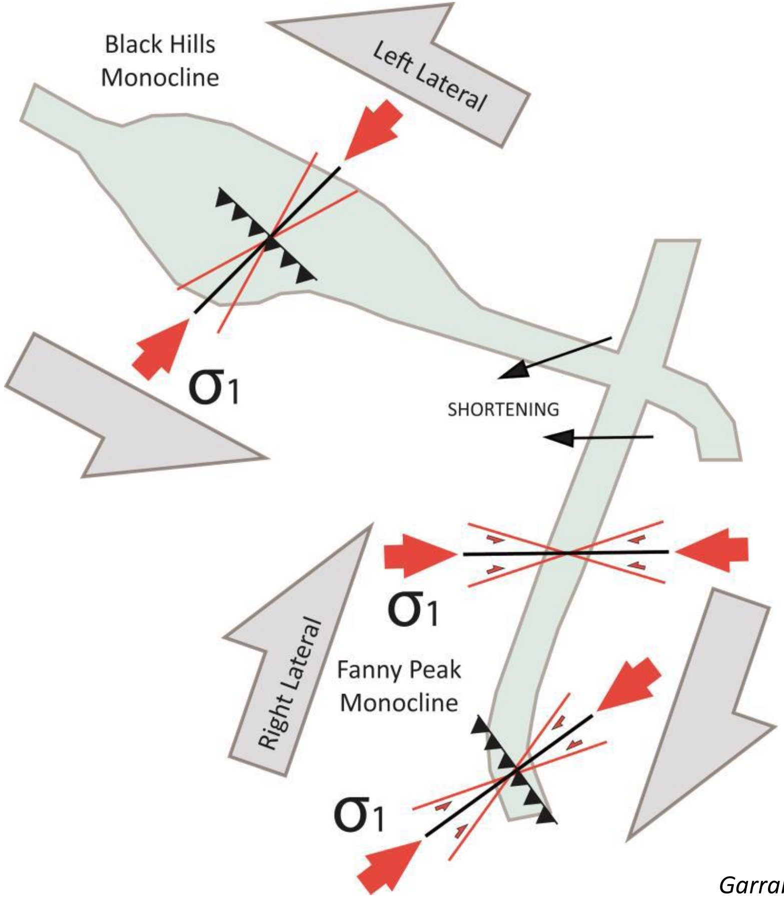


Garrand (2015)

Previous Studies



Simplified from Lisenbee (1985), DeWitt et al. (1989), and Redden and DeWitt (2008)

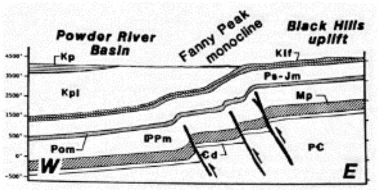


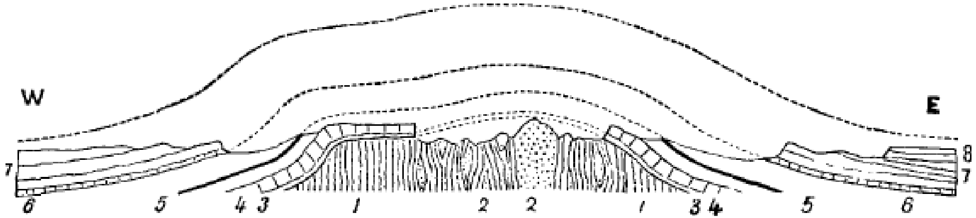
Garrand (2015)

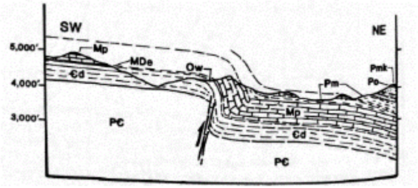
Project Goals

1) ***Document style of Laramide brittle deformation & shortening/extension directions in Phanerozoic strata surrounding the uplift.***

- ENE-directed subhorizontal shortening like CO & WY Rockies?
- Do we see spatial variability of shortening directions across the uplift?







Lisenbee (1988)

Project Goals

2) Evaluate role of Precambrian structures in Laramide deformation

- Were Precambrian fabrics reactivated as Laramide faults?
- Did Precambrian structures influence the location & geometry of the Laramide uplift?

Project Goals

3) ***Determine timing of Laramide uplift & magnitude of exhumation using low-T thermochronology***

Prior et al. presentation tomorrow morning.

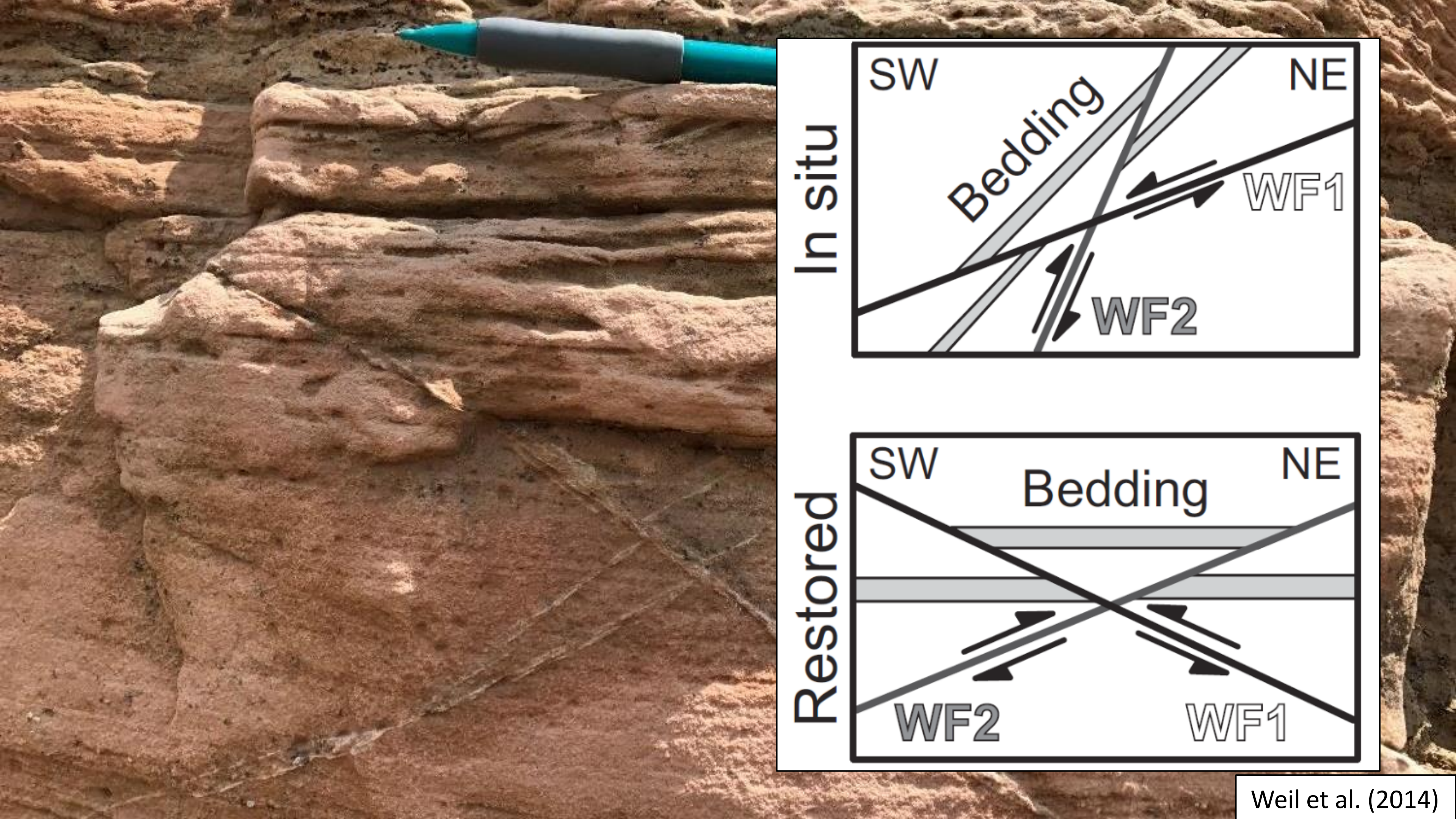
httpblog.delamomotorsports.com201308sturgis-2013-august-5th-10th.html

Brittle faulting in sedimentary strata

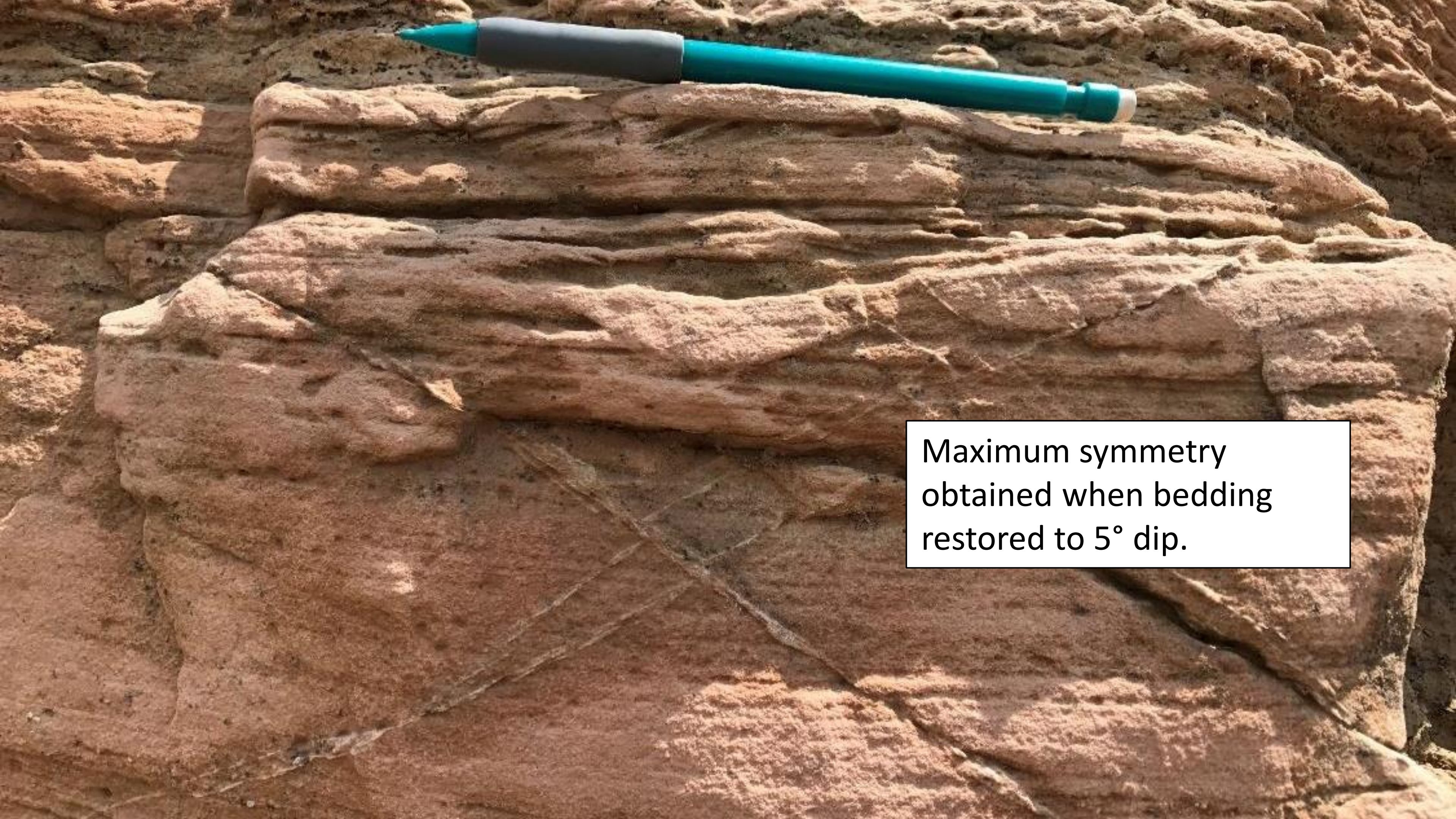
Brittle faulting in sedimentary strata

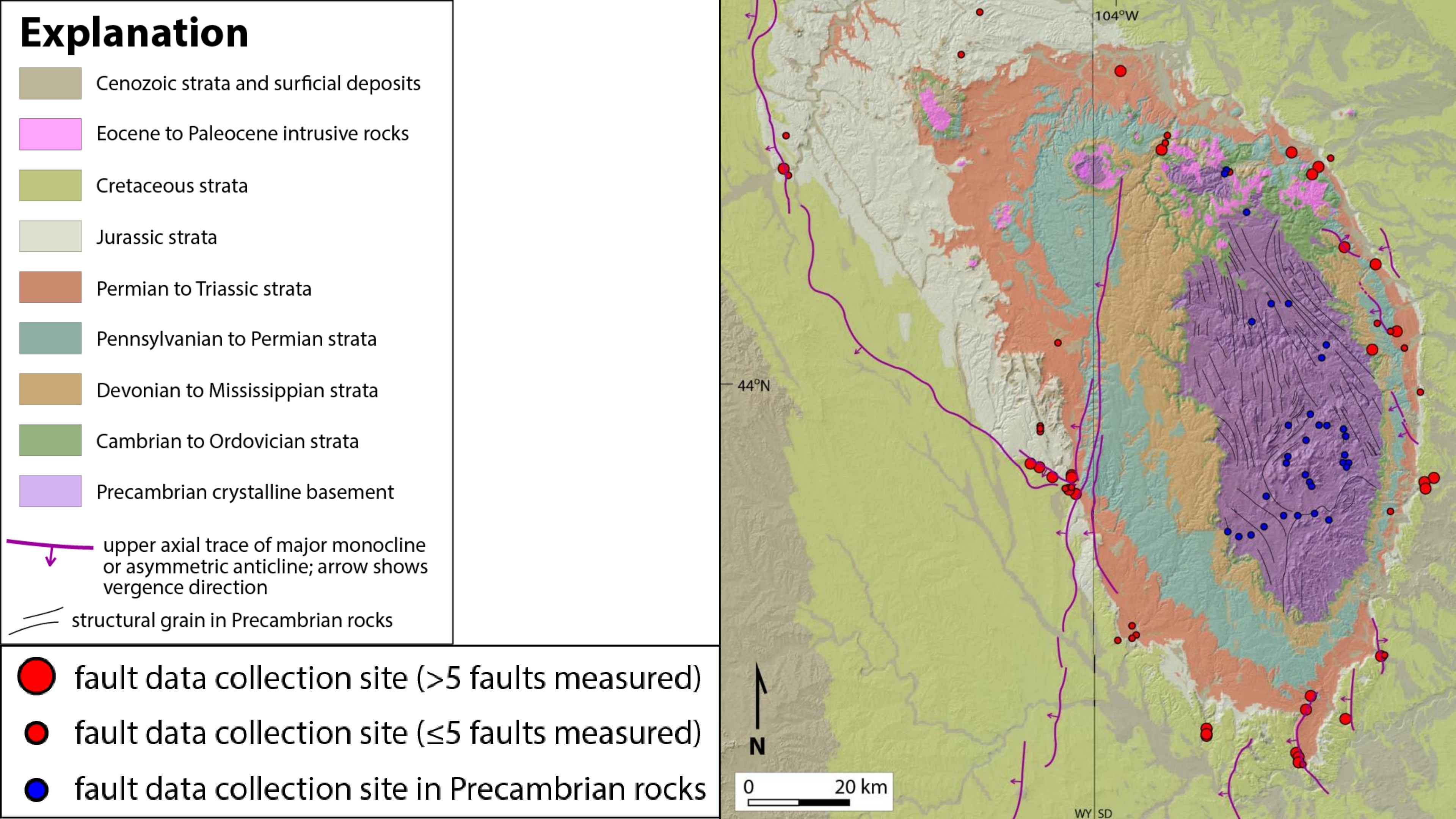
We focused brittle measurements in Mesozoic strata for several reasons:

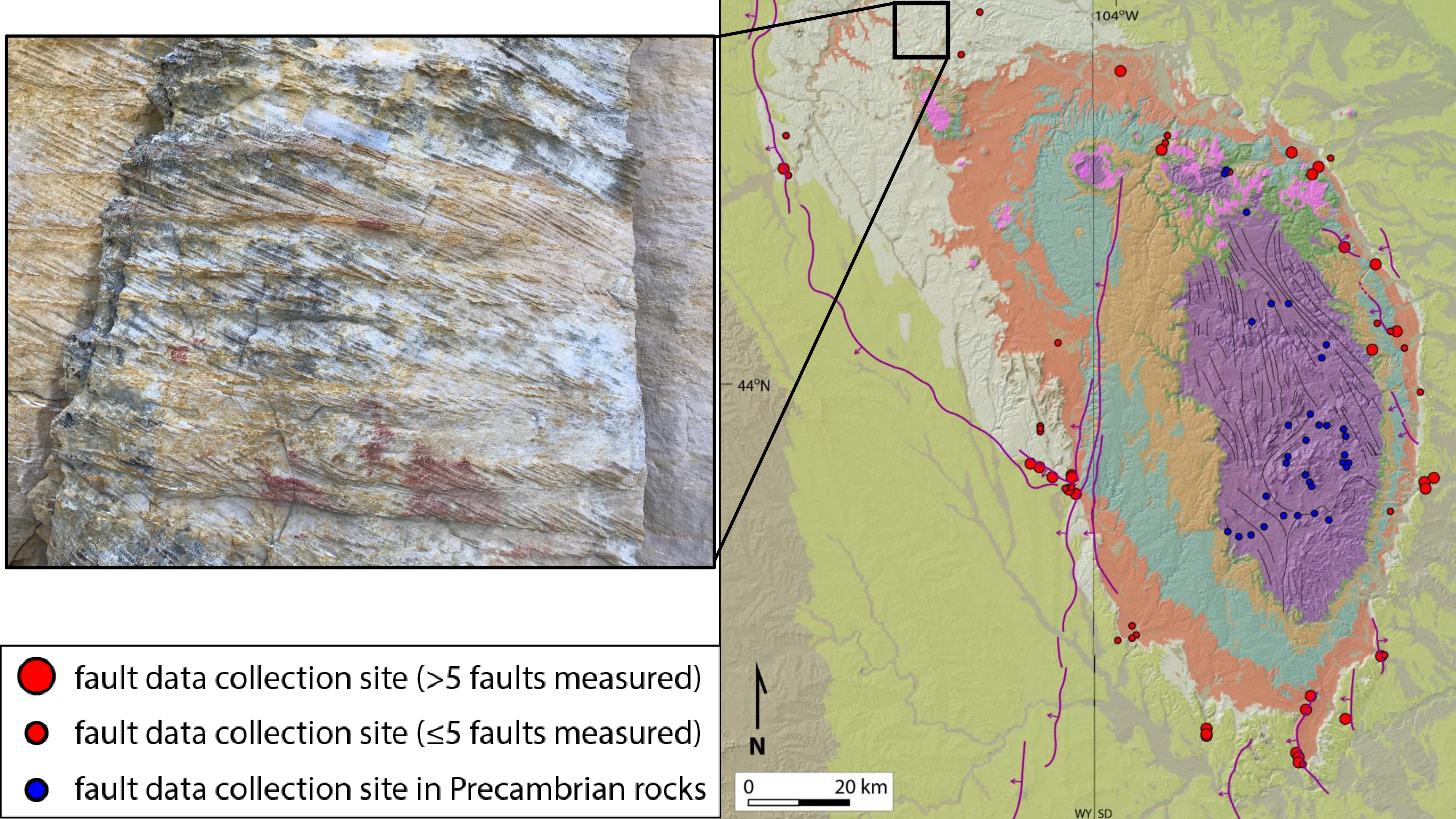
- To remove any possible complexities with inherited pre-Cretaceous deformation fabrics (e.g.: Ancestral Rocky Mountain orogeny).
- Mesozoic units provide several well-indurated strata that preserve brittle faults.



Weil et al. (2014)


Maximum symmetry obtained when bedding restored to 5° dip.


Explanation
Cenozoic strata and surficial deposits
Eocene to Paleocene intrusive rocks
Cretaceous strata
Jurassic strata
Permian to Triassic strata
Pennsylvanian to Permian strata
Devonian to Mississippian strata
Cambrian to Ordovician strata
Precambrian crystalline basement
upper axial trace of major monocline or asymmetric anticline; arrow shows vergence direction
structural grain in Precambrian rocks
fault data collection site (>5 faults measured)
fault data collection site (≤5 faults measured)
fault data collection site in Precambrian rocks
104°W
44°N
N
0
20 km
WY
SD



fault data collection site (>5 faults measured)
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fault data collection site in Precambrian rocks
104°W
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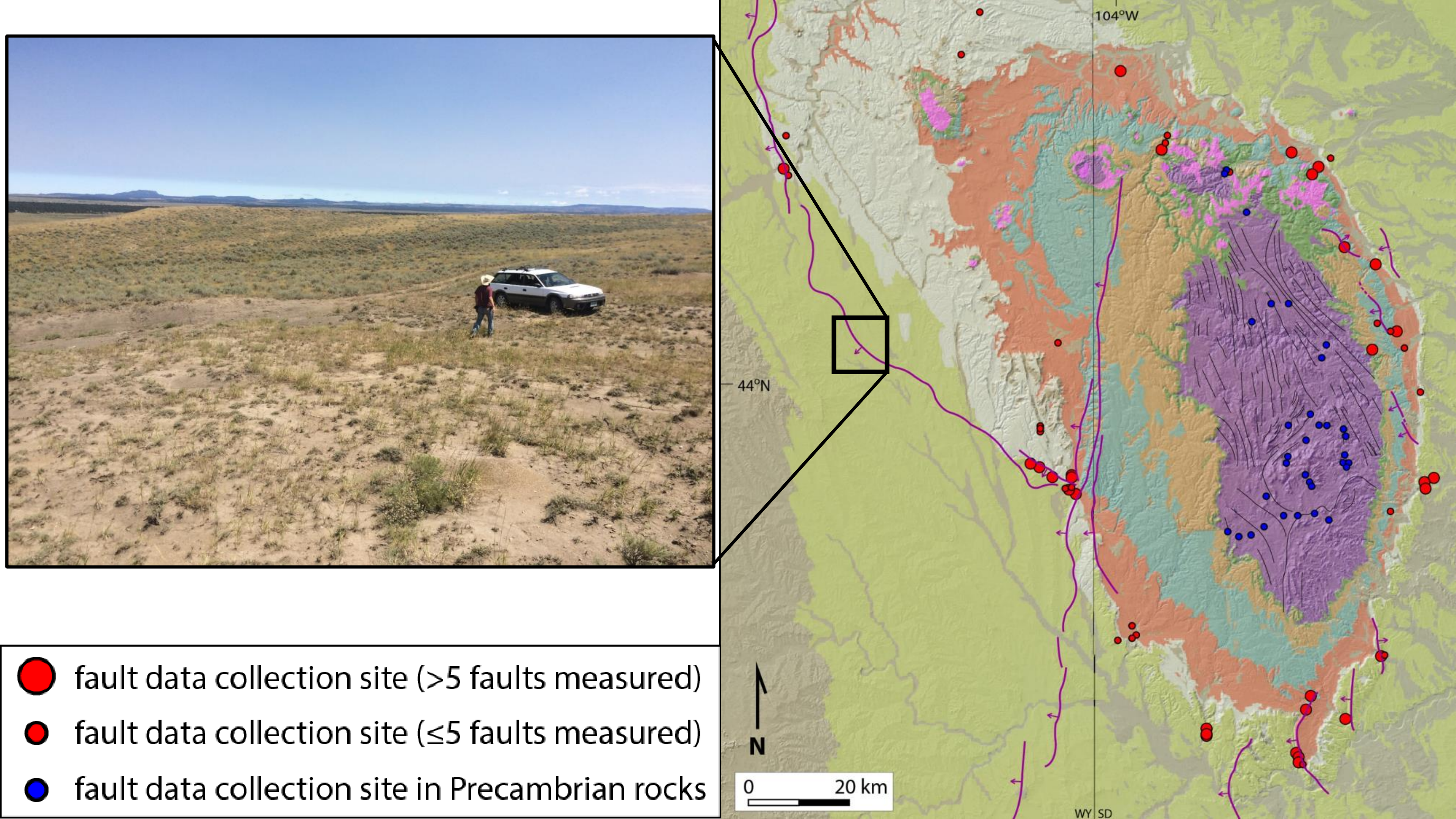
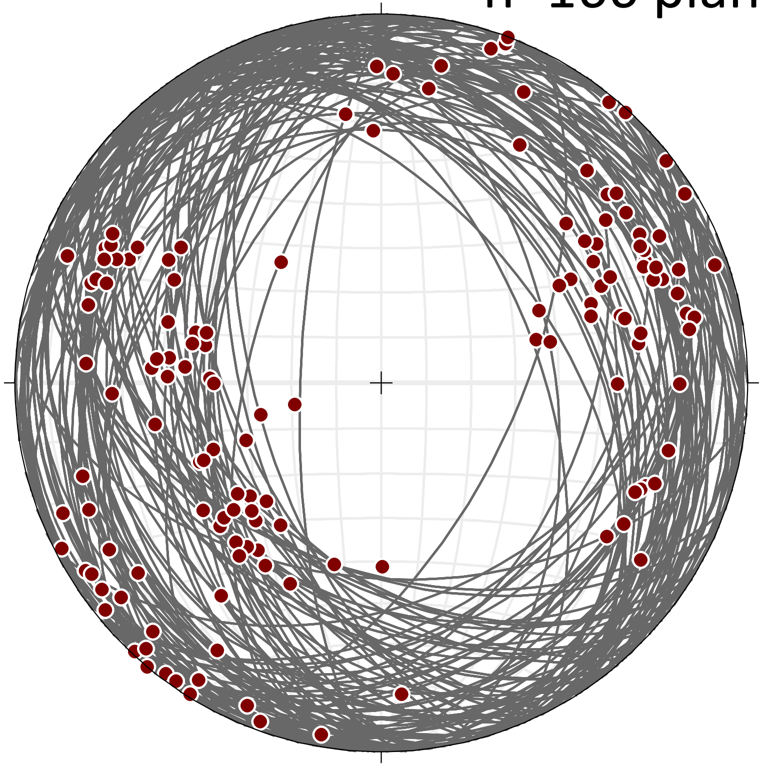


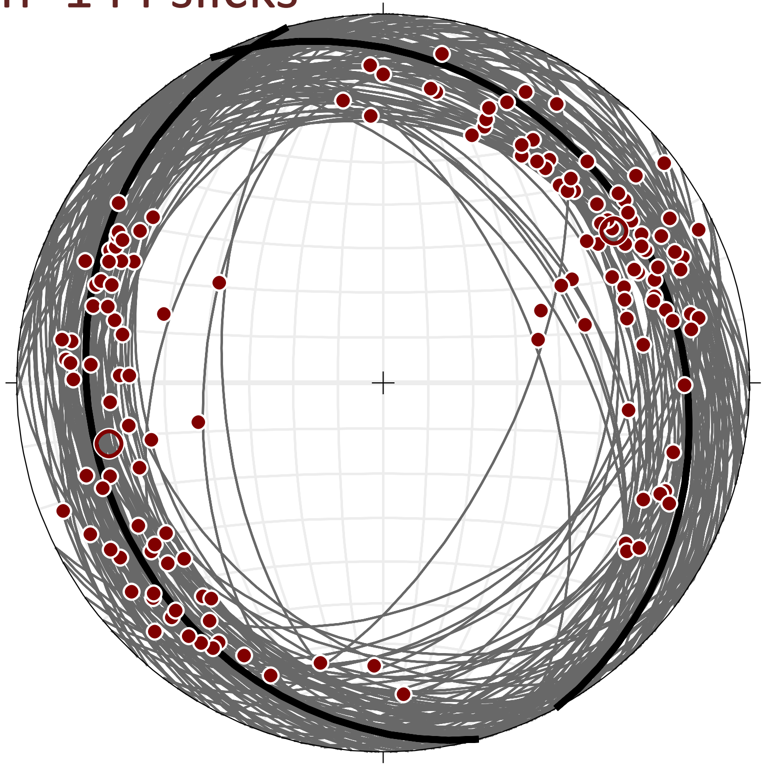
104°W
44°N
N
0
20 km
WY
SD
fault data collection site (>5 faults measured)
fault data collection site (≤5 faults measured)
fault data collection site in Precambrian rocks

Thrust Faults

All fault planes and slickenlines.
n=166 planes, n=144 slicks



No rotation



Bedding rotated to 5° dip

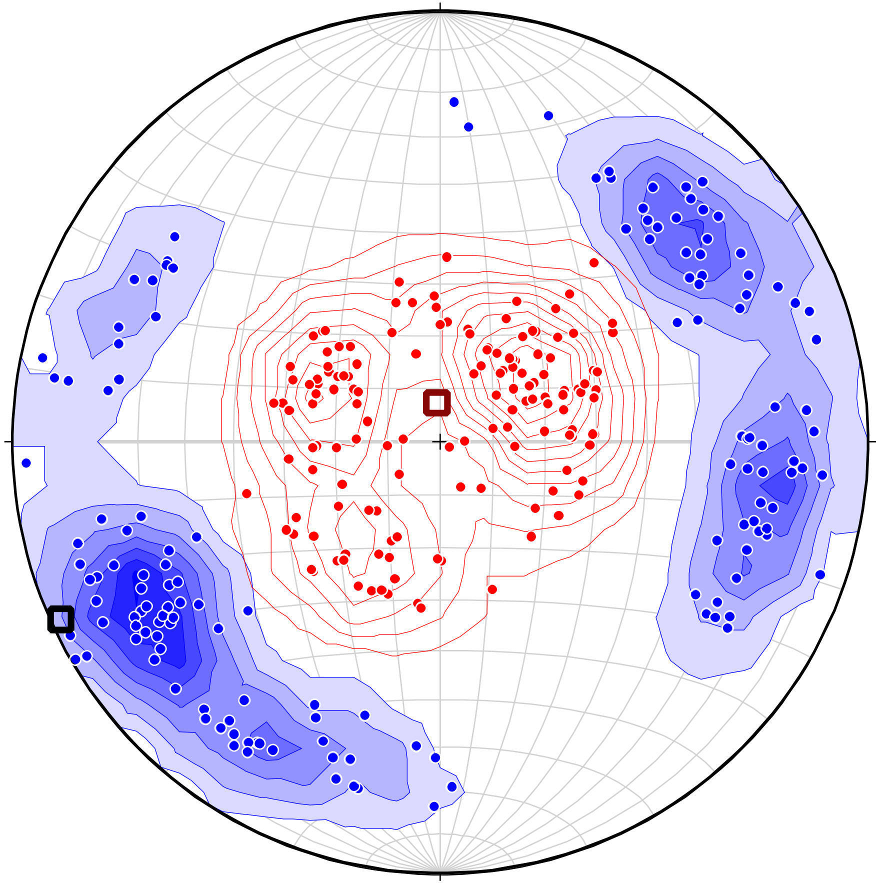
Thrust Faults

Shortening and extension axes
for all rotated thrust faults.

Linked Bingham mean
shortening axis: 245/02

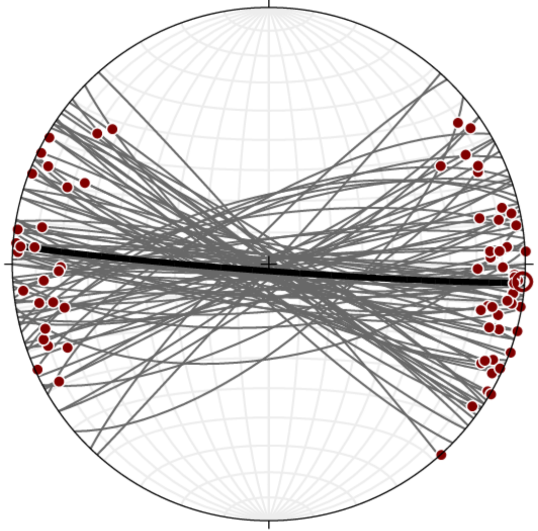
Mean extension axis: 354/83

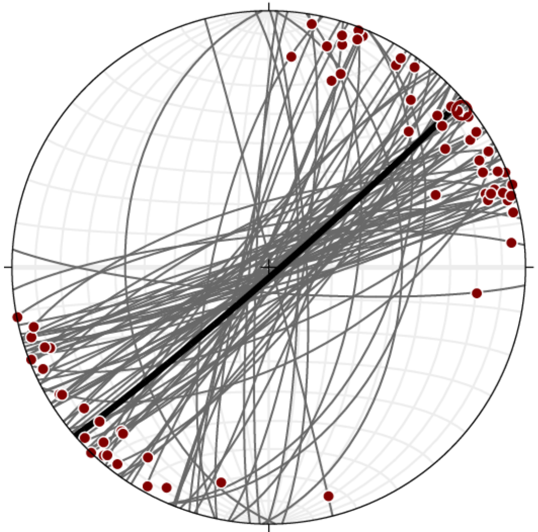
Average conjugate planes:
322/20 NE and 165/21 SW



Bedding rotated to 5° dip

Strike-Slip Faults





Right-lateral (top, n=87 planes) and left-lateral (bottom, n= 80 planes) with slickenlines.

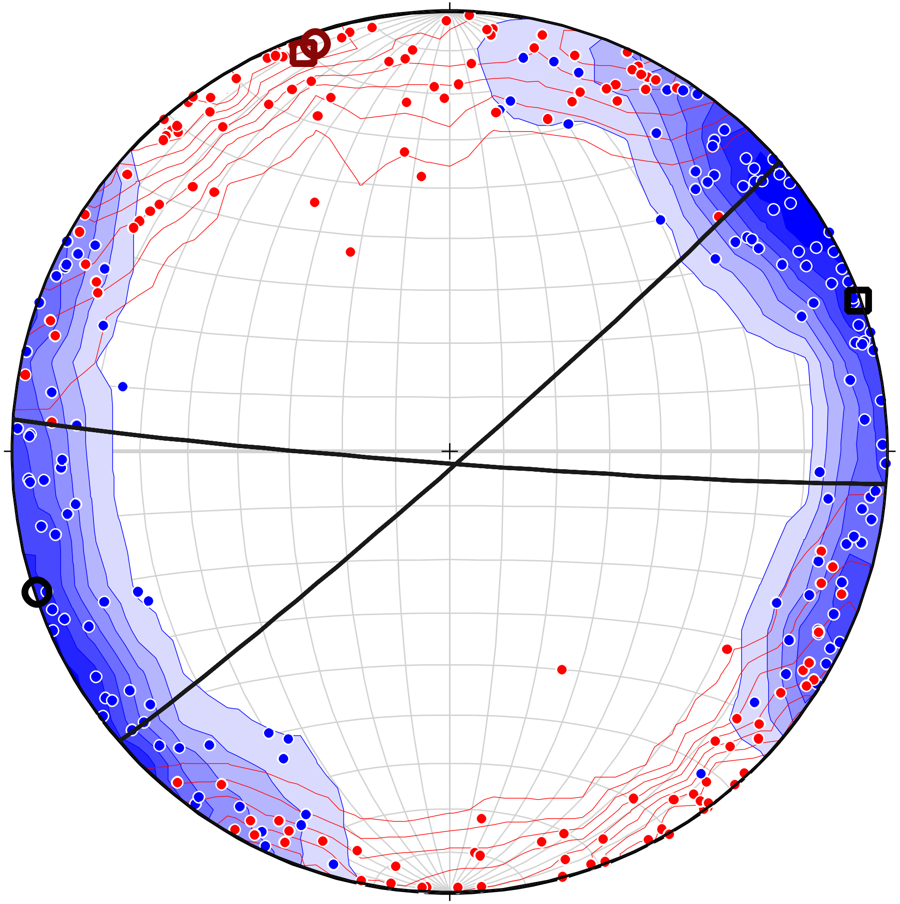
Bedding rotated to 5° dip

Strike-Slip Faults

Shortening and extension axes for all rotated strike-slip faults.

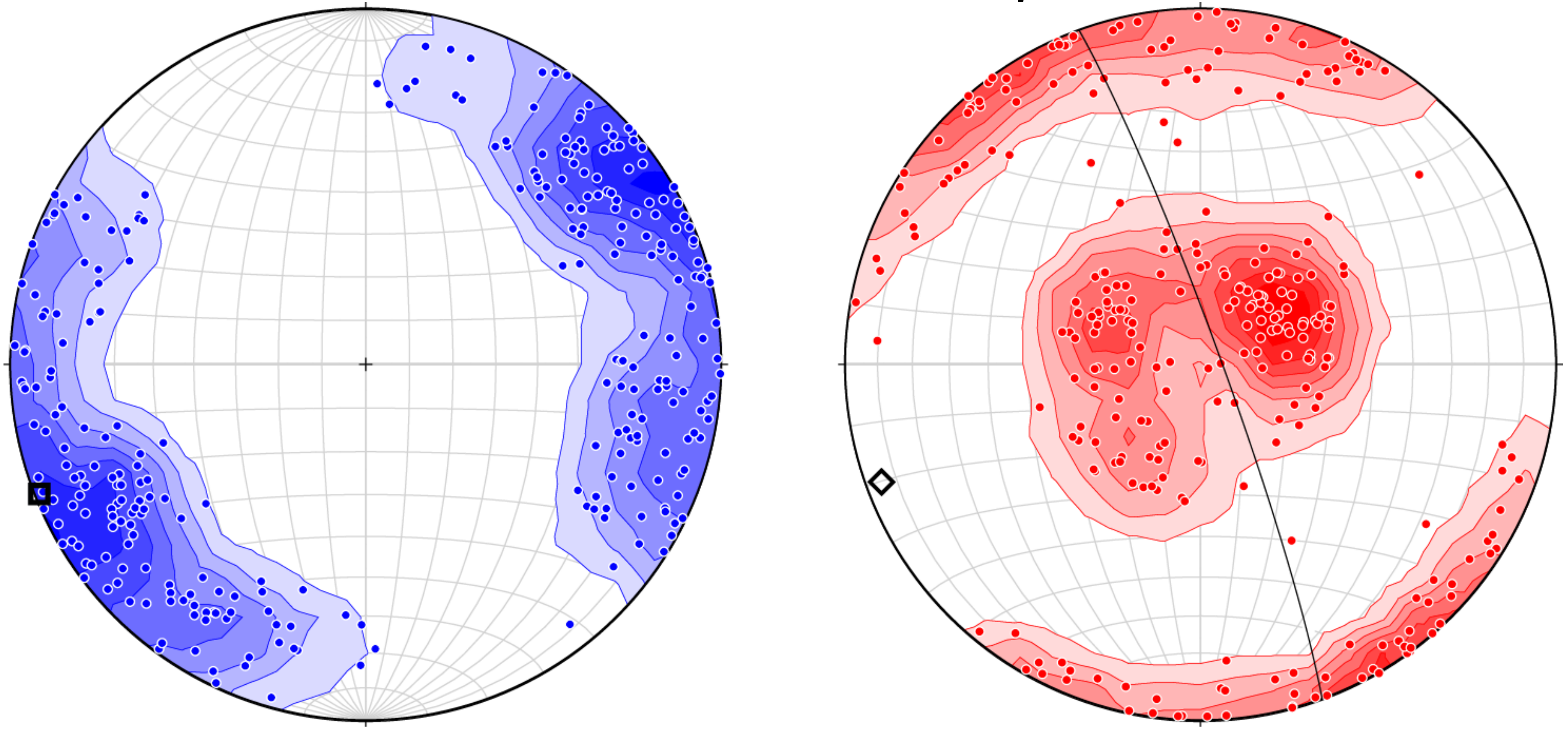
Linked Bingham mean shortening axis: 070/01

Acute bisector to average conjugate planes: 252/00



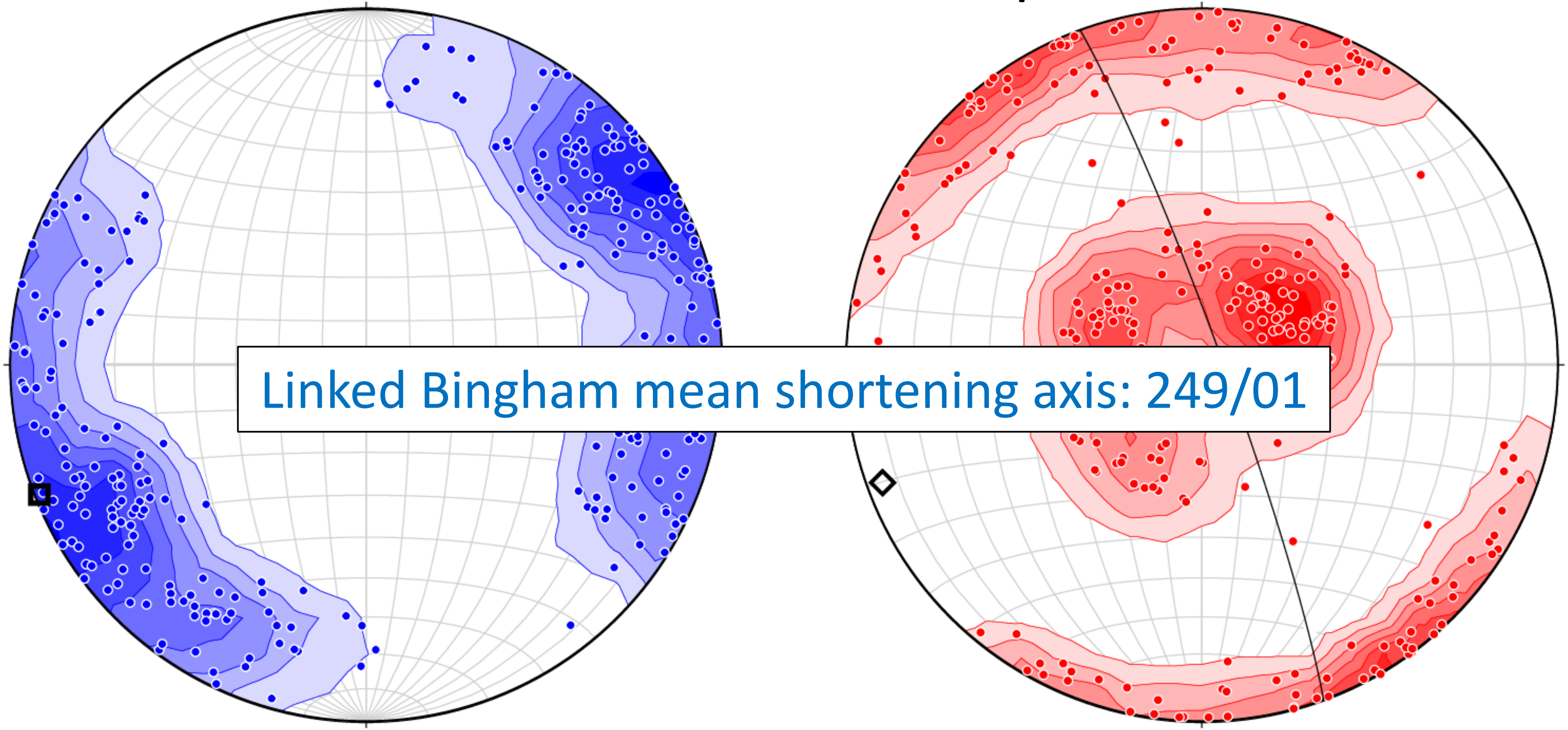
Bedding rotated to 5° dip

Thrust and Strike-Slip Faults



Shortening axes and extension axes for all strike-slip and thrust faults with slickenlines. Bedding rotated to 5°.

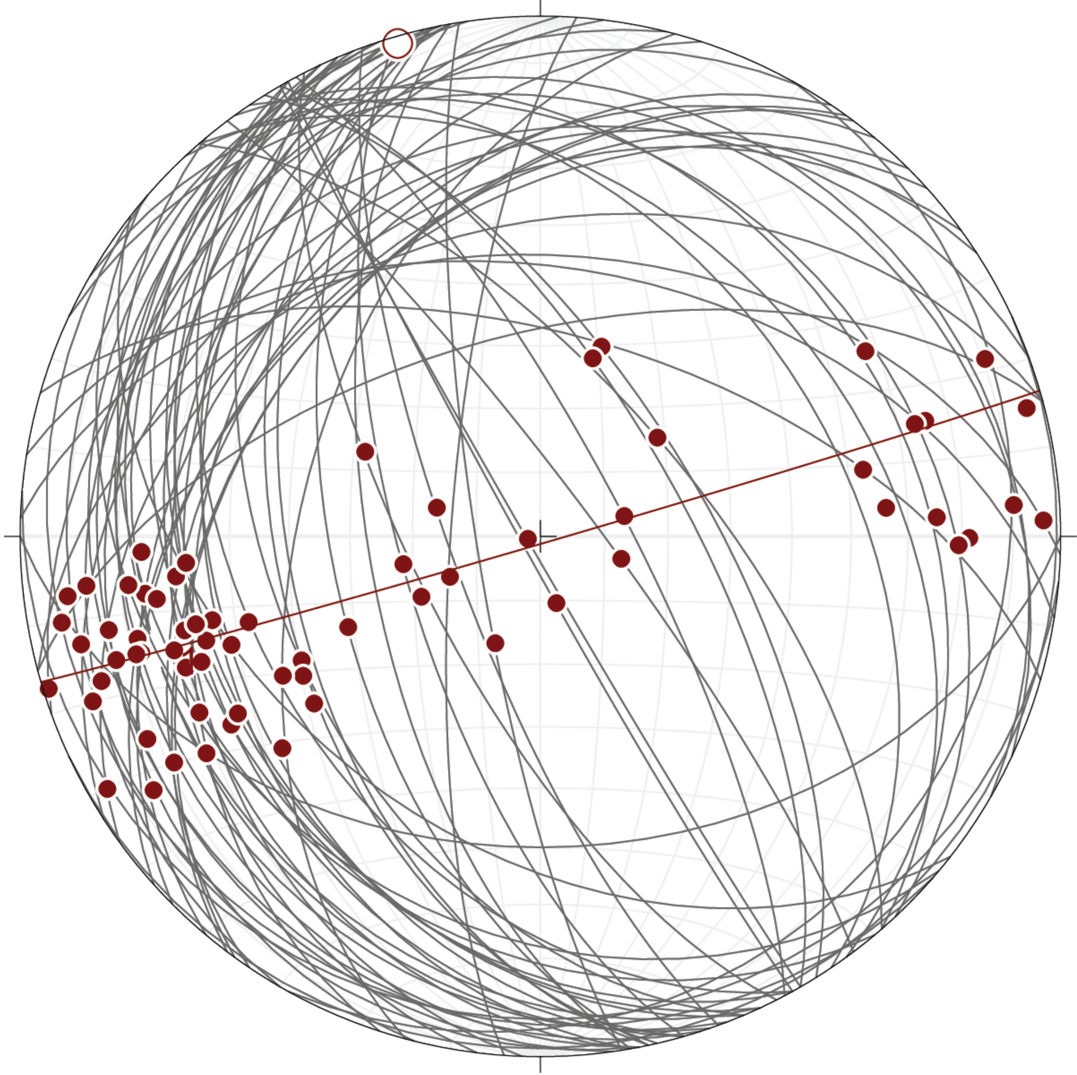
Thrust and Strike-Slip Faults

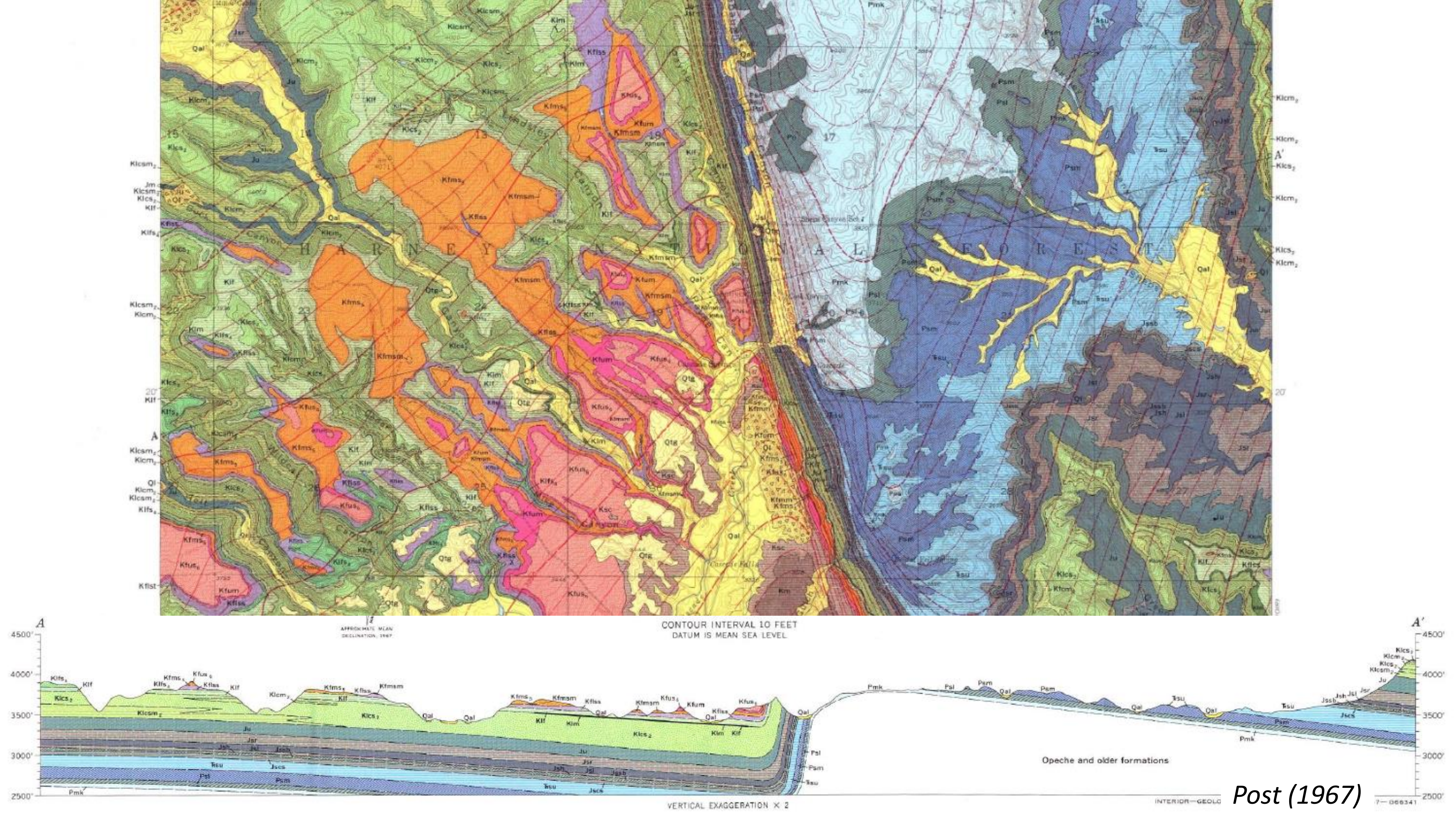


Shortening axes and extension axes for all strike-slip and thrust faults with slickenlines. Bedding rotated to 5°.

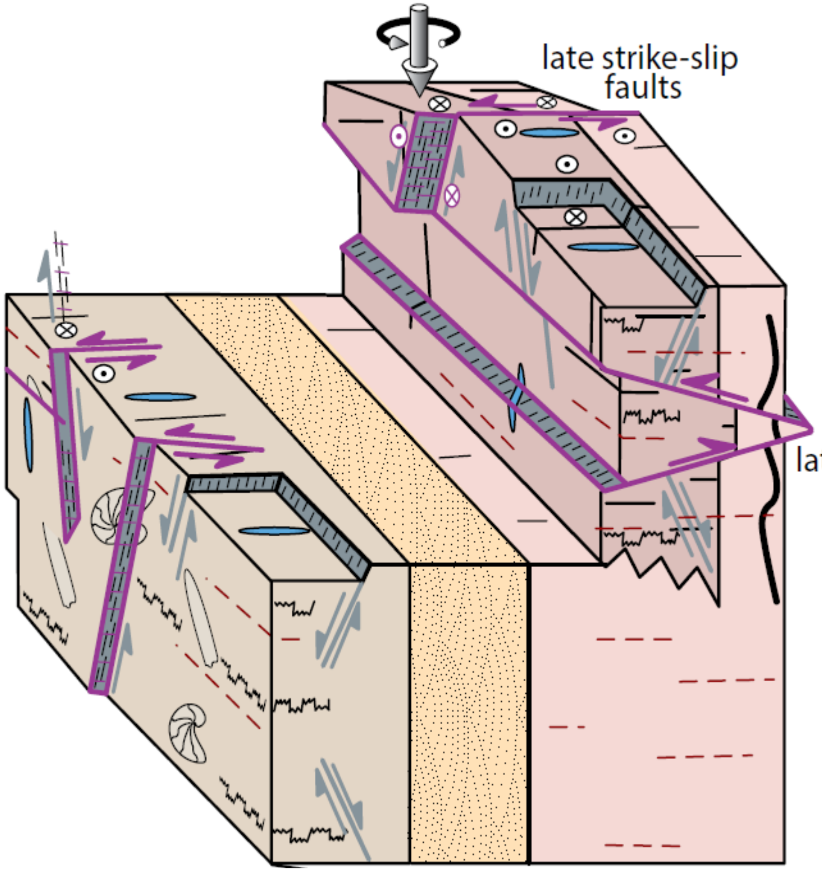
Faults in Steeply dipping strata (>50°)

All fault planes and slickenlines, no rotation.
n=66

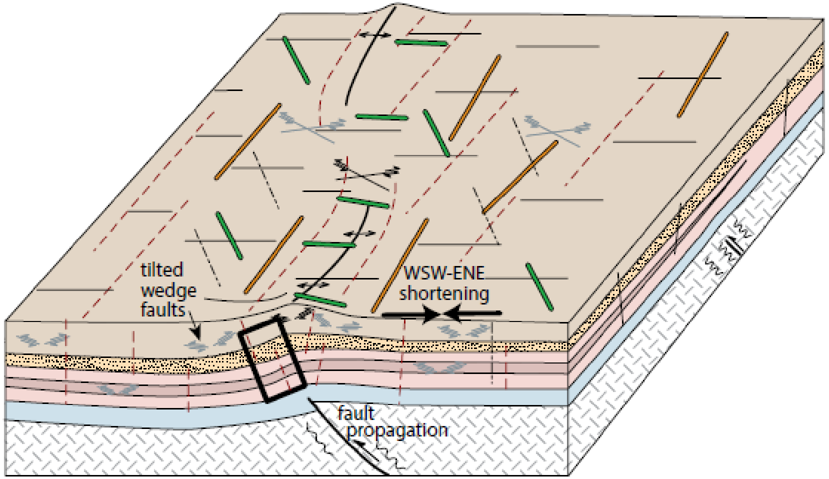



H A R N E Y N A T I O N A L F O R E S T
A
A'
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
APPROXIMATE MEAN DECLINATION, 1967
Opeche and older formations
VERTICAL EXAGGERATION X 2
4500'
4000'
3500'
3000'
2500'

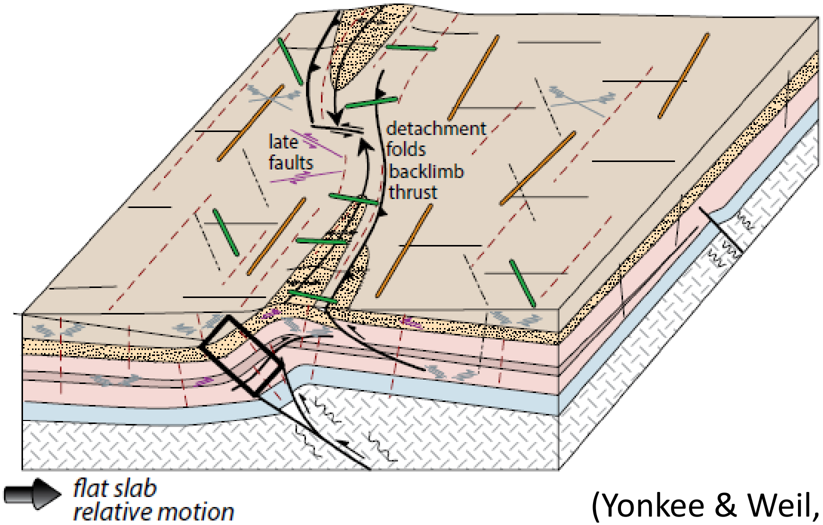
Post (1967)



(iiia) late Laramide: large-scale folding, fault propagation



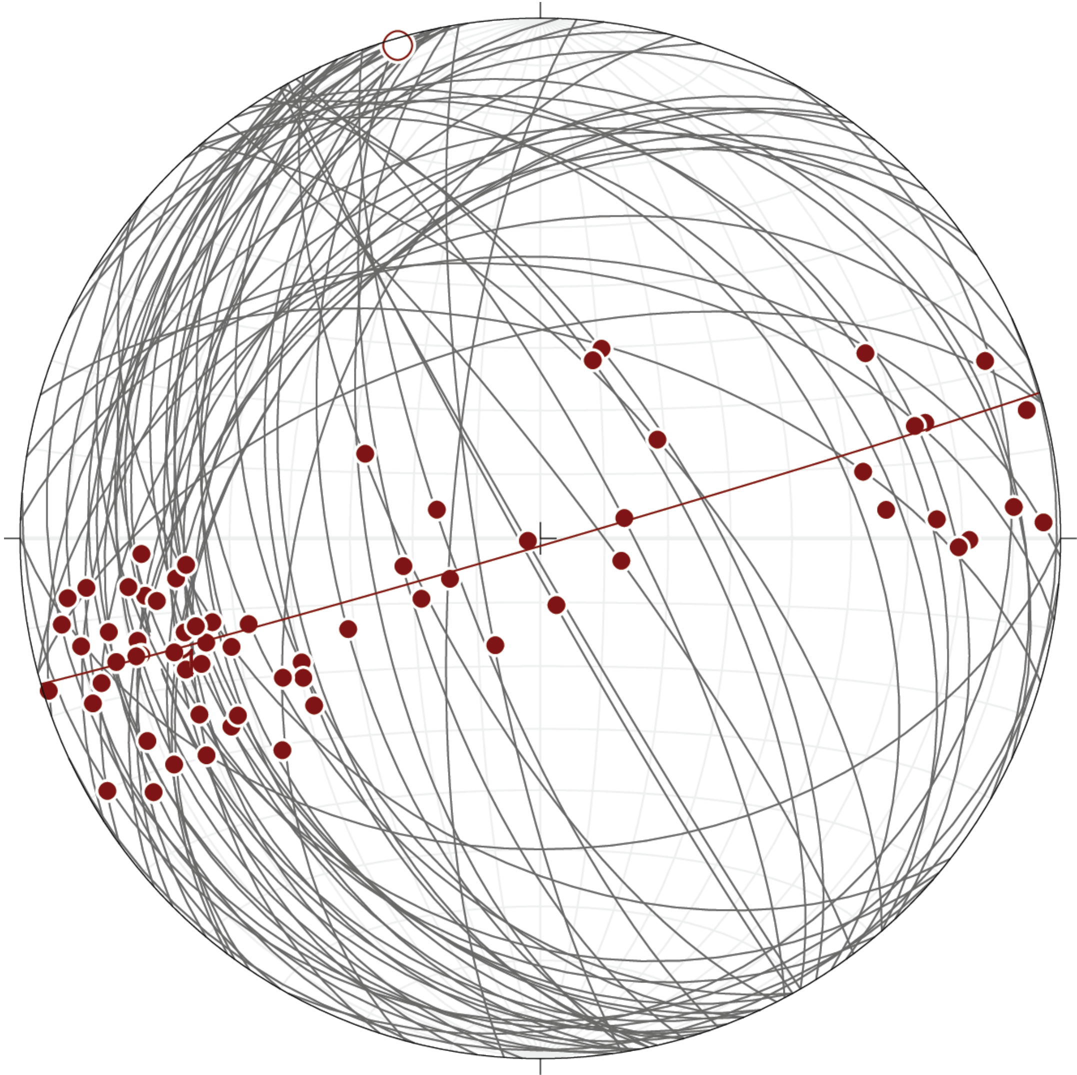
(iiib) late Laramide: fold tightening, fault linkage



(Yonkee & Weil, 2017)

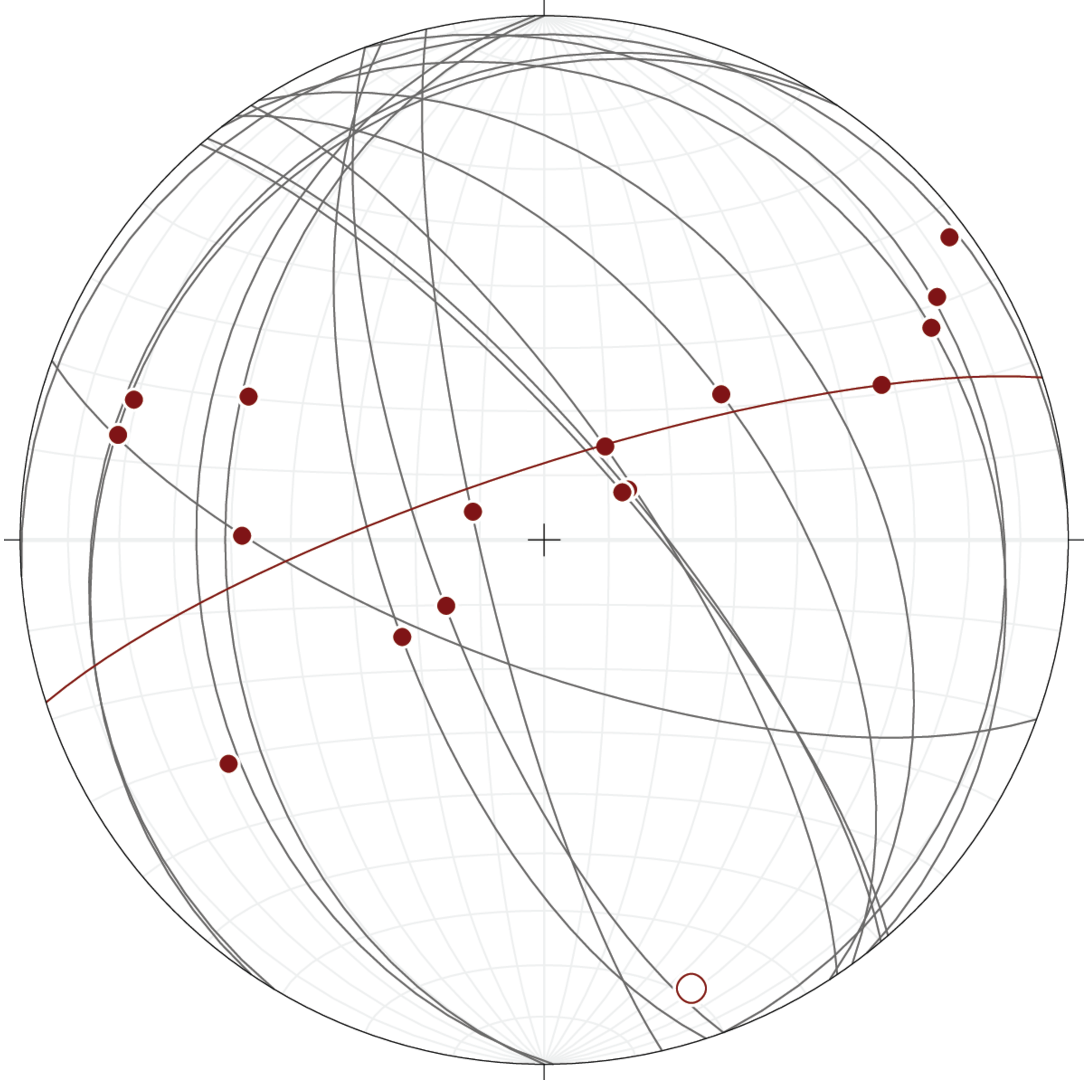
Faults in Steeply dipping strata (>50°)

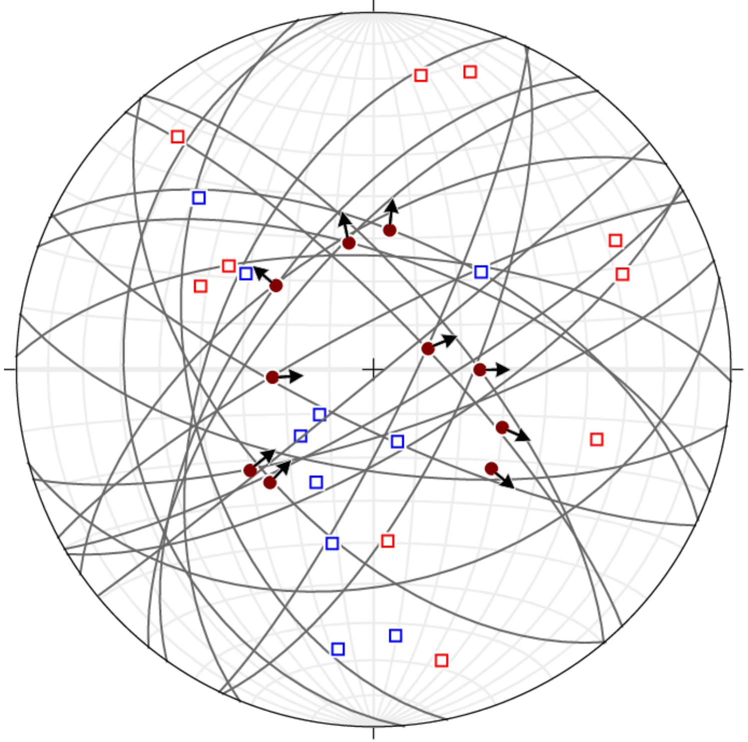
All fault planes and slickenlines, no rotation.
n=66



Bedding parallel faults

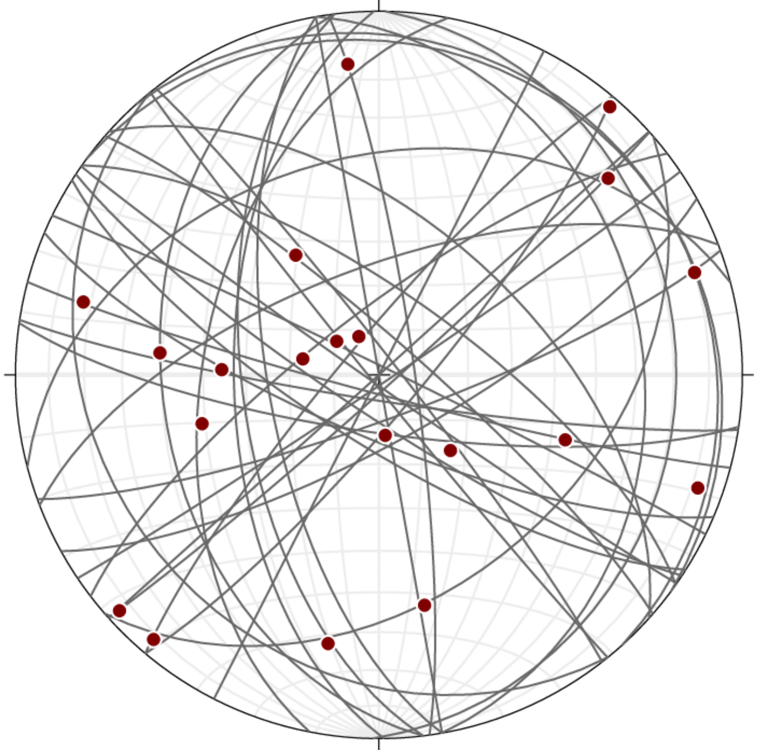
All fault planes and slickenlines, no rotation.
n=16





Normal faults

n=22 planes, n=10 slickenlines
Shortening and extension axes
Bedding rotated to 5° dip.



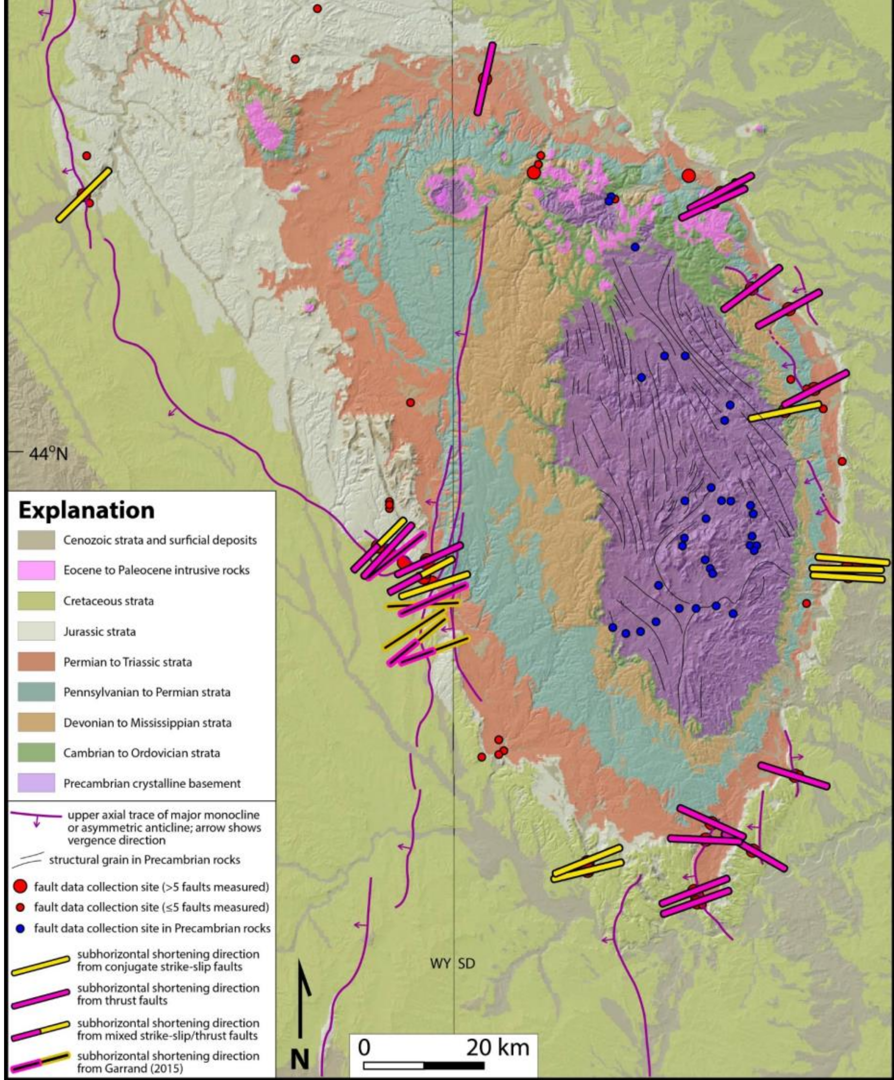
Faults with unknown sense of slip

n=37 planes,
n=20 slickenlines
Bedding rotated to 5° dip.

Yellow = strike-slip faults

Pink = thrust faults

Pink/Yellow = mixed strike-slip/thrust



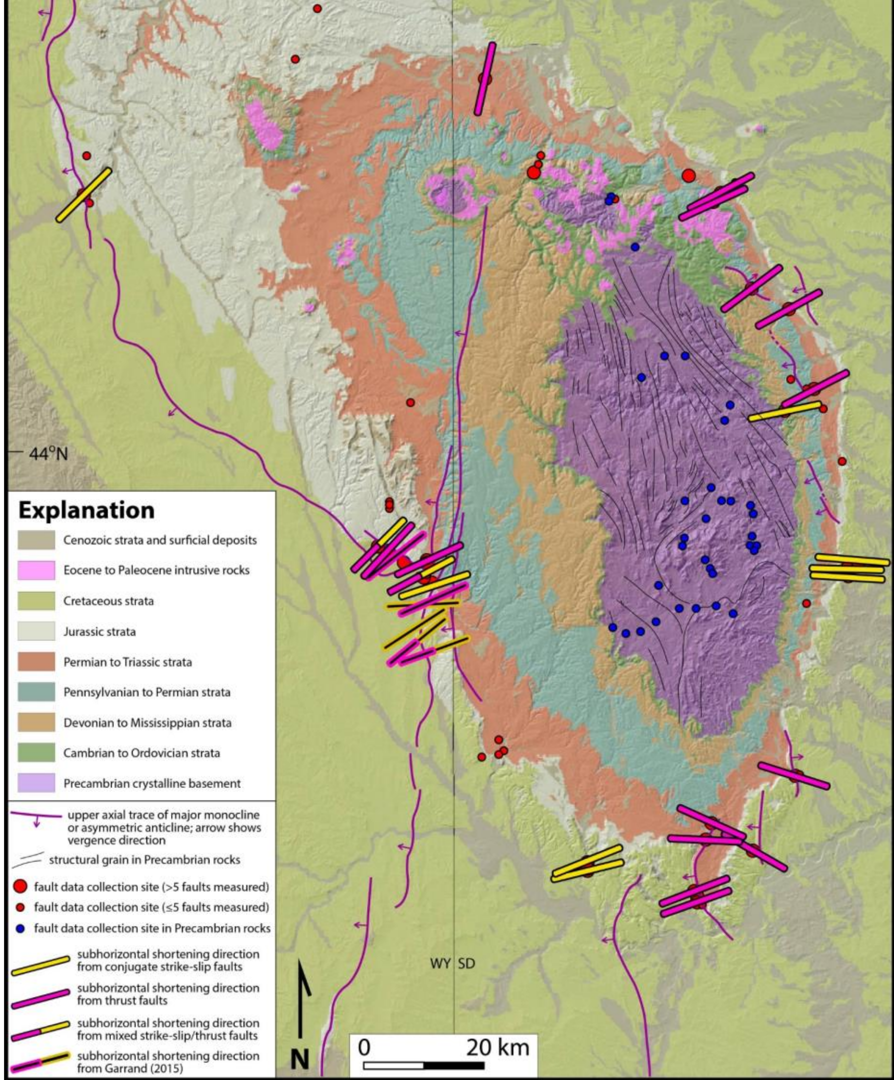
Key Observations:

- Broadly ENE-WSW shortening
- Shortening orthogonal to strike
- Conjugate thrust faults somewhat more common near map-scale monoclines

Yellow = strike-slip faults

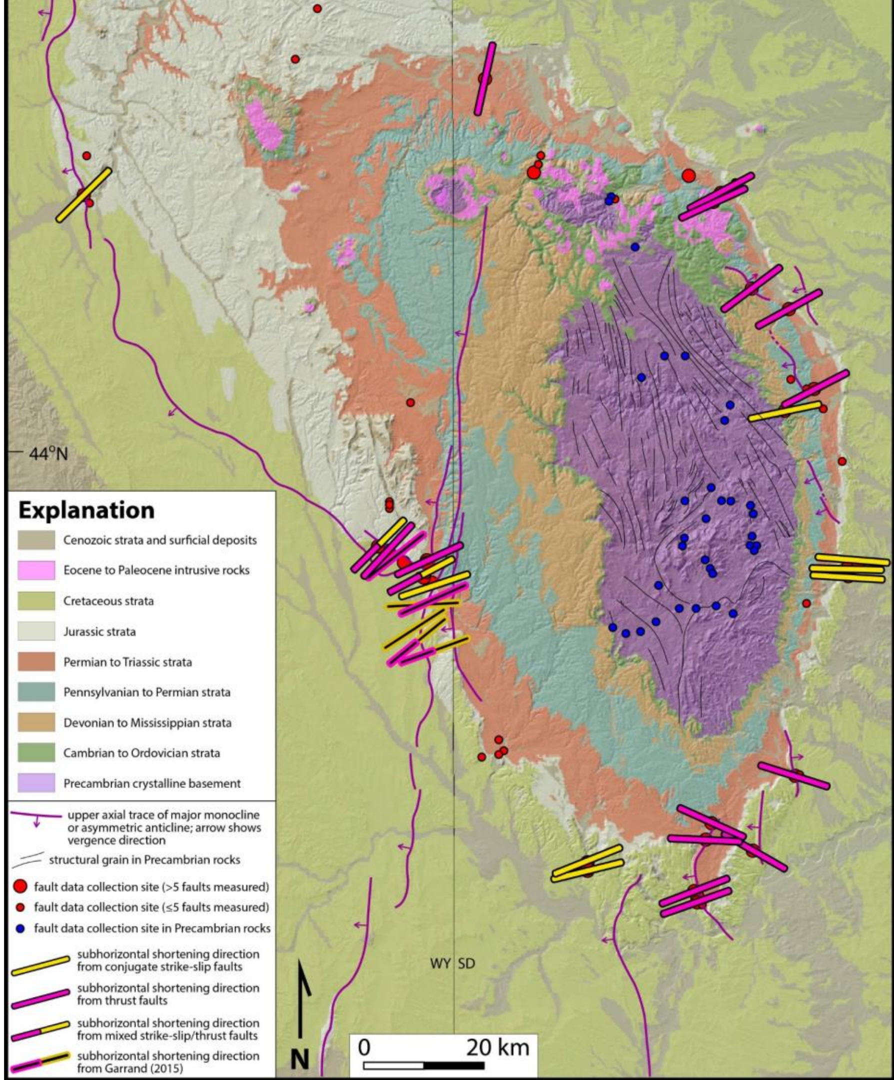
Pink = thrust faults

Pink/Yellow = mixed strike-slip/thrust



Interpretations:

- Laramide shortening
- Shortening direction pattern could be related to:
    - Basement anisotropy
    - Pre-existing topography



Yellow = strike-slip faults

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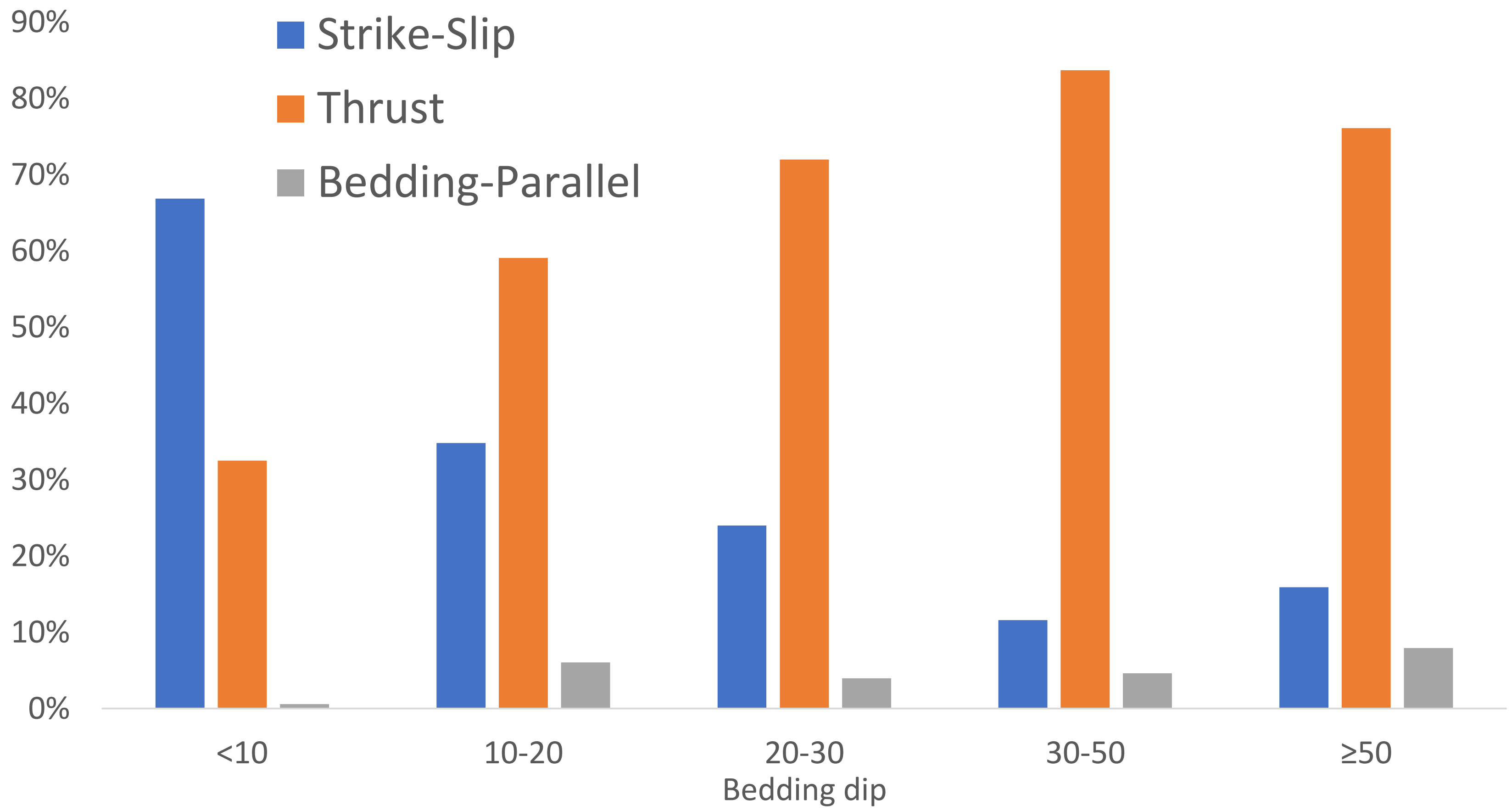
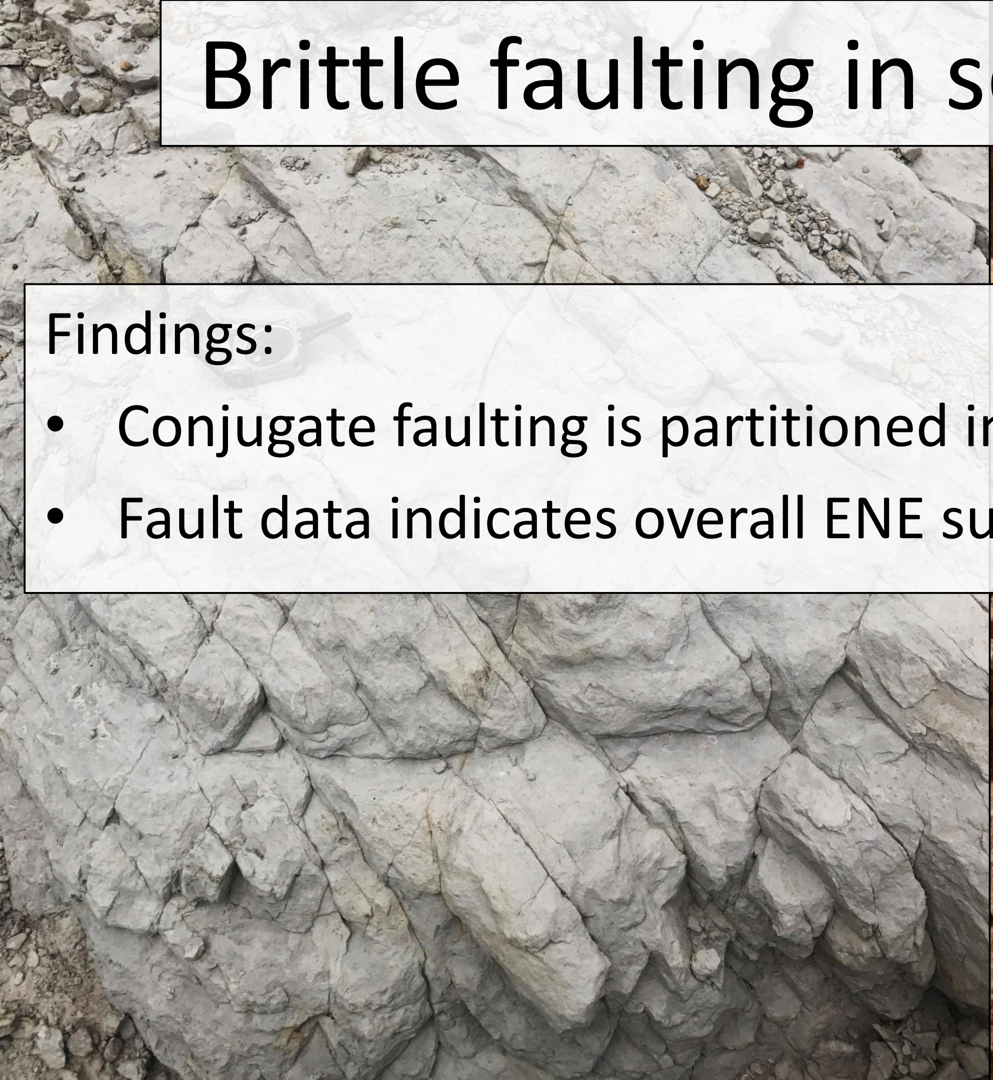


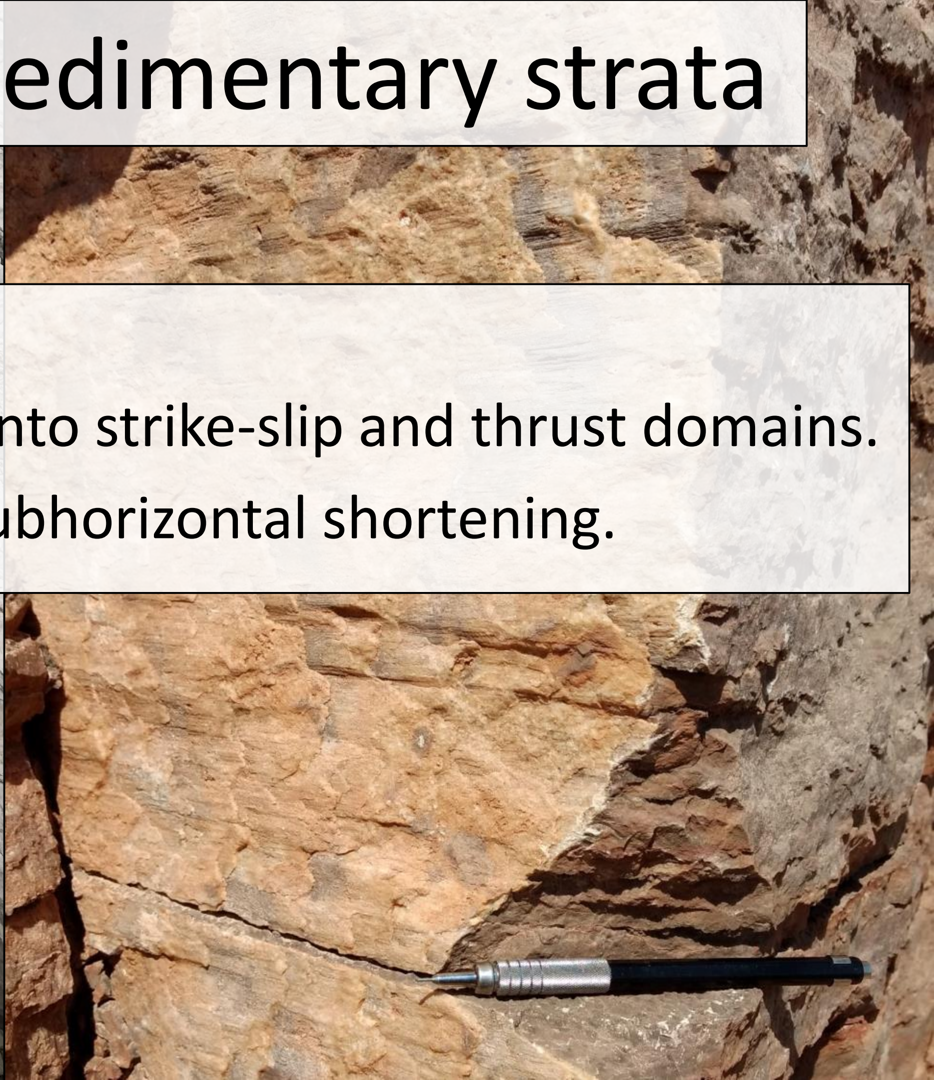
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Strike-Slip
Thrust
Bedding-Parallel
<10
10-20
20-30
30-50
≥50
Bedding dip

Brittle faulting in sedimentary strata

Findings:

- Conjugate faulting is partitioned into strike-slip and thrust domains.
- Fault data indicates overall ENE subhorizontal shortening.





Fabrics and faults in crystalline rocks

2) Evaluate role of Precambrian structures in Laramide deformation

- Were Precambrian fabrics reactivated as Laramide faults?
- Did Precambrian structures influence the location & geometry of the Laramide uplift?

Photo Credit: John Singleton

Reactivation angle analysis

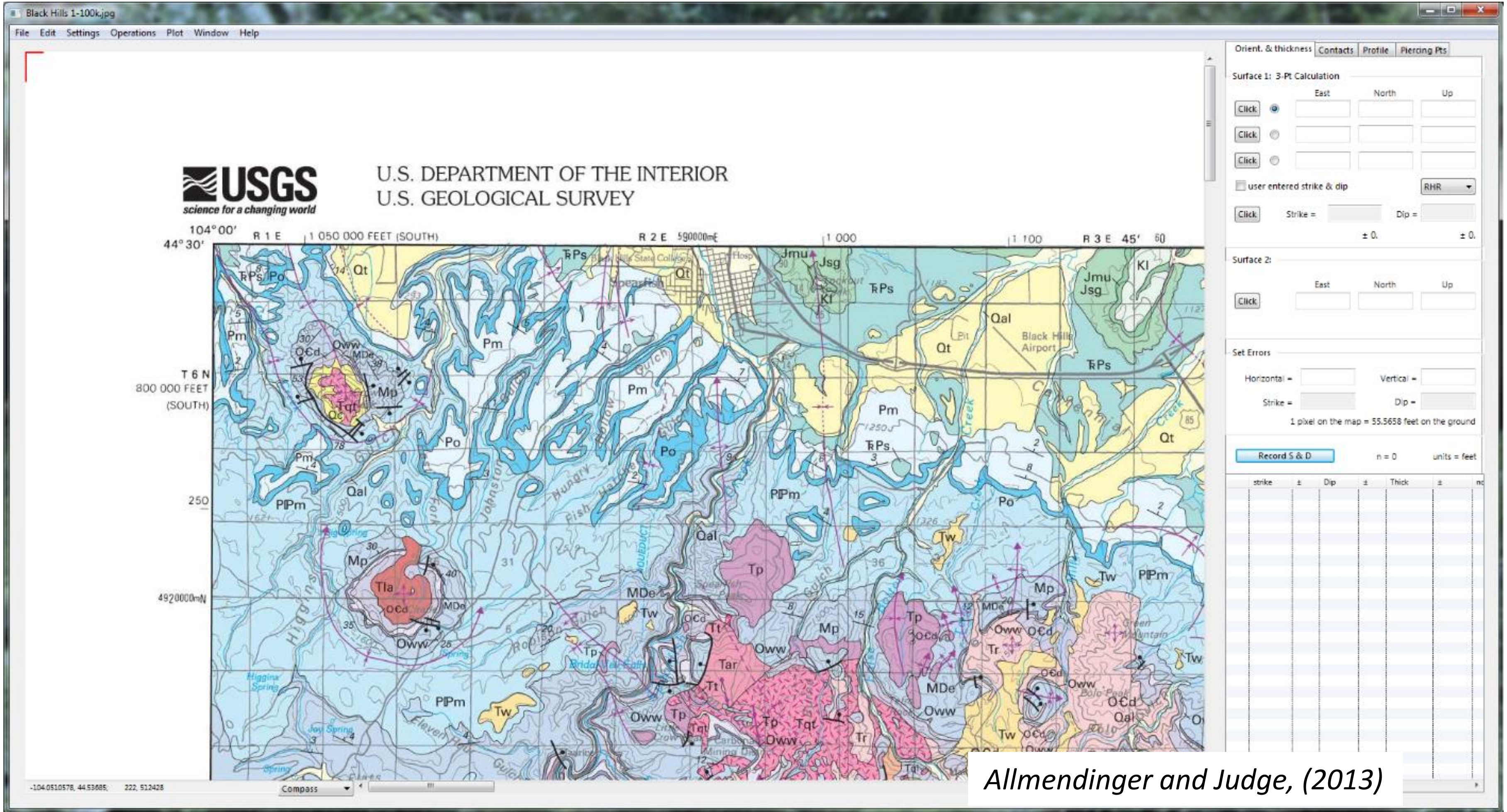
Are basement fabrics favorably oriented for Laramide reactivation?

Assumptions:

- *2.5 km maximum burial depth based on thermochronology (Prior et al., this meeting)*
- *Horizontal N70°E shortening*
- *2.6 g/cm^3 overburden density*
- *Coulomb failure envelope C = 40 MPa and μ = 0.6*
- *Coefficient of static friction on pre-existing fractures = .85*

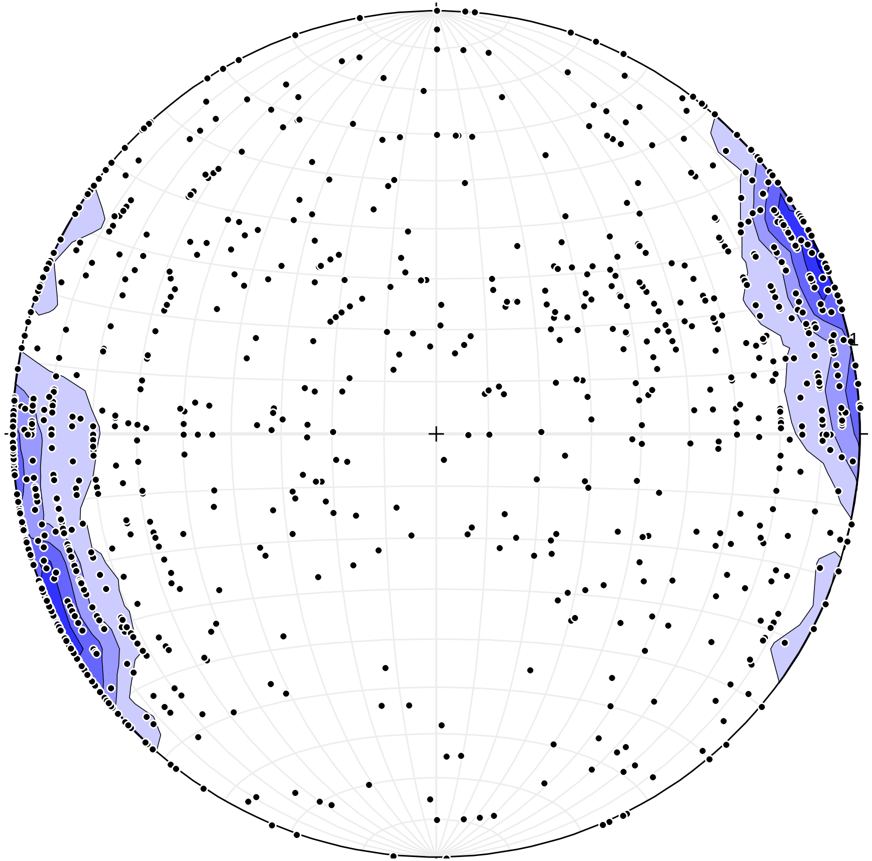
Which fabric orientations can be reactivated before new faults initiate?

GeolMapDataExtractor



Allmendinger and Judge, (2013)

All Map data

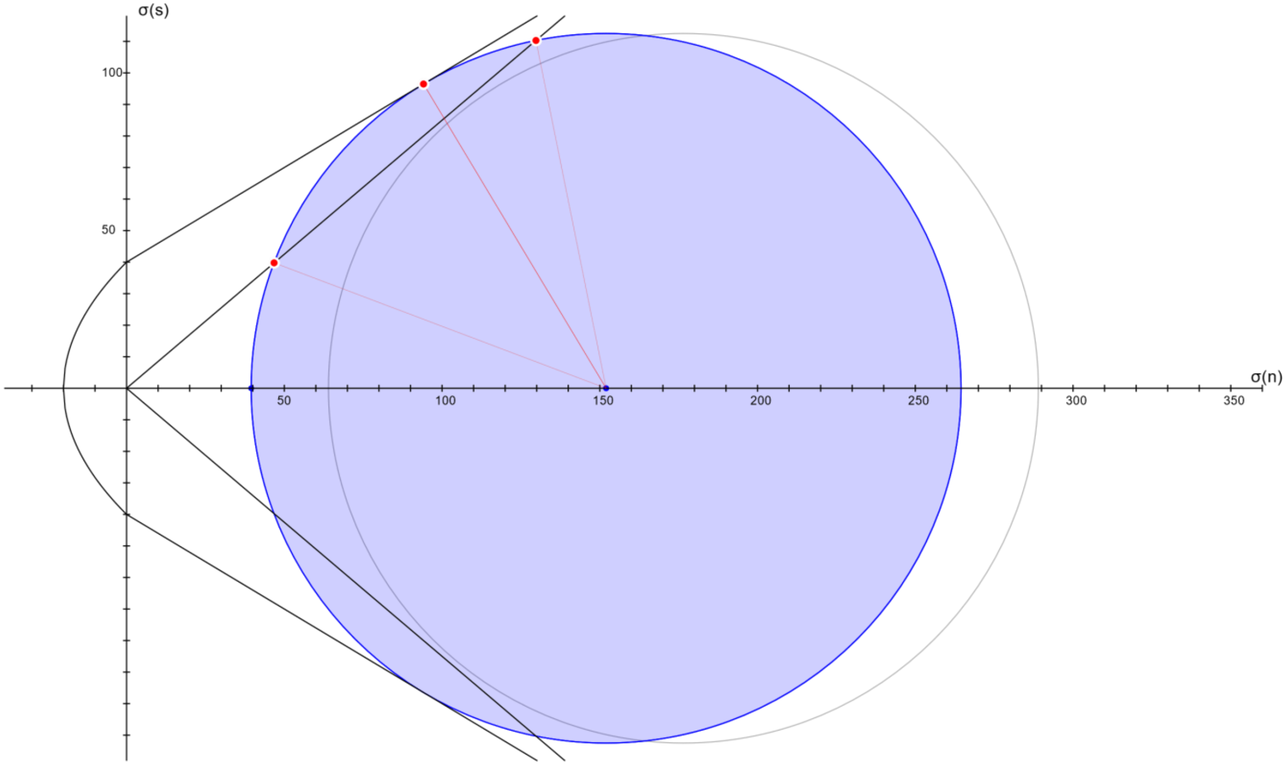


n=989

Compiled from Redden and DeWitt, 2008

Reactivation angle analysis

Hydrostatic pore fluid pressure

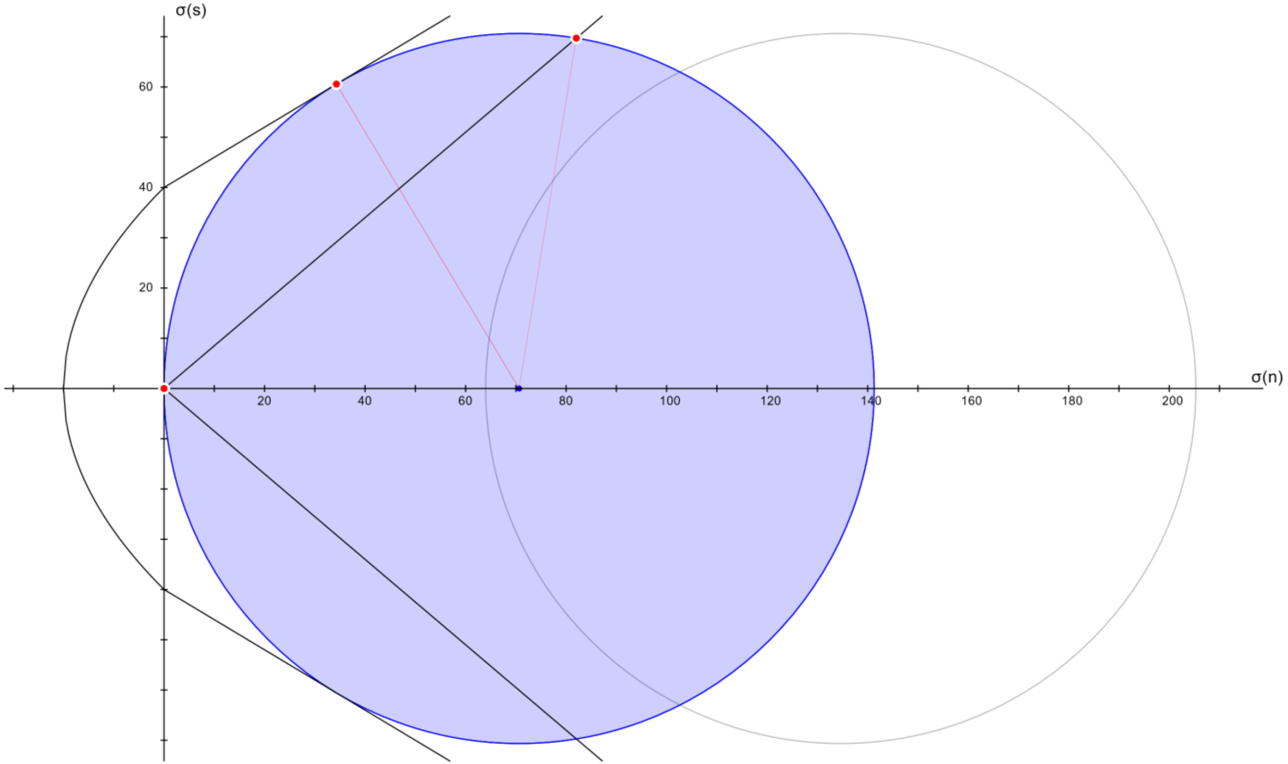


Reactivation will occur for pre-existing planes dipping between 10-39° in the σ_1 direction.

This represents 4% of the compiled fabric orientations.

Reactivation angle analysis

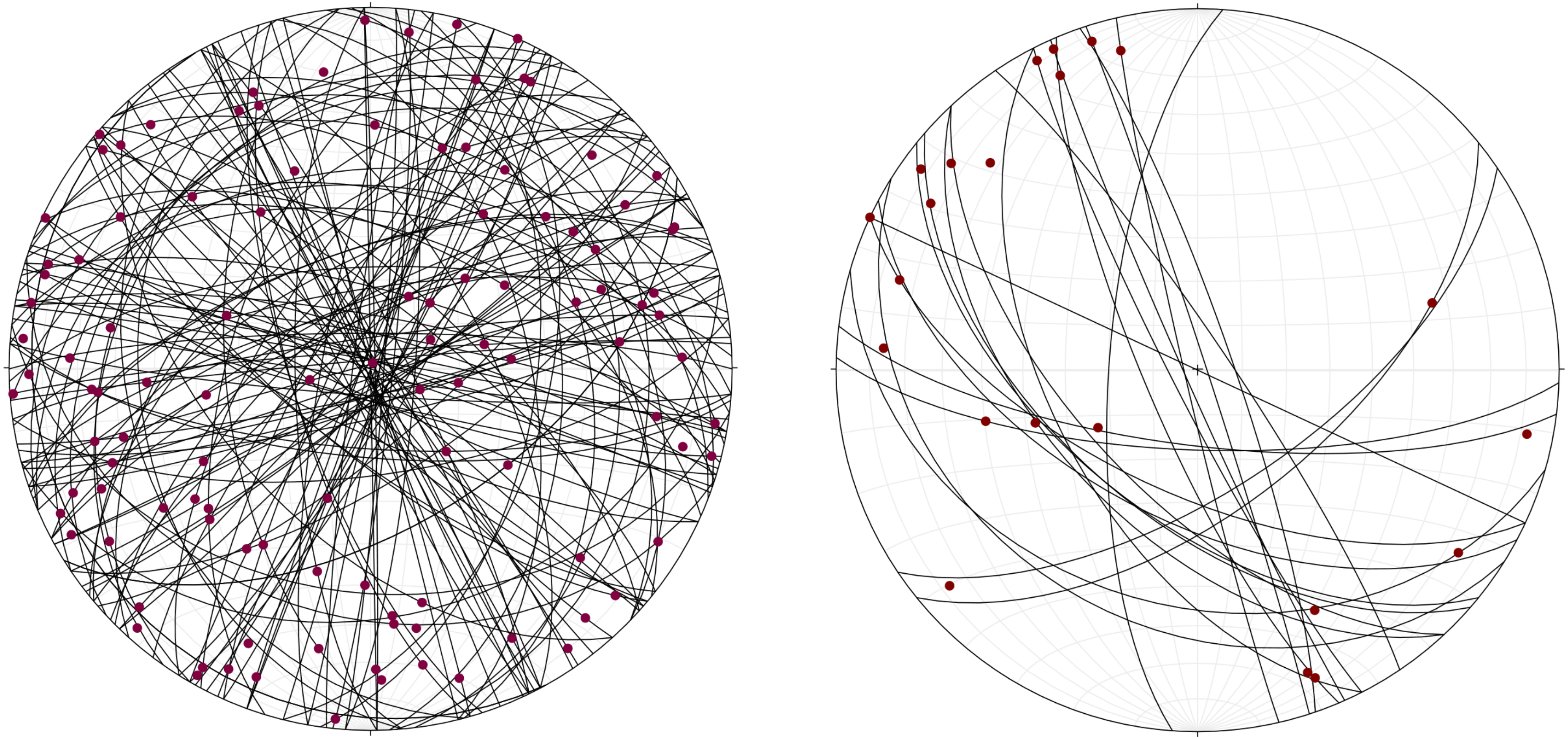
Lithostatic pore fluid pressure



Reactivation will occur for pre-existing planes dipping between <50° in the σ_1 direction.

This represents <8% of the compiled fabric orientations.

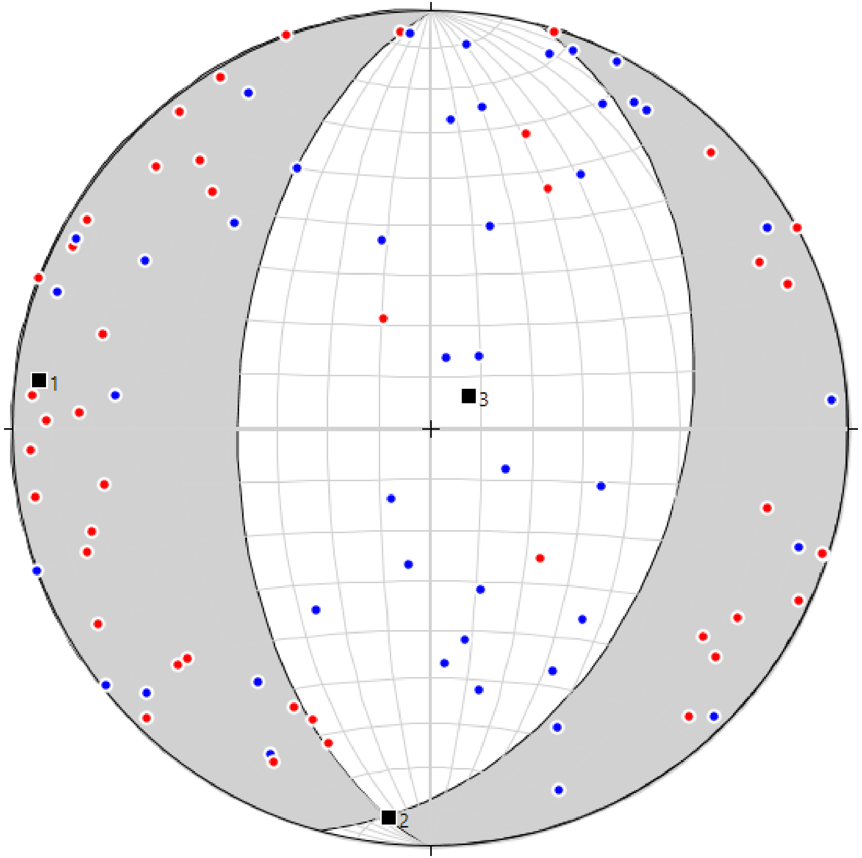
Brittle faults in foliated Precambrian units



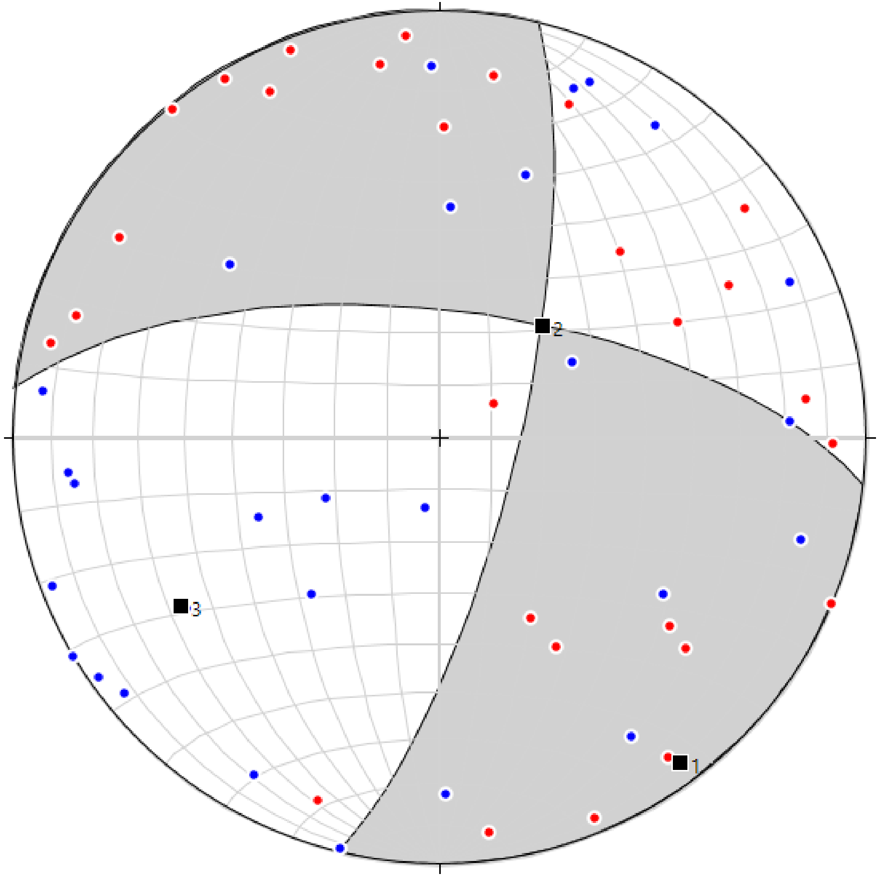
Faults cutting foliation
n=139

Foliation parallel faults
n=22

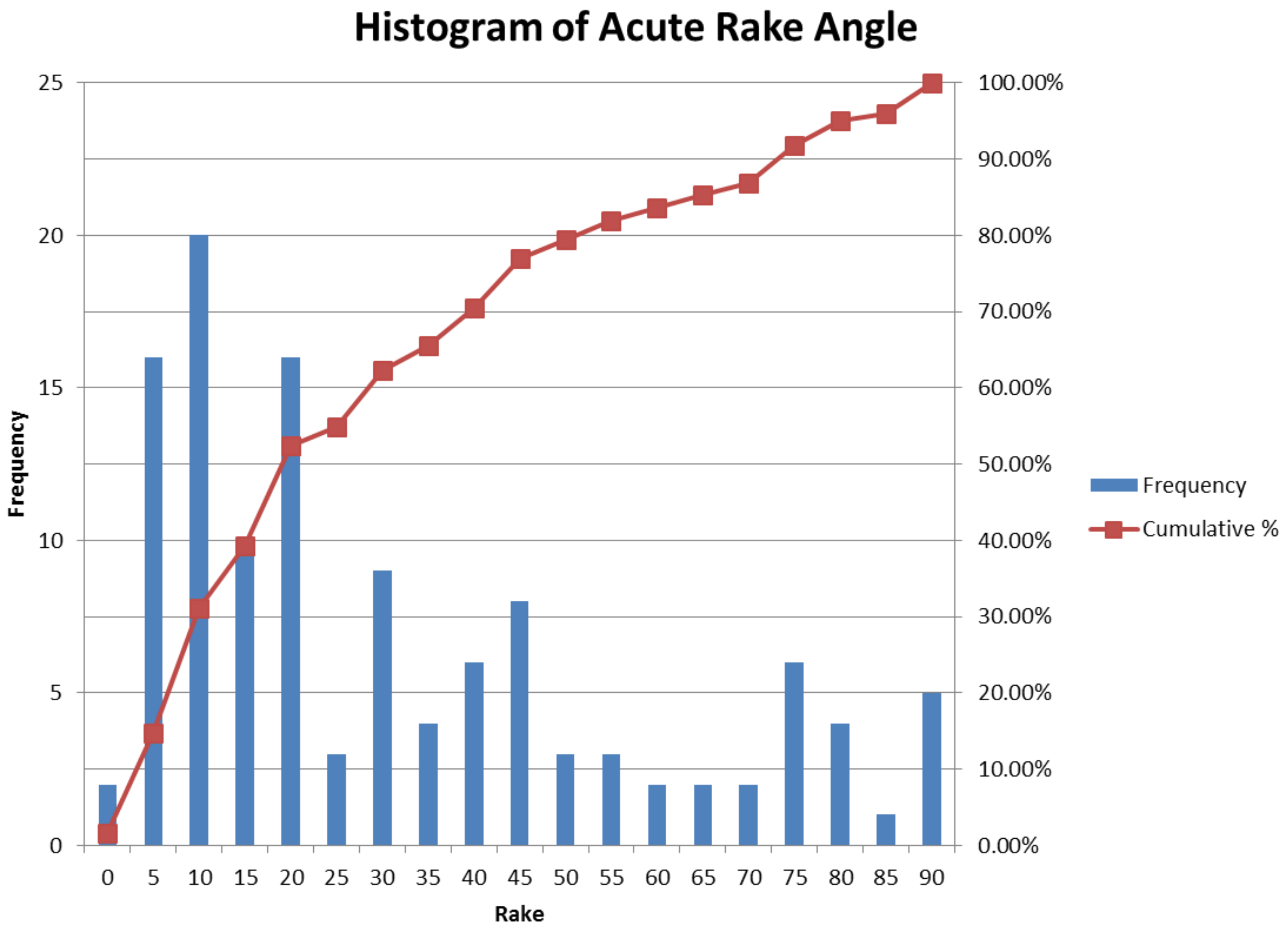
Faults with slip sense



Foliated metamorphic units



Non-foliated Harney Peak Granite


Histogram of Acute Rake Angle
Frequency
0
5
10
15
20
25
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
Rake
Frequency
Cumulative %

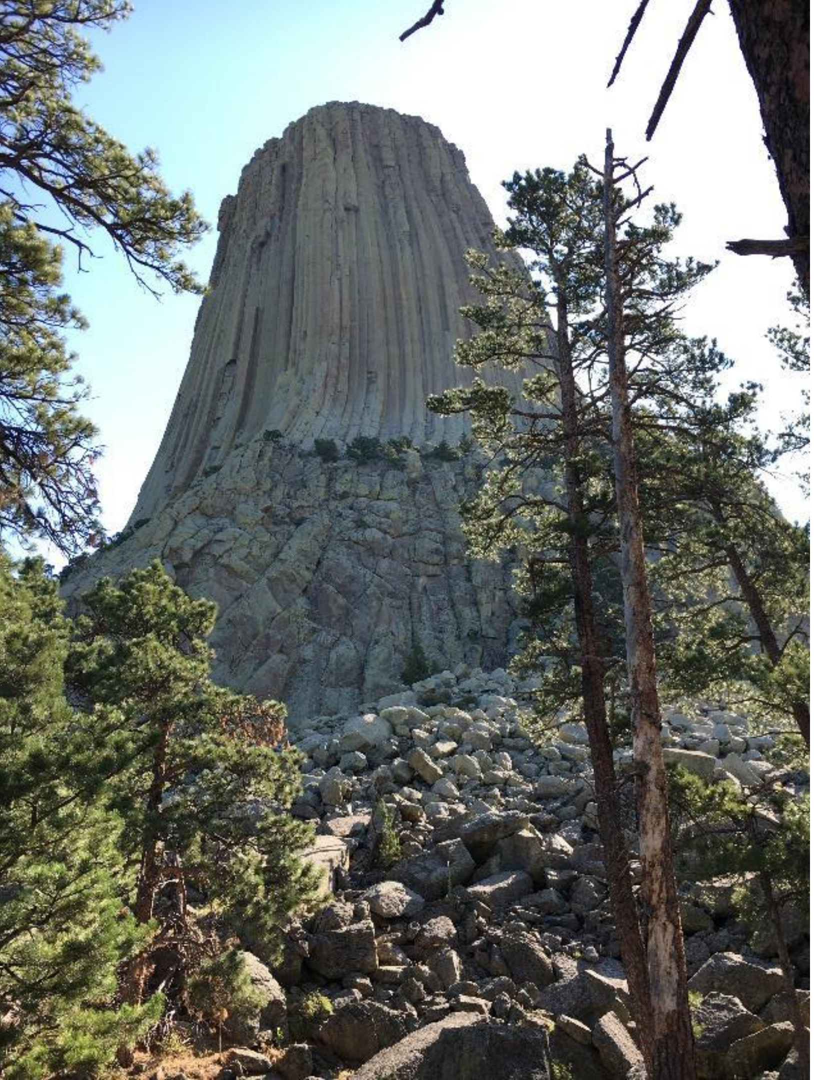
Fabrics and faults in crystalline rocks

Findings:

- Compiled fabric orientations are poorly oriented for reactivation by subhorizontal shortening.

- Most observed faults cut metamorphic fabrics.

Photo Credit: John Singleton



Conclusions

1. ***The Black Hills uplift records subhorizontal ENE shortening accommodated by conjugate strike-slip and thrust faulting.***

2. ***Shortening directions show a radiating outwards pattern across the uplift and are influenced by Precambrian basement.***

3. ***Precambrian fabrics were not favorably oriented for reactivation during the Laramide, consistent with outcrop scale fault data.***