The Missing Link: The Role of Basement Anisotropies in the Structural and Tectonic Evolution of the Wyoming Craton*

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Abstract

Seismic studies (COCORP, BASE, EarthScope) over the past three decades have provided a better understanding of Laramide tectonism, especially at deeper crustal levels. However, deformational mechanisms in the upper crust related to Laramide contraction, mid-crustal detachment, and subsequent thick-skinned thrusting remain unclear. Internal controls on Laramide tectonism in the upper crust have been proposed to be related to basement anisotropies, which may provide the link between evolution of foreland arches at deeper crustal levels, and structures observed at the surface. This study examines Precambrian anisotropies of the Wyoming craton and provides a hypothesis on their potential role in Laramide orogenisis. Anisotropies are generally oriented in two directions; W-NW and N-NW. They have a complex/long history of deformation since the Precambrian, most recently, during the Laramide when NE-SW-contraction dominated the area. In Wyoming, it is proposed that W-NW structures were displaced as reverse, left-lateral oblique slip faults and, where connected, acted as lateral ramps facilitating major uplifts along the N-NW-trending structures. In Montana, where only W-NW basement structures are present, sinistral slip occurred along high-angle basement-seated faults without the associated vertical slip seen in Wyoming. This is likely due to the absence of N-NW-trending “connections” in basement rocks of Montana and thus explains the lack of Laramide arches in the state. Basement-seated faults are expressed at the surface as oblique, left-slip reverse faults/sinistral strike-slip faults (W-NW deformational zones in Wyoming/Montana) and medium-angle reverse faults/thrust faults (N-NW arches only in Wyoming) that are interconnected as part of a proposed cratonic deformational system. This system includes the Black Hills, which are bound on the east by the southern extension of the west-dipping Cedar Creek fault, likely representing the suture between Archean crust of the Wyoming craton and Proterozoic terranes of the Trans-Hudson Orogen. East-directed

thrusting on the Cedar Creek fault during the Laramide likely facilitated uplift of the Black Hills with the Nye-Bowler fault acting as the sinistral lateral ramp. At depth, major thrust/reverse faults likely sole-out into a low-angle decollement in the middle crust. This cratonic deformational system is postulated to be the fundamental tectonic feature controlling formation of Laramide arches at upper crustal levels.

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Yeck, W.L., A.F. Sheehan, M.L. Anderson, E.A. Erslev, K.C. Miller, and C.S. Siddoway, 2014, Structure of the Bighorn Mountain Region, Wyoming, from Teleseismic Receiver Function Analysis: Implications for the Kinematics of Laramide Shortening: Journal of Geophysical Research Solid Earth, v. 119, p. 7028.7042. doi:10.1002/ 2013JB010769

The Missing Link

The Role of Basement Anisotropies in the Structural and Tectonic Evolution of the Wyoming Craton

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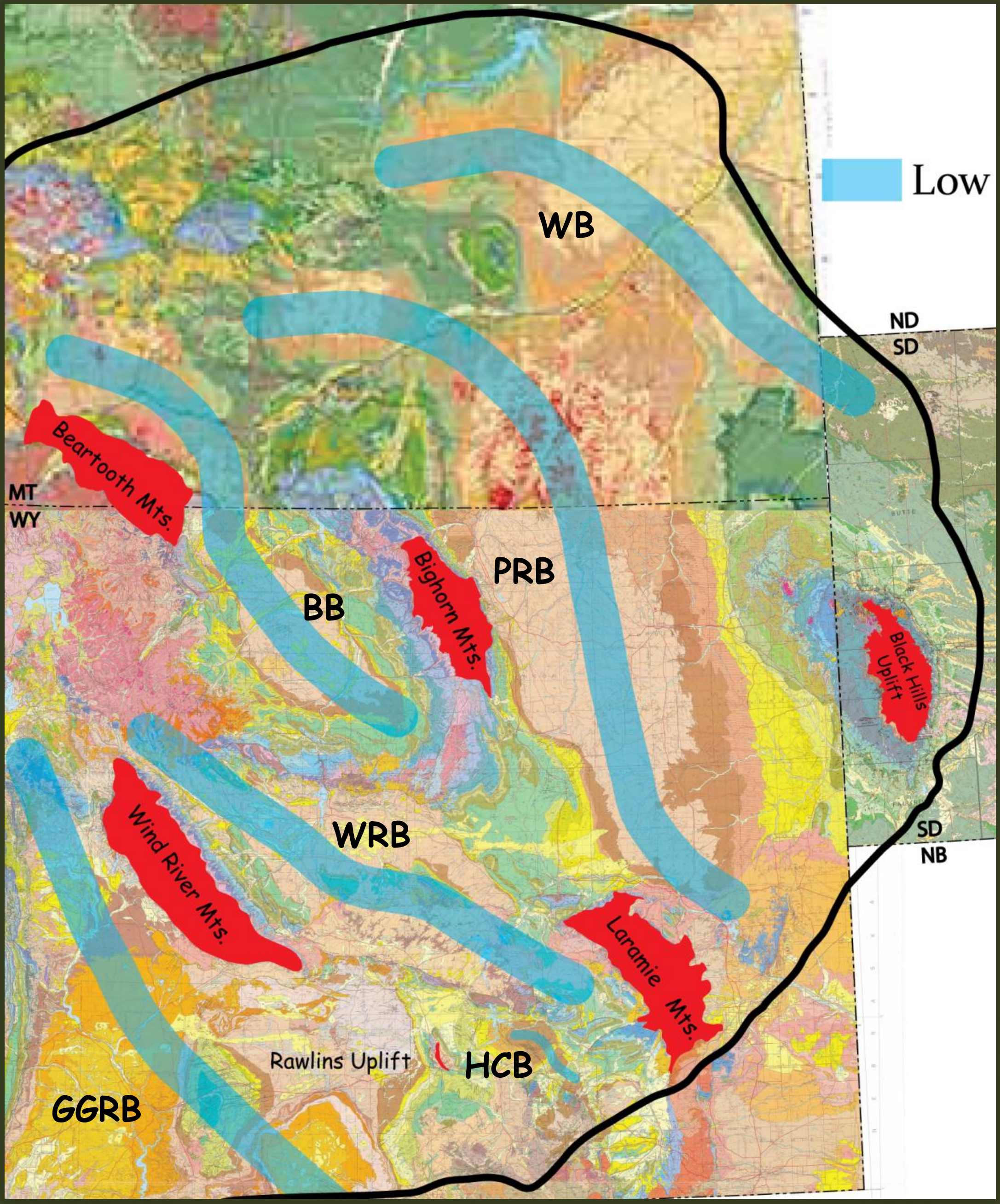
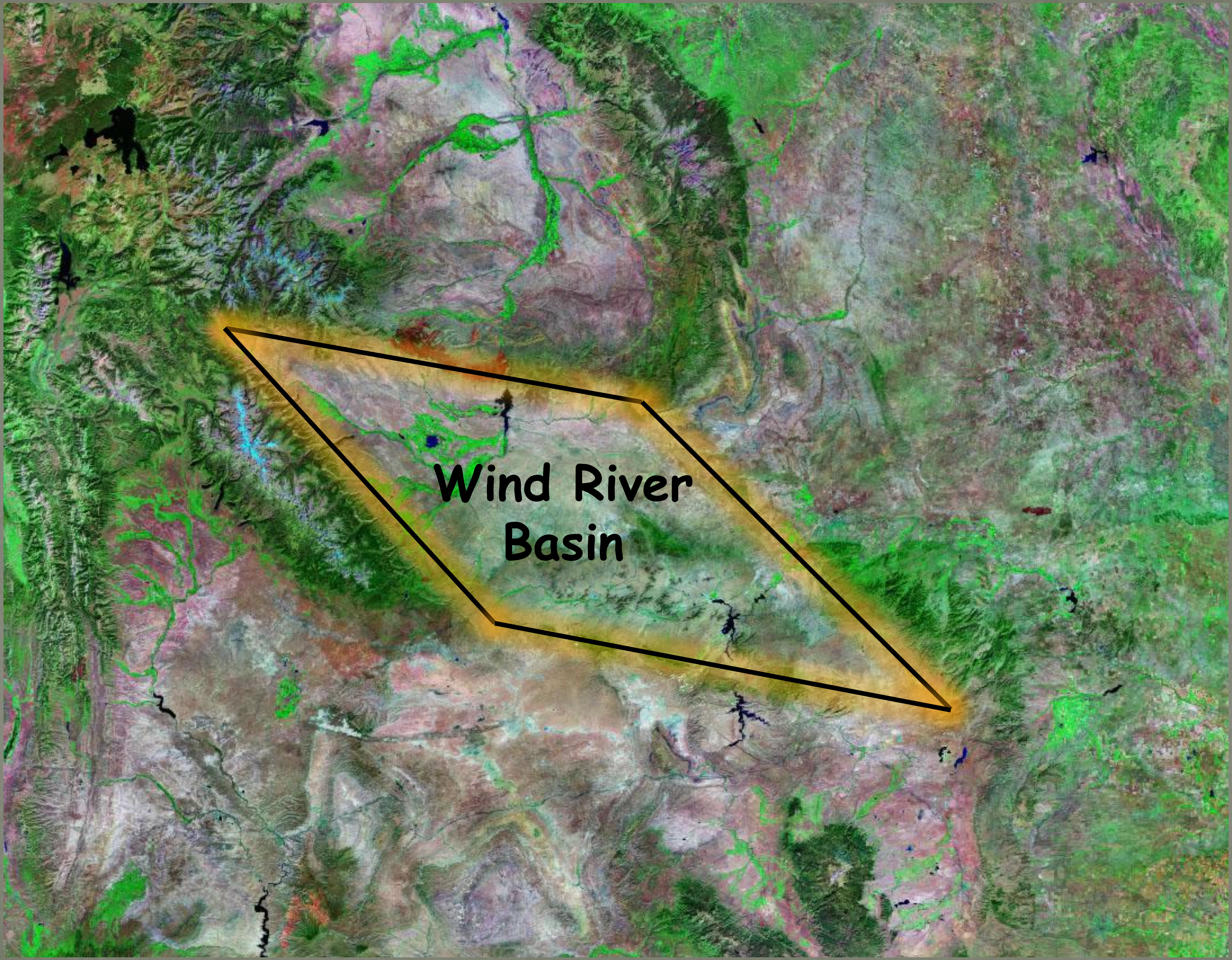
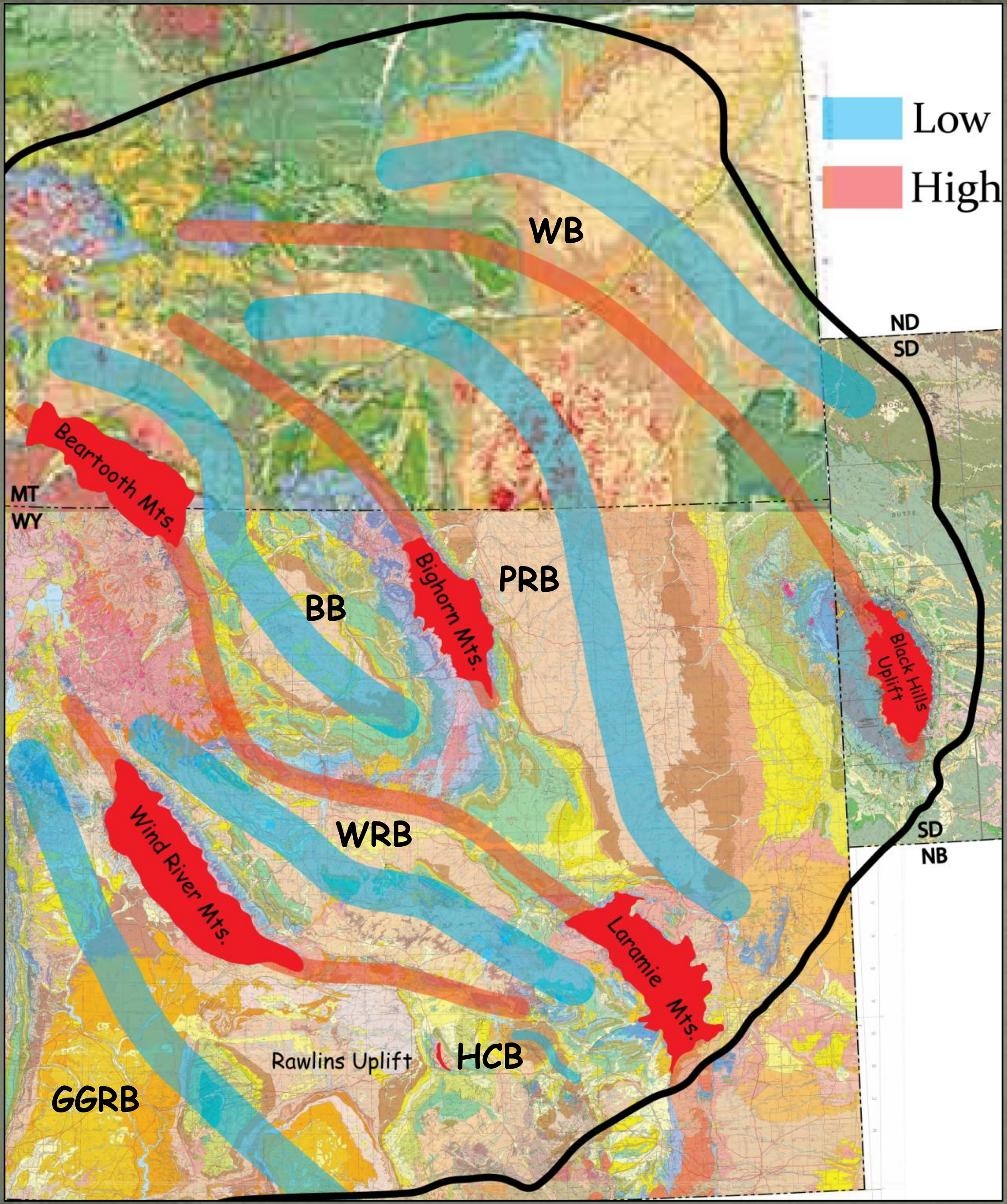
STUDY
AREA
ND
SD
MT
ID
UT
NV
WY
NE
CO



Basin Symmetry

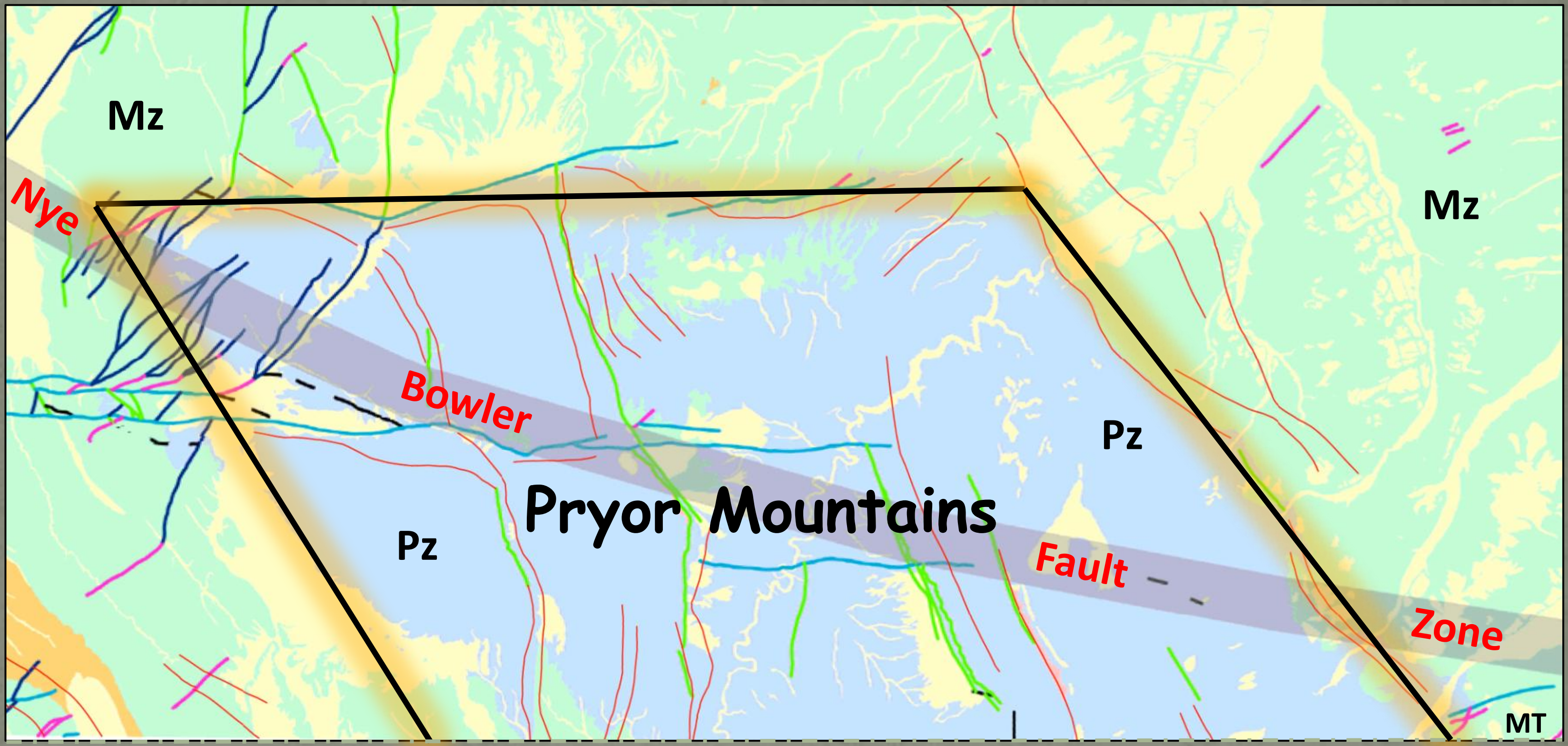
- Structural lows
- Basins symmetrical
  - Curvilinear shape
  - Flattened, reverse S
  - Taper to NW and SE
- Present in all basins
- Present across entire craton
- WHY!


Wind River
Basin

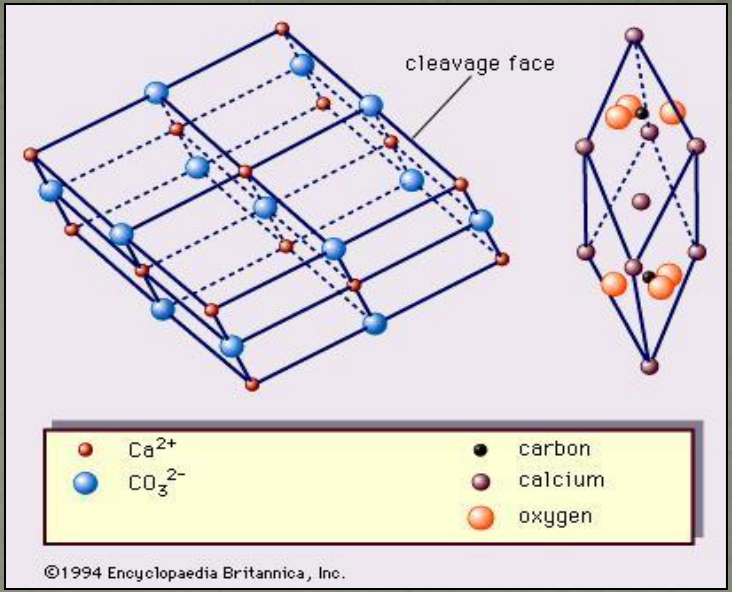


"Arch" Symmetry

- Similar to basins
- Orderly to SW-NE
- "Connected"
- WHY!



Modified from Bader, 2011



Orderly and systematic

- Fundamental origins;
- Scales may be imperceptible to the naked eye; and
- Can be broken up, disguising original symmetry

Hypothesis:

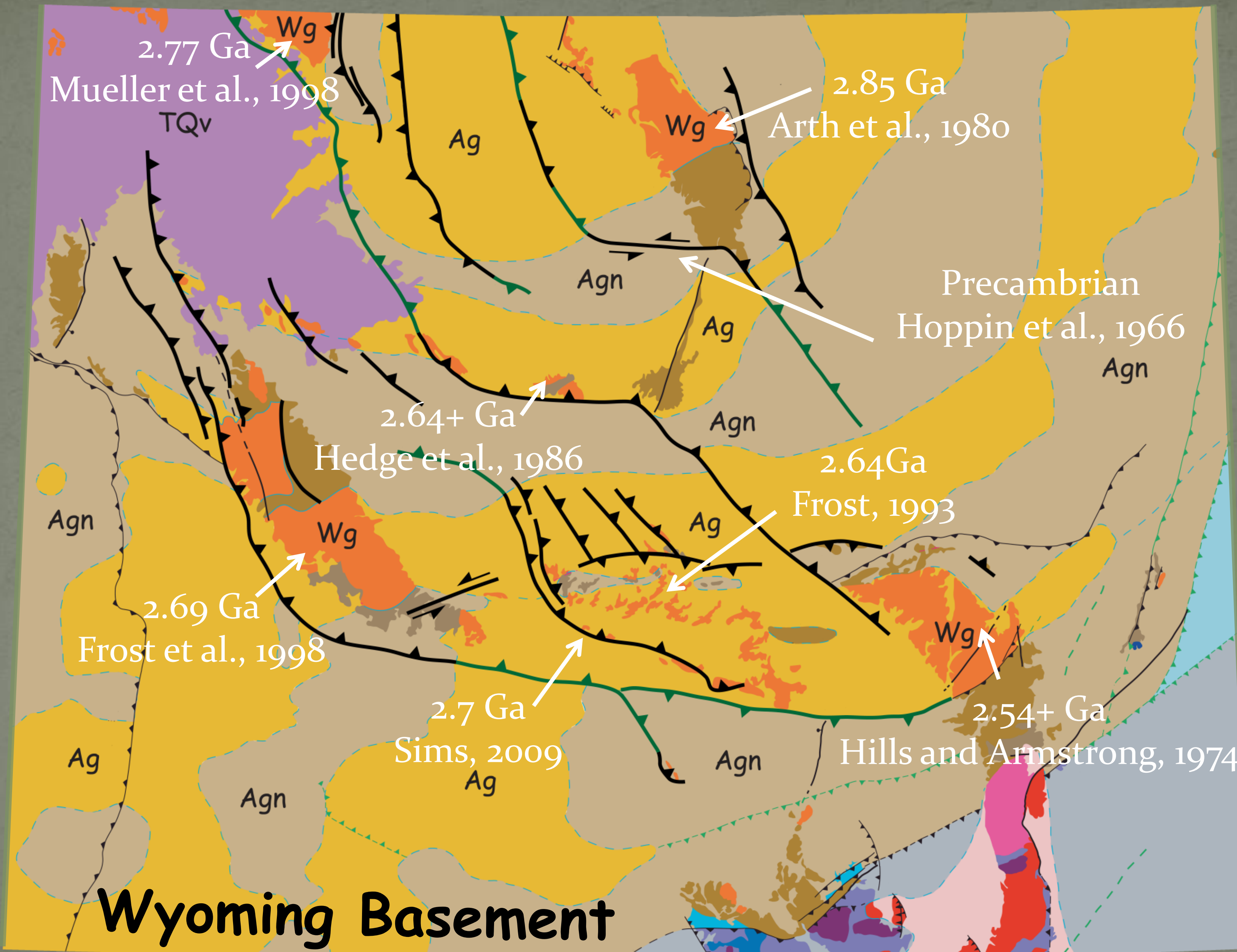
Basement weakness zones play a significant role in development of Laramide structures of the Wyoming craton

Methods:

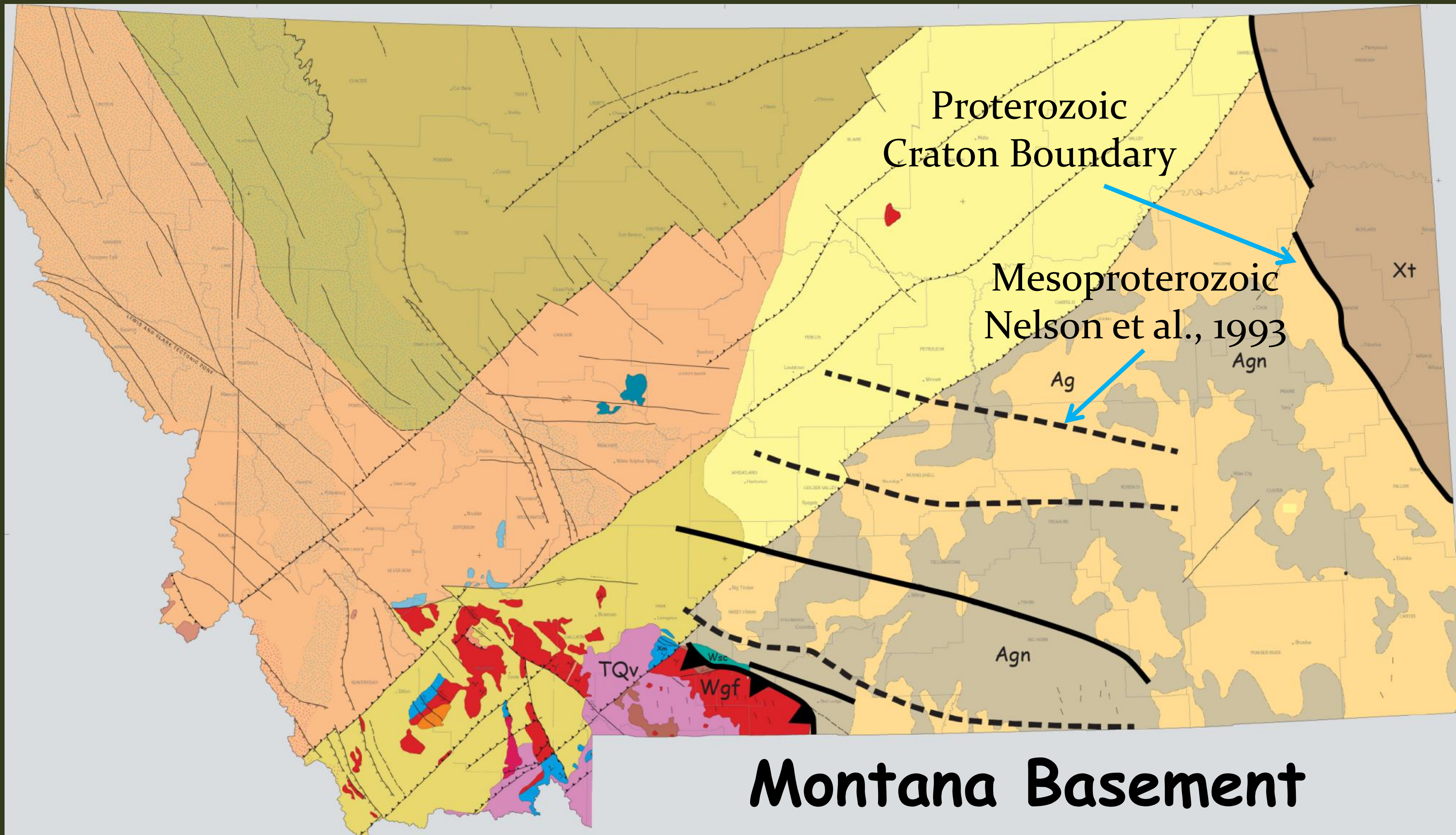
- Complete **tectonic map** of eastern Montana
- **Thoroughly research current/attainable published data** to assess **similarities**, if any, between basement/surface structures in eastern Montana, Wyoming, and South Dakota
- Prepare a structural/tectonic **model**
- **Test model** against currently established models for Laramide deformation:
  - Low-angle subduction;
  - NE-SW PHS;
  - Mid-crustal detachment; and
  - Thick-skinned tectonics with development of Laramide arches along reverse/thrust faults that sole out at depth.
- **Modify**, as necessary, and integrate model with "accepted" models

Outline:

- Basement
  - Are there **Precambrian-age** anisotropies?
  - If so, what are the **orientations/ages** of these features?
- What is the **nature** of these features as compared to Phanerozoic deformations, emphasizing the Laramide?
- Is there a **genetic relationship?**
  - Model
- Conclusions/Further Work

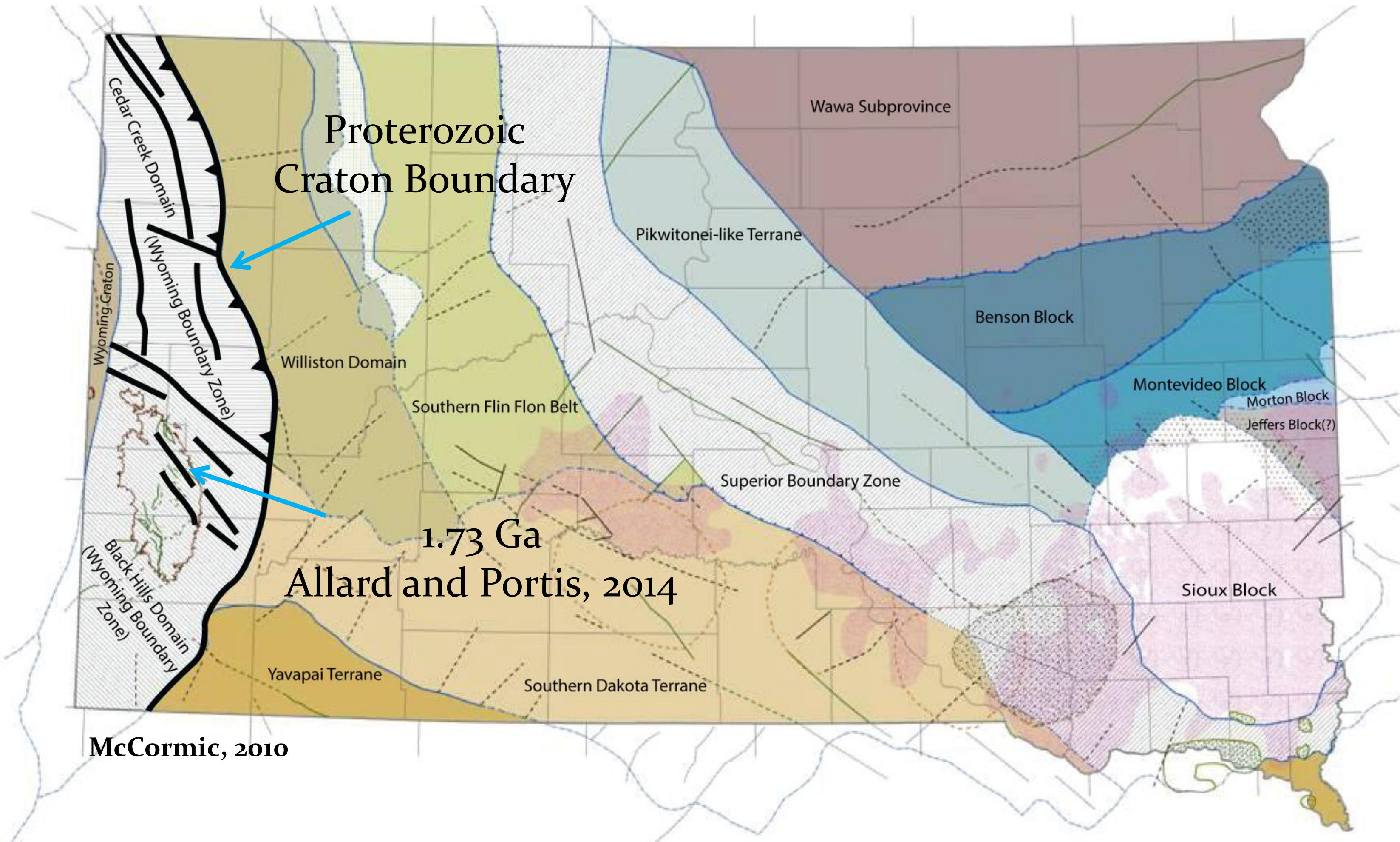

Wyoming Basement
2.77 Ga
Mueller et al., 1998
TQv
Wg
Ag
2.85 Ga
Arth et al., 1980
Agn
Precambrian
Hoppin et al., 1966
2.64+ Ga
Hedge et al., 1986
2.64Ga
Frost, 1993
2.69 Ga
Frost et al., 1998
2.7 Ga
Sims, 2009
2.54+ Ga
Hills and Armstrong, 1974

Sims, 2001



Proterozoic
Craton Boundary
Mesoproterozoic
Nelson et al., 1993
Xt
Agn
Ag
Agn
TQv
Wgf
Wsc
Montana Basement

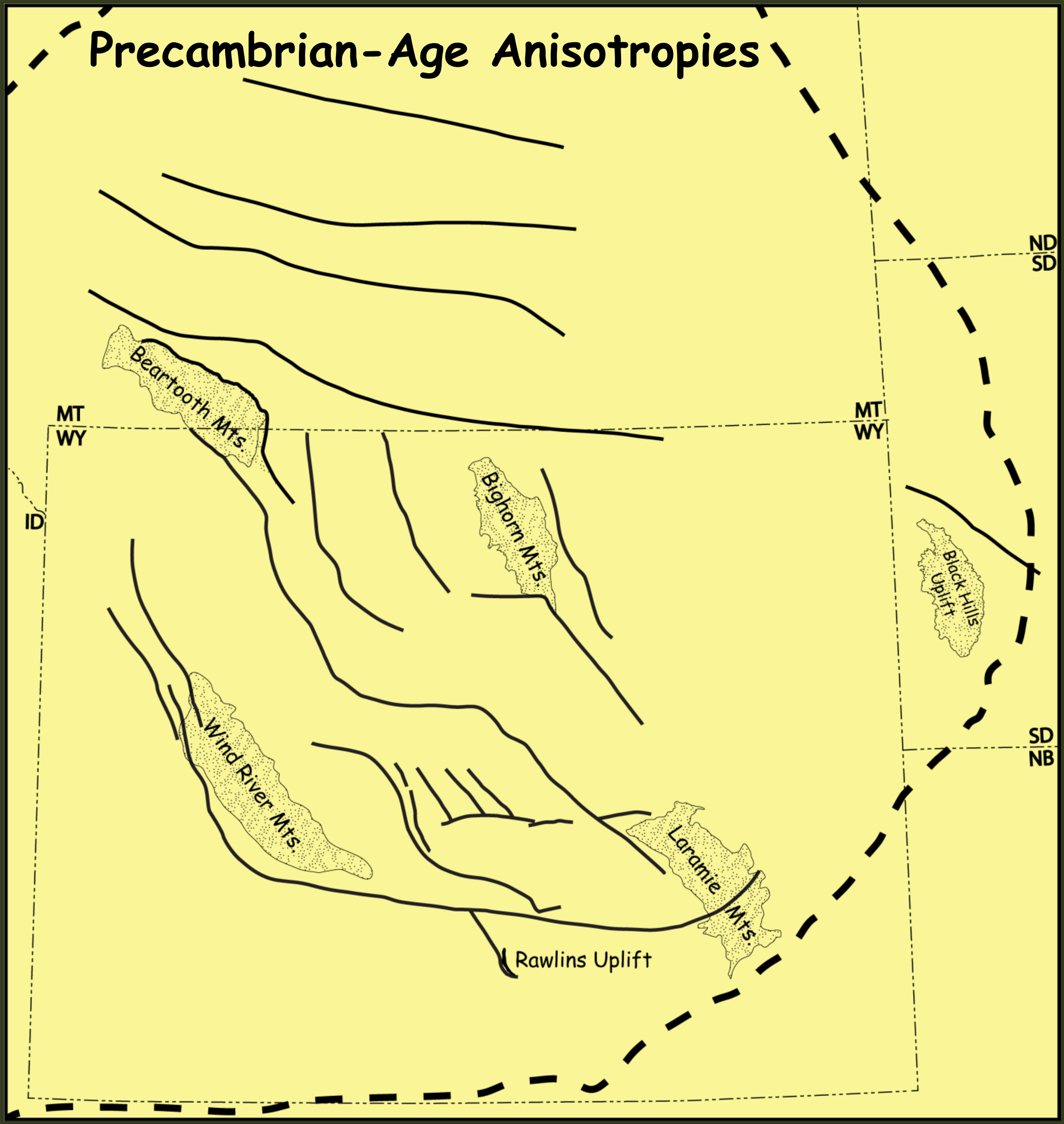
Sims, 2004

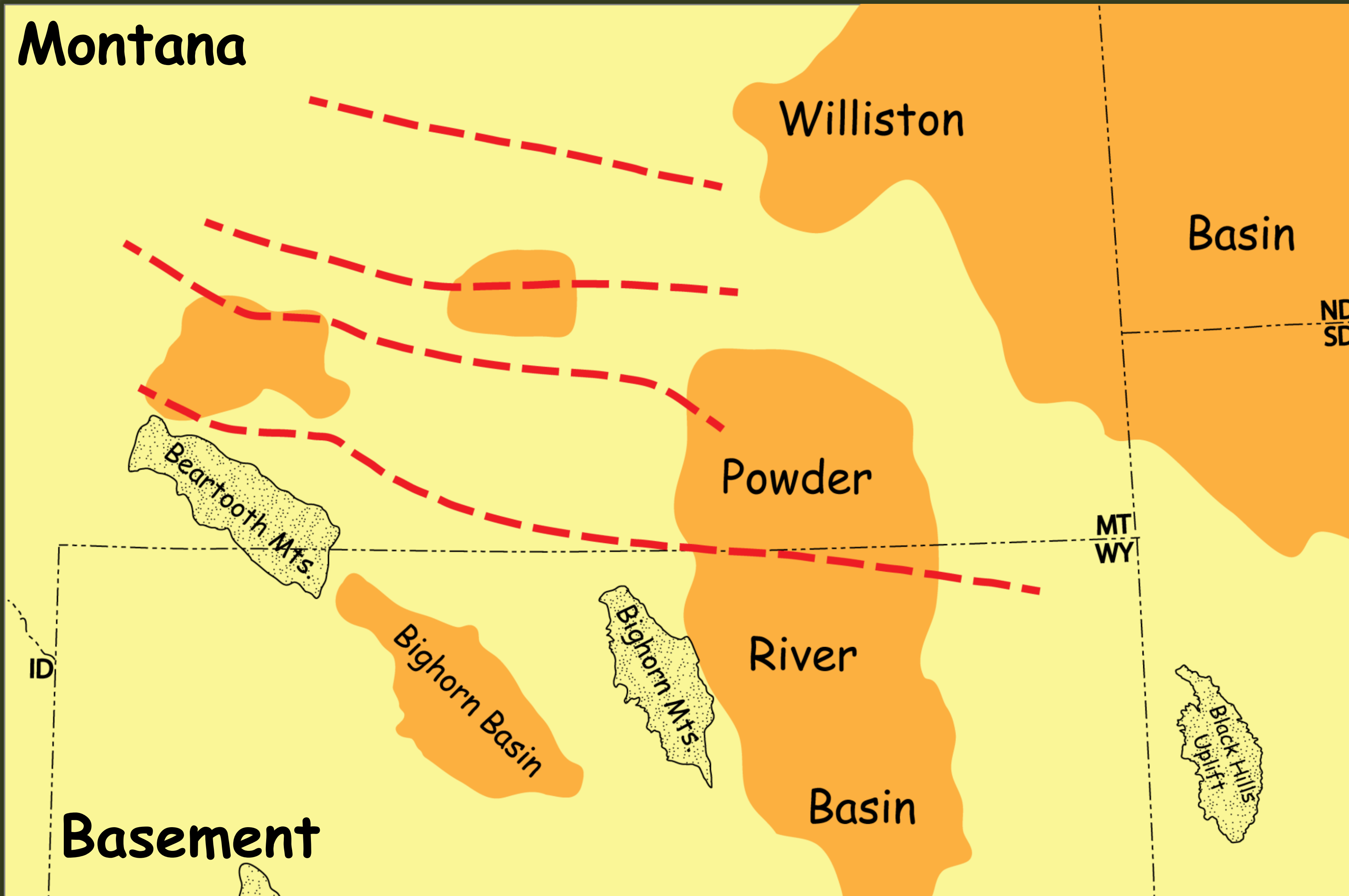


South Dakota Basement

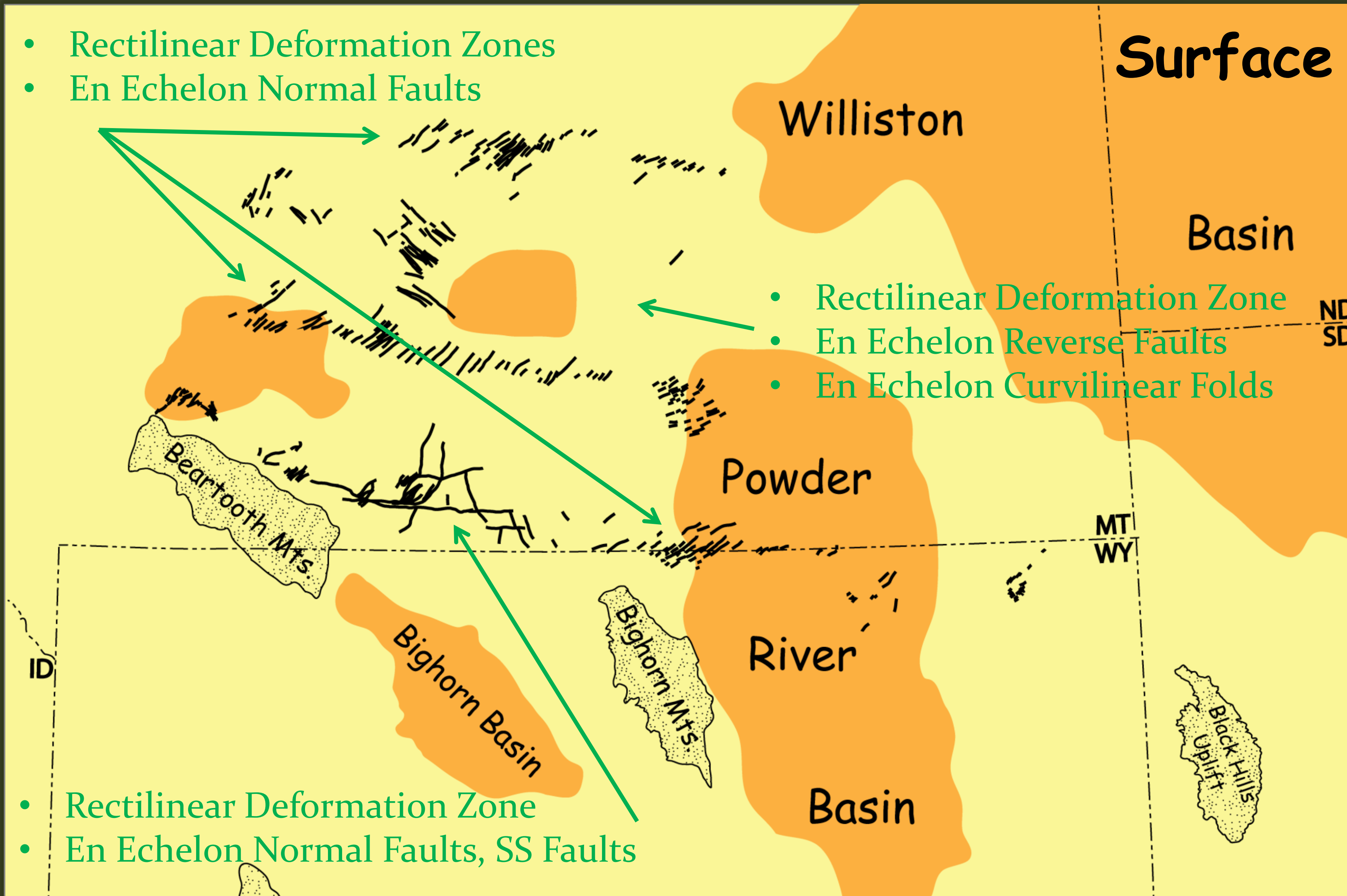
Laramide Surface Deformation

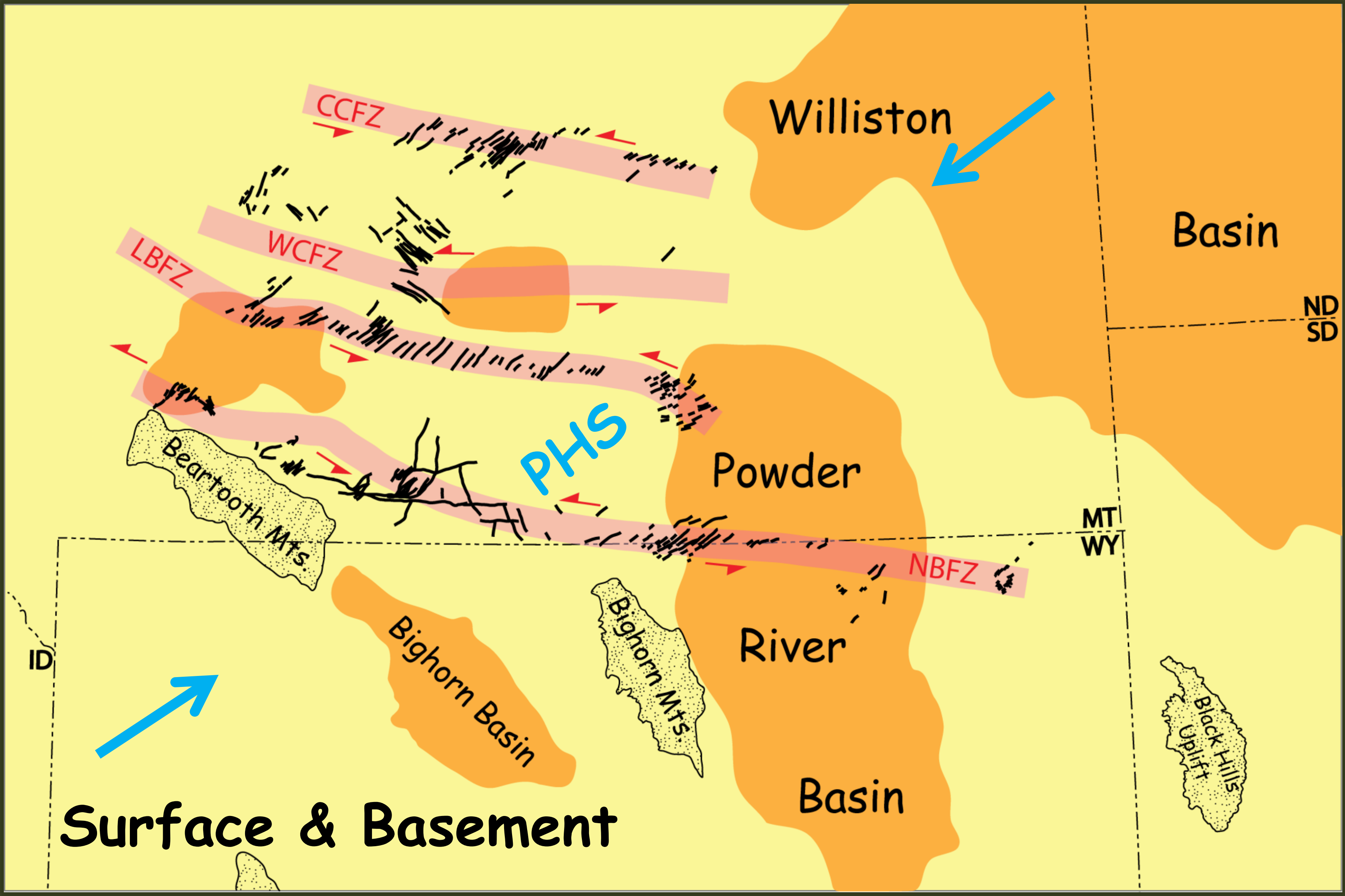
- MT: W-NW Trends
- WY: W-NW Trends
- WY: N-NW Trends
- Coincidence ?

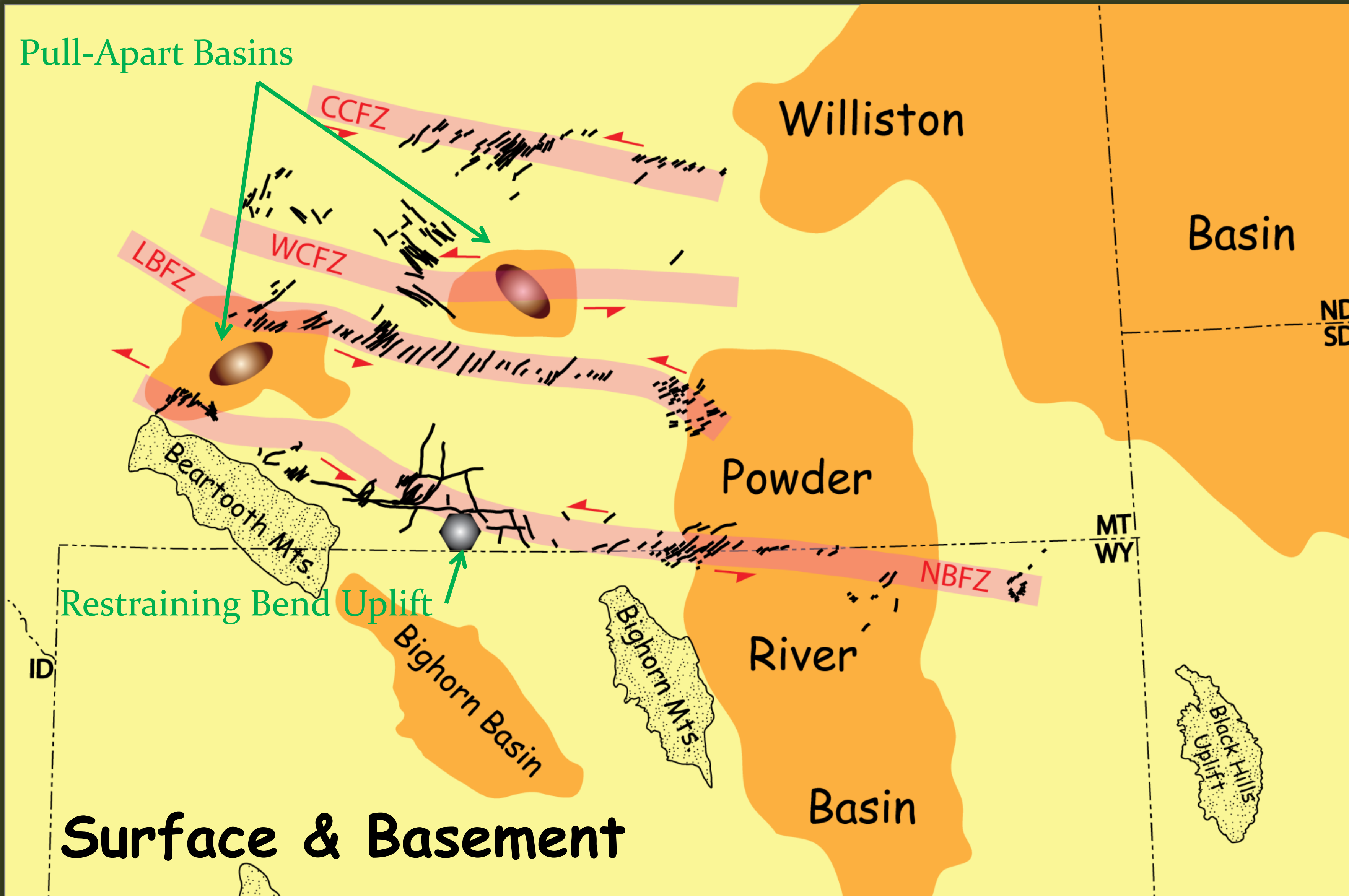


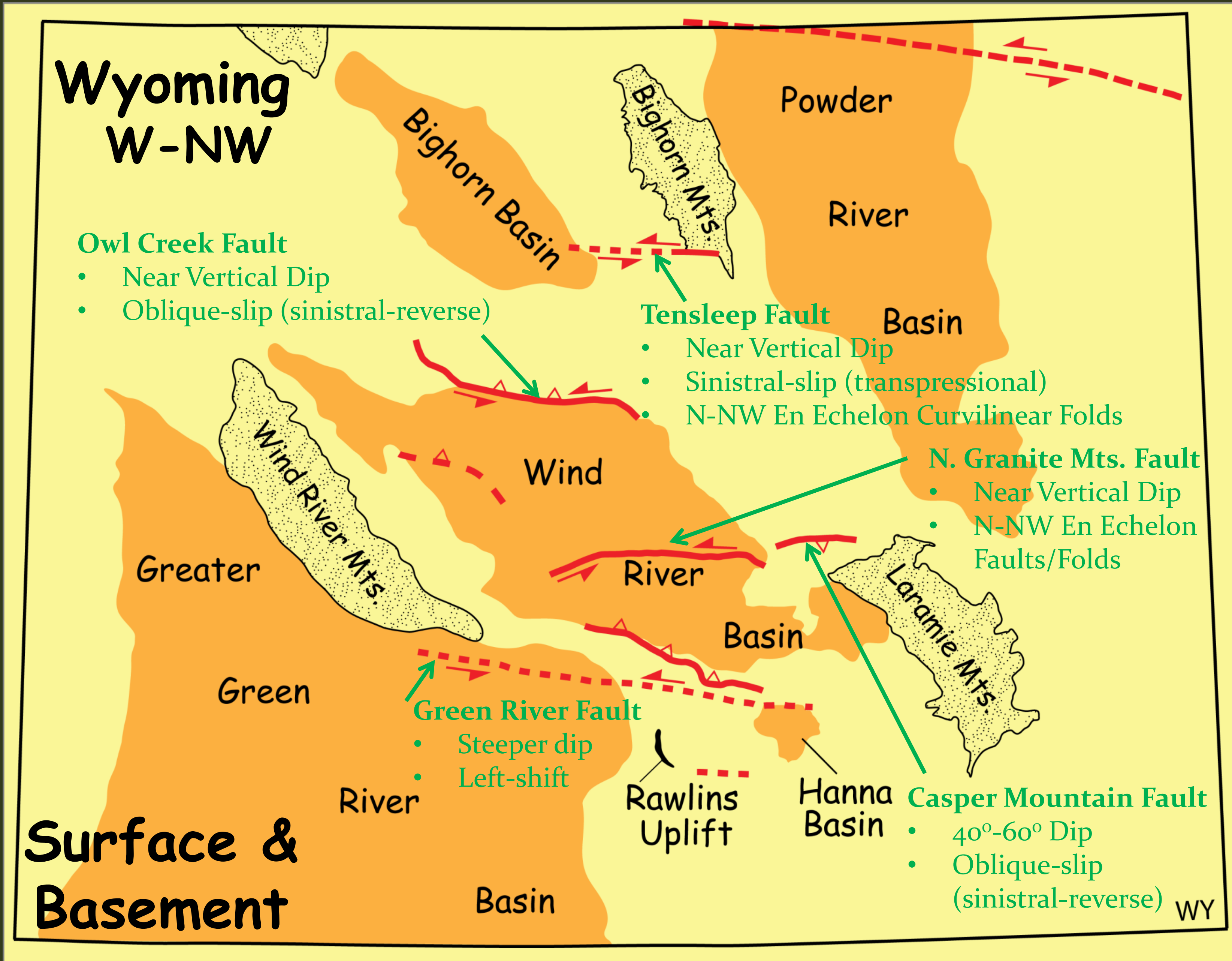


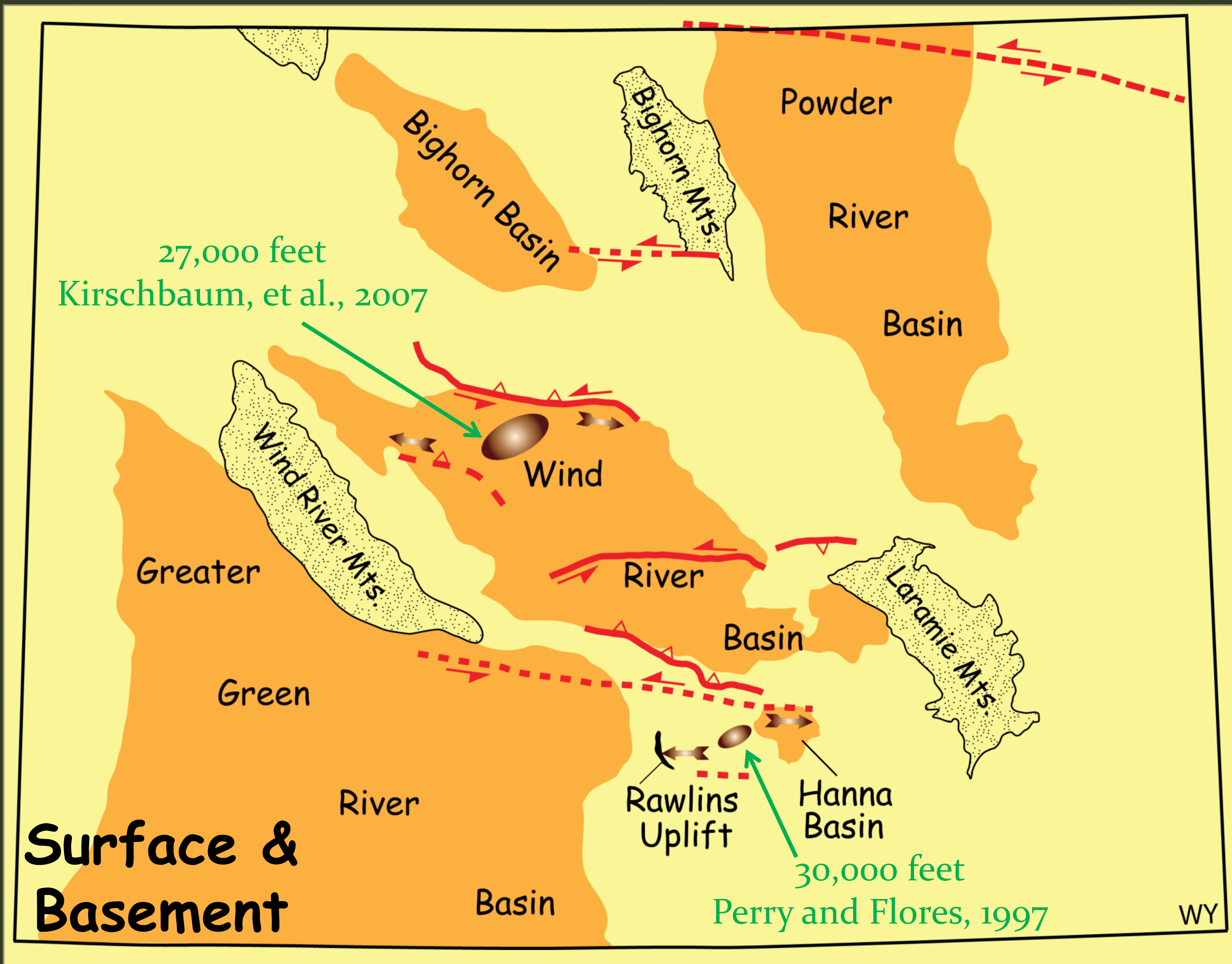
Montana
Williston
Basin
ND
SD
Powder
River
Basin
MT
WY
Beartooth Mts.
Bighorn Basin
Bighorn Mts.
Black Hills Uplift
ID
Basement


Surface
Rectilinear Deformation Zones
En Echelon Normal Faults
Williston
Basin
Rectilinear Deformation Zone
En Echelon Reverse Faults
En Echelon Curvilinear Folds
ND
SD
Beartooth Mts.
Powder
River
Basin
MT
WY
Bighorn Basin
Bighorn Mts.
ID
Black Hills Uplift
Rectilinear Deformation Zone
En Echelon Normal Faults, SS Faults

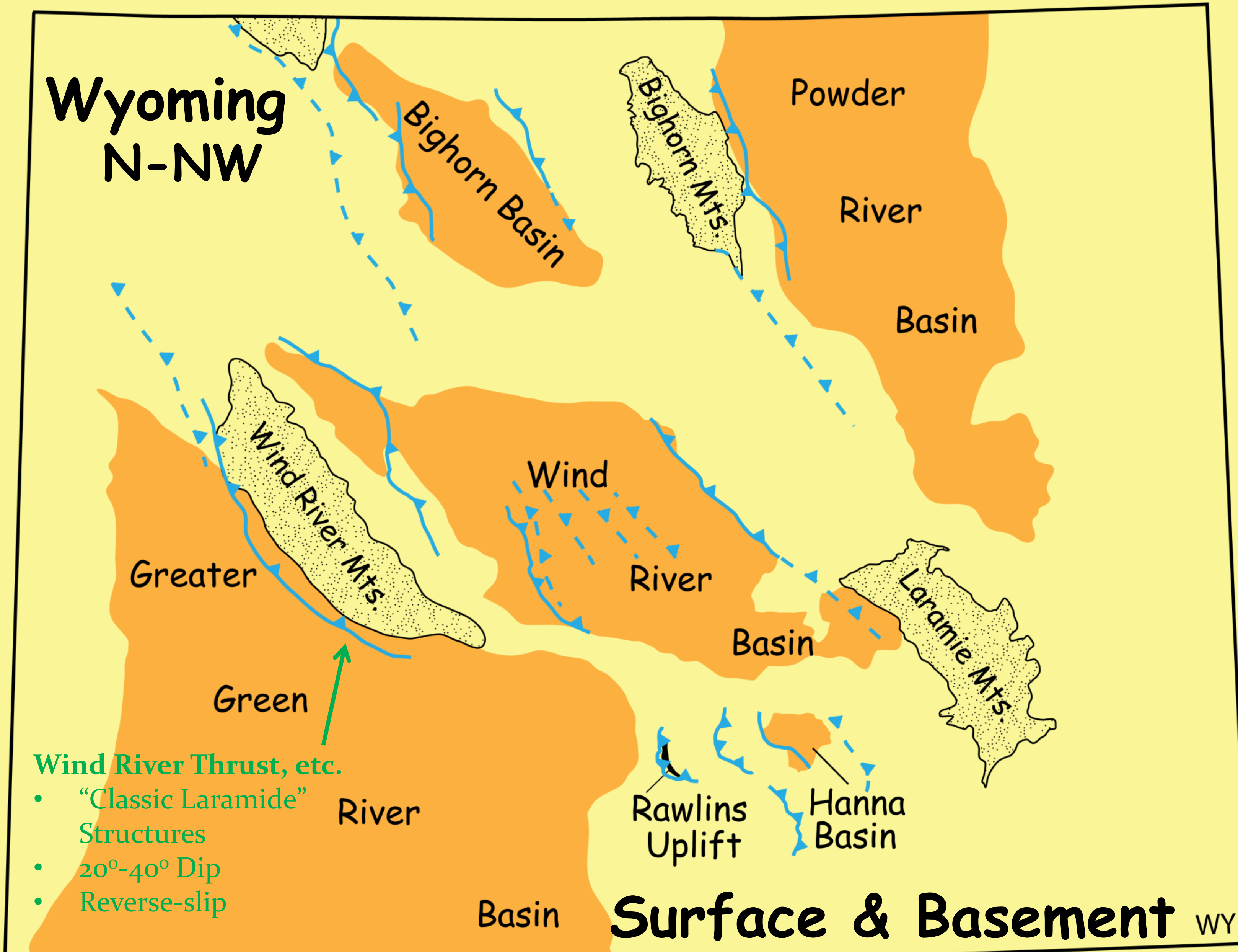

CCFZ
WCFZ
LBFZ
NBFZ
PHS
Williston
Basin
ND
SD
MT
WY
ID
Powder
River
Basin
Beartooth Mts.
Bighorn Basin
Bighorn Mts.
Black Hills Uplift
Surface & Basement


Pull-Apart Basins
CCFZ
WCFZ
LBFZ
NBFZ
Williston
Basin
ND
SD
Powder
River
Basin
MT
WY
ID
Beartooth Mts.
Bighorn Basin
Bighorn Mts.
Black Hills Uplift
Restraining Bend Uplift
Surface & Basement


Wyoming
W-NW
Bighorn Basin
Bighorn Mts.
Powder
River
Basin
Owl Creek Fault
• Near Vertical Dip
• Oblique-slip (sinistral-reverse)
Tensleep Fault
• Near Vertical Dip
• Sinistral-slip (transpressional)
• N-NW En Echelon Curvilinear Folds
Wind River Mts.
Wind
River
Basin
N. Granite Mts. Fault
• Near Vertical Dip
• N-NW En Echelon Faults/Folds
Greater
Green
River
Basin
Laramie Mts.
Green River Fault
• Steeper dip
• Left-shift
Rawlins Uplift
Hanna Basin
Casper Mountain Fault
• 40°-60° Dip
• Oblique-slip (sinistral-reverse)
Surface &
Basement
WY



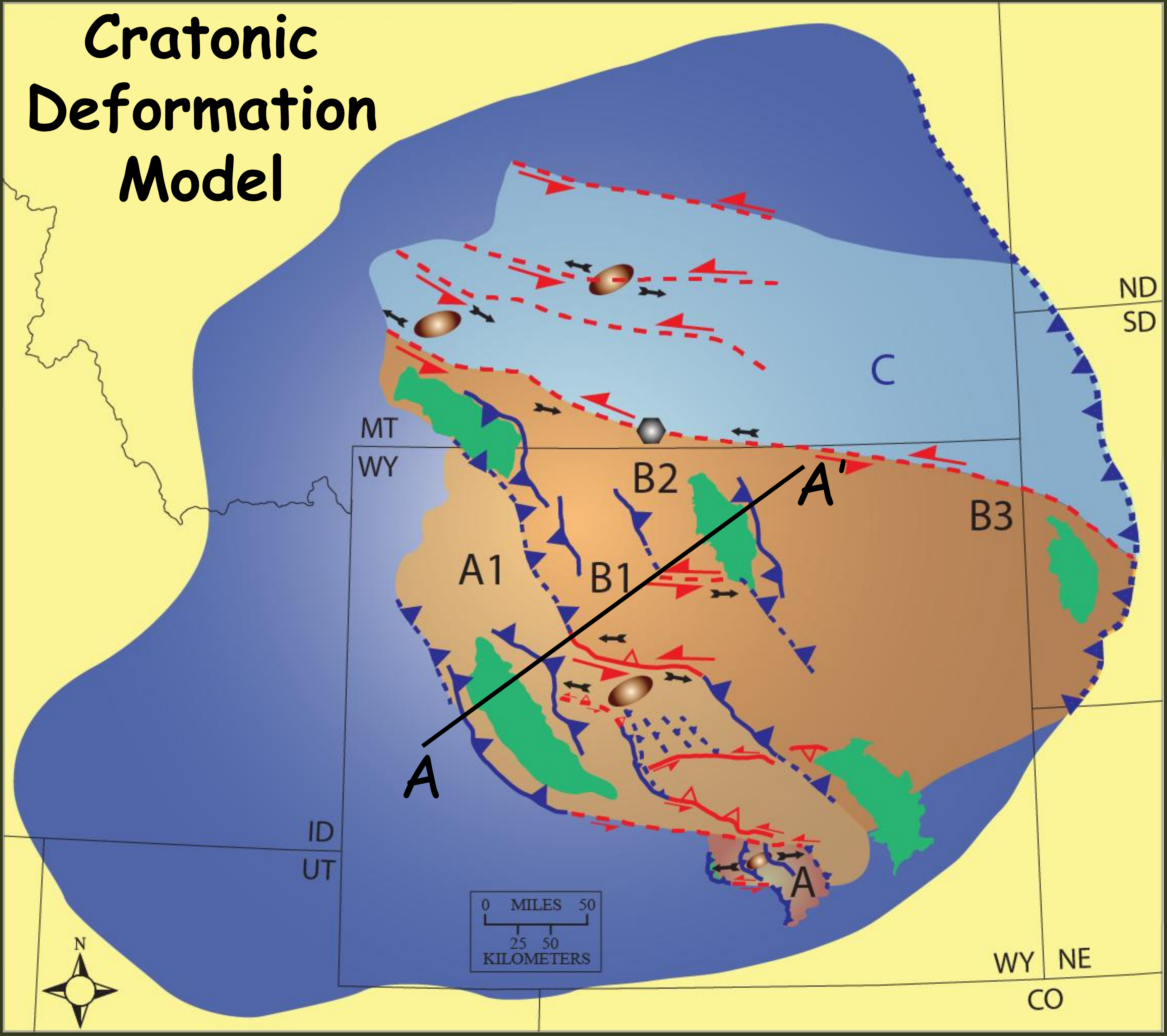
Bighorn Basin
Bighorn Mts.
Powder
River
Basin
27,000 feet
Kirschbaum, et al., 2007
Wind River Mts.
Wind
River
Basin
Greater
Green
River
Basin
Laramie Mts.
Rawlins Uplift
Hanna Basin
30,000 feet
Perry and Flores, 1997
Surface &
Basement
WY



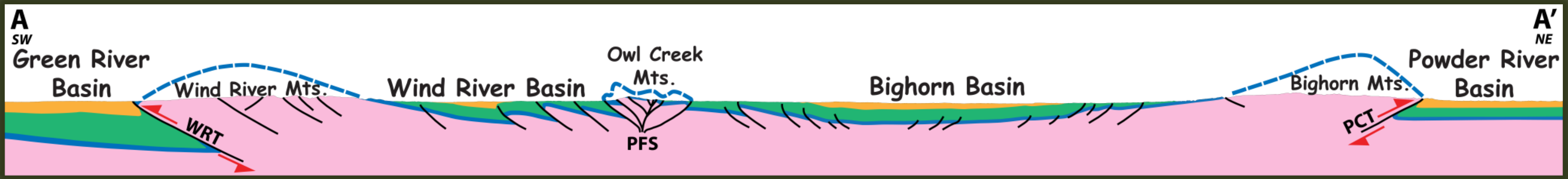
Wind River Thrust, etc.

- "Classic Laramide" Structures
- 20°-40° Dip
- Reverse-slip

Cratonic Deformation Model



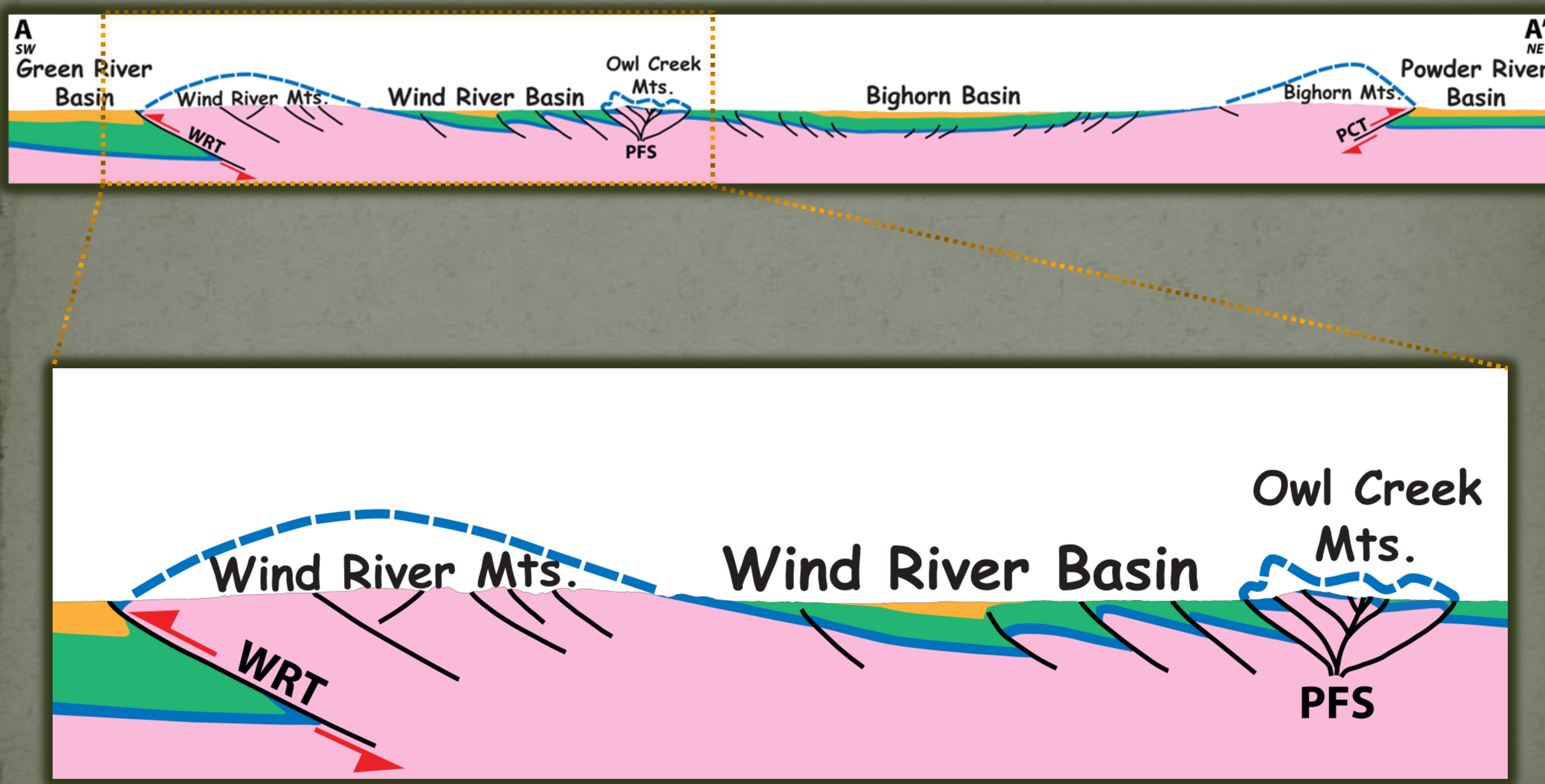
Upper Crustal Levels



Stone, 1987

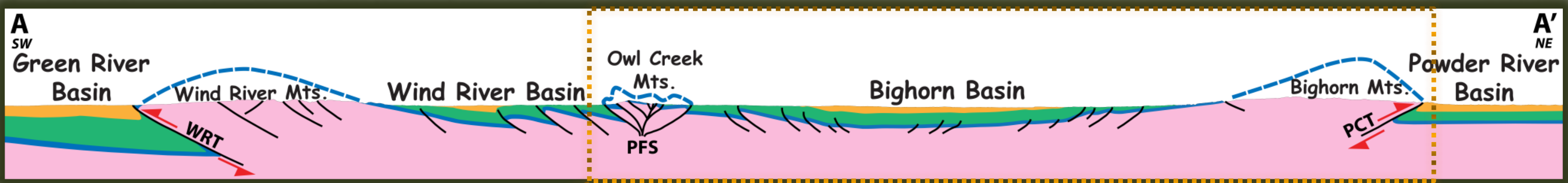
Southwest

- Arch versus Uplift
  - Clearly not the same!
- Wind River Basin Faults?

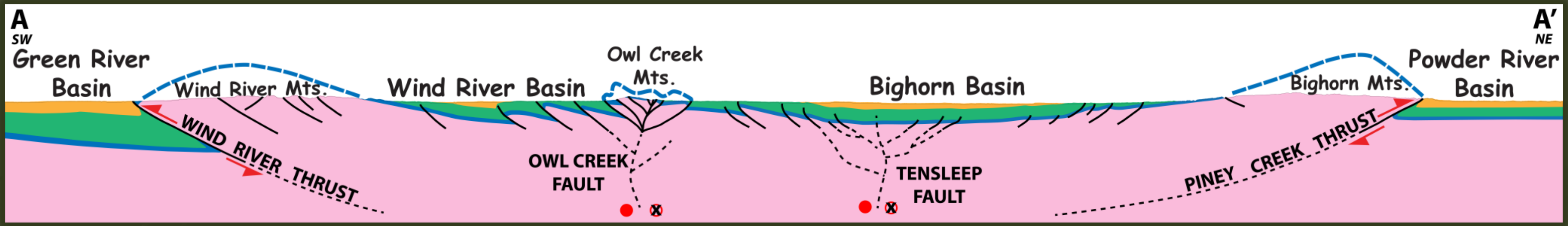


Northeast

- Arch versus Uplift
  - Clearly not the same!
- Bighorn Basin Faults?



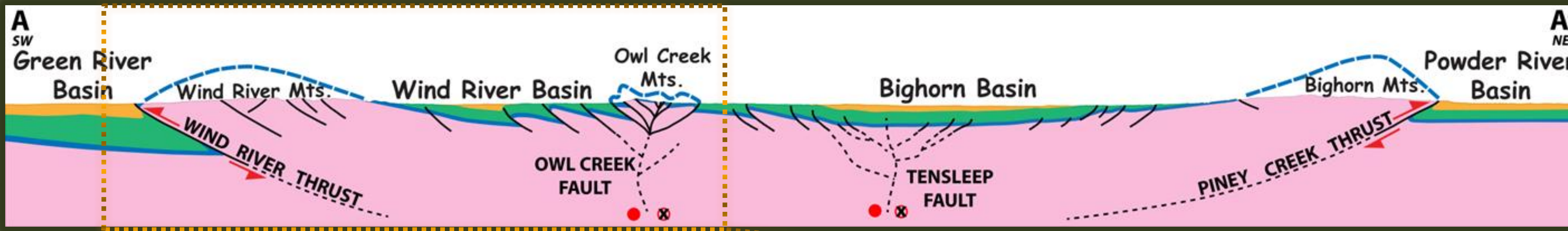
Mid-Crustal Levels

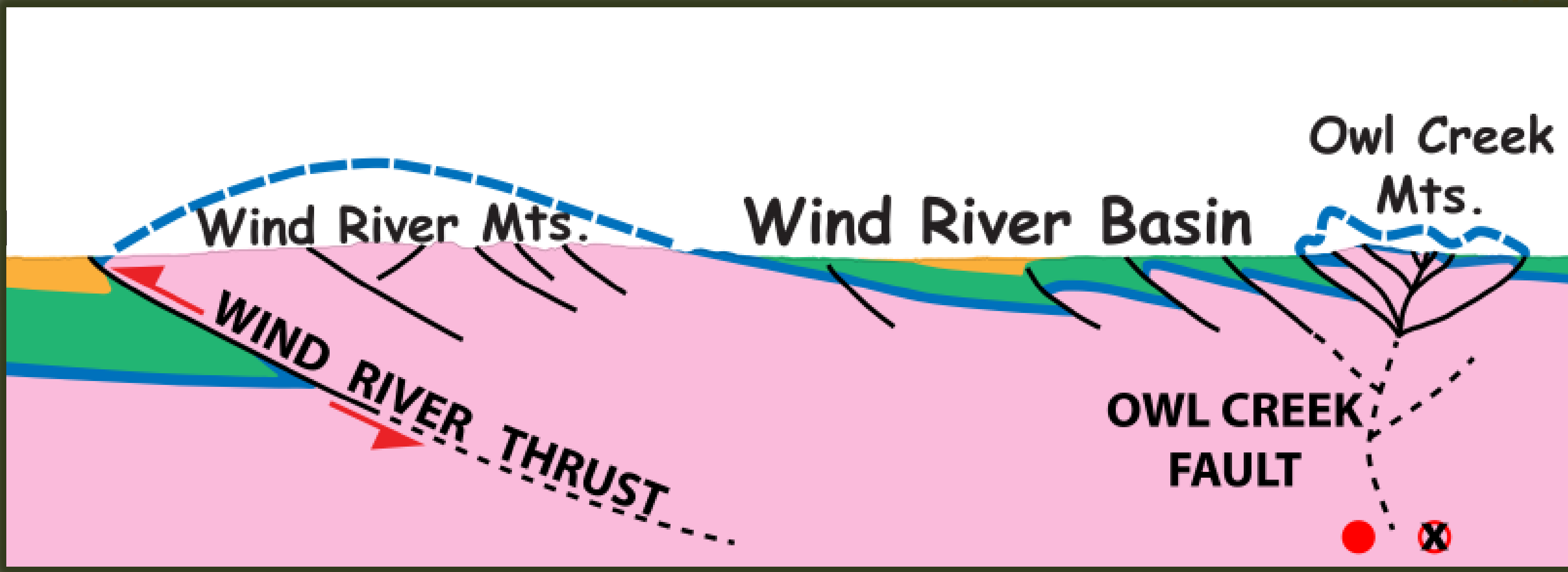


Modified from Stone, 1987

Southwest

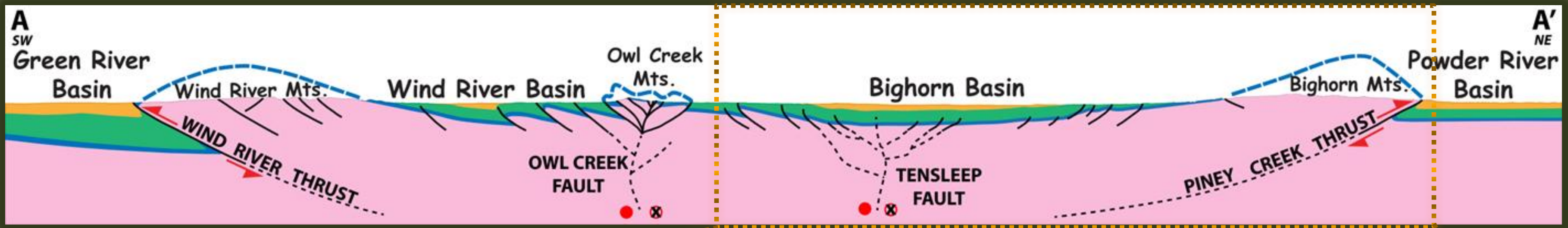
- Reverse/Thrust versus Oblique (sinistral/reverse)
  - Slip is different!
- Wind River Basin Faults = Splays off master Owl Creek Fault! Thrusts/SS

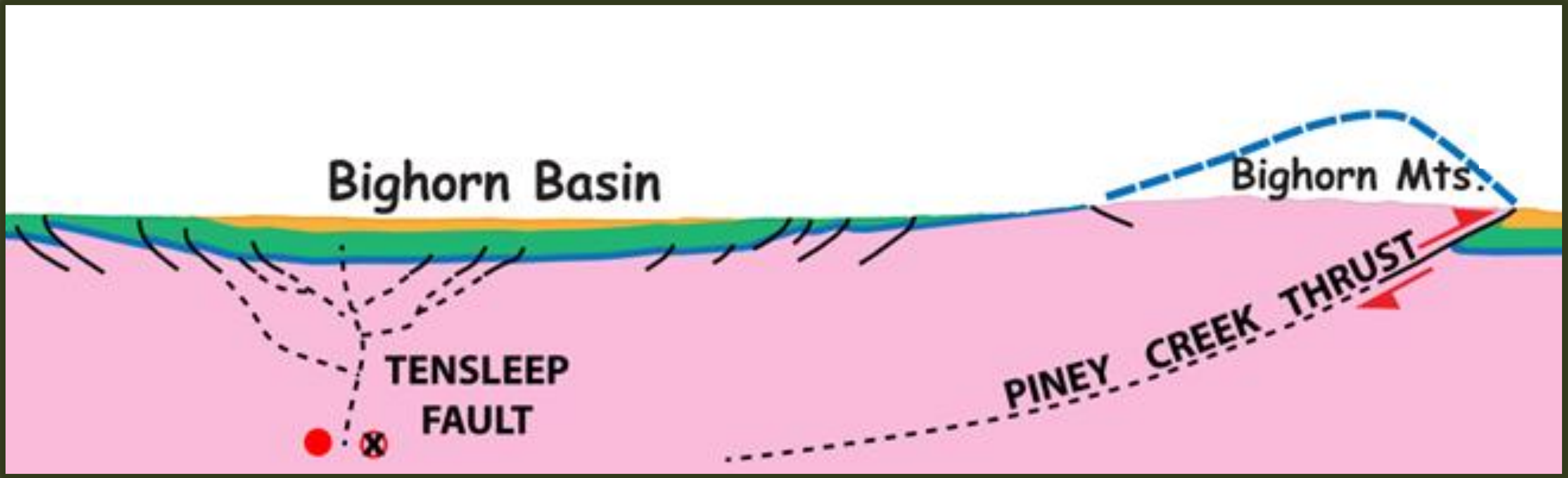




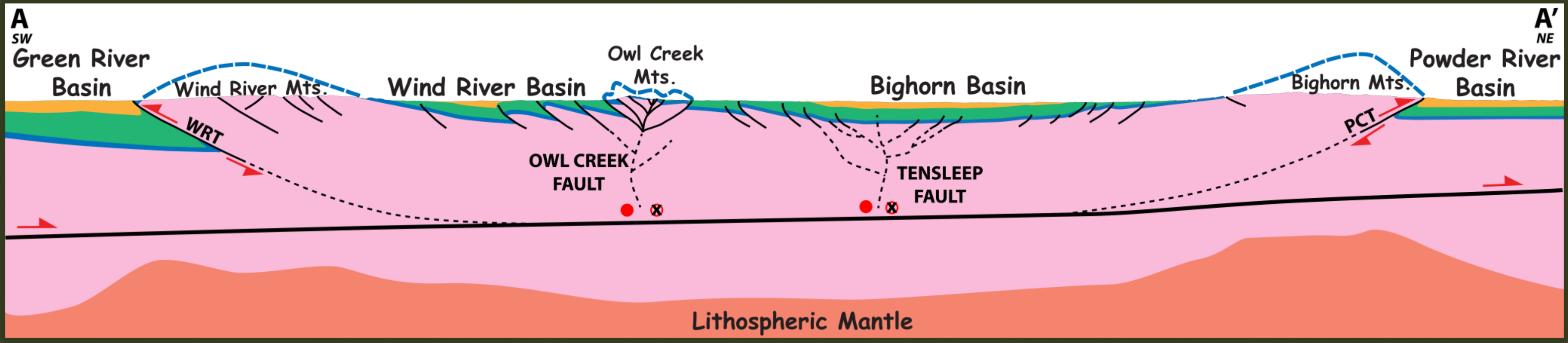
Northeast

- Reverse/Thrust versus Oblique (sinistral/reverse)
  - Slip is different!
- Bighorn Basin Faults = Splays off master Tensleep Fault! Thrusts/SS





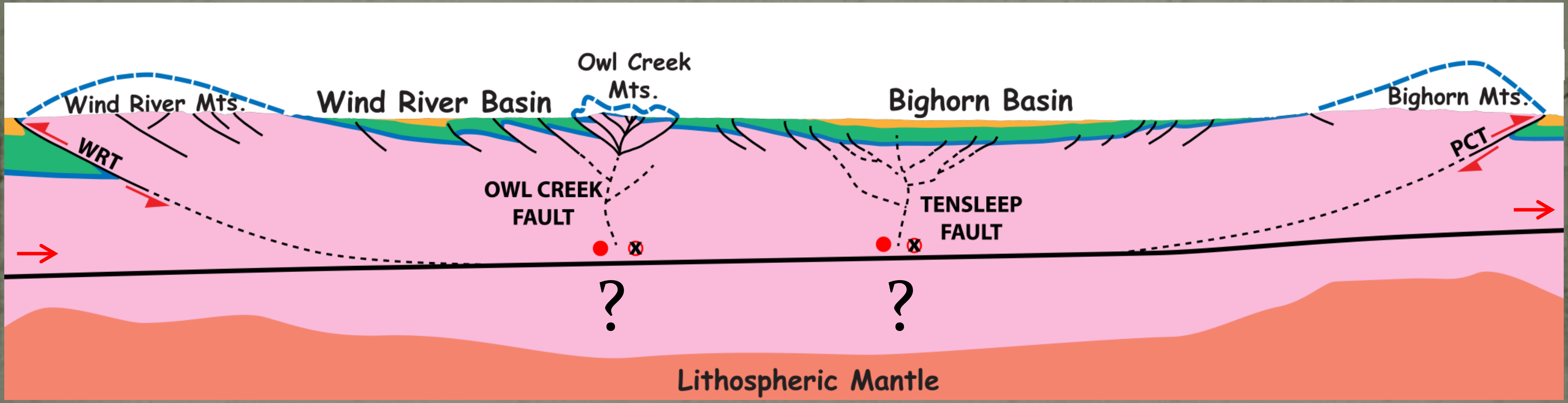
Lower Crustal/Upper Mantle Levels

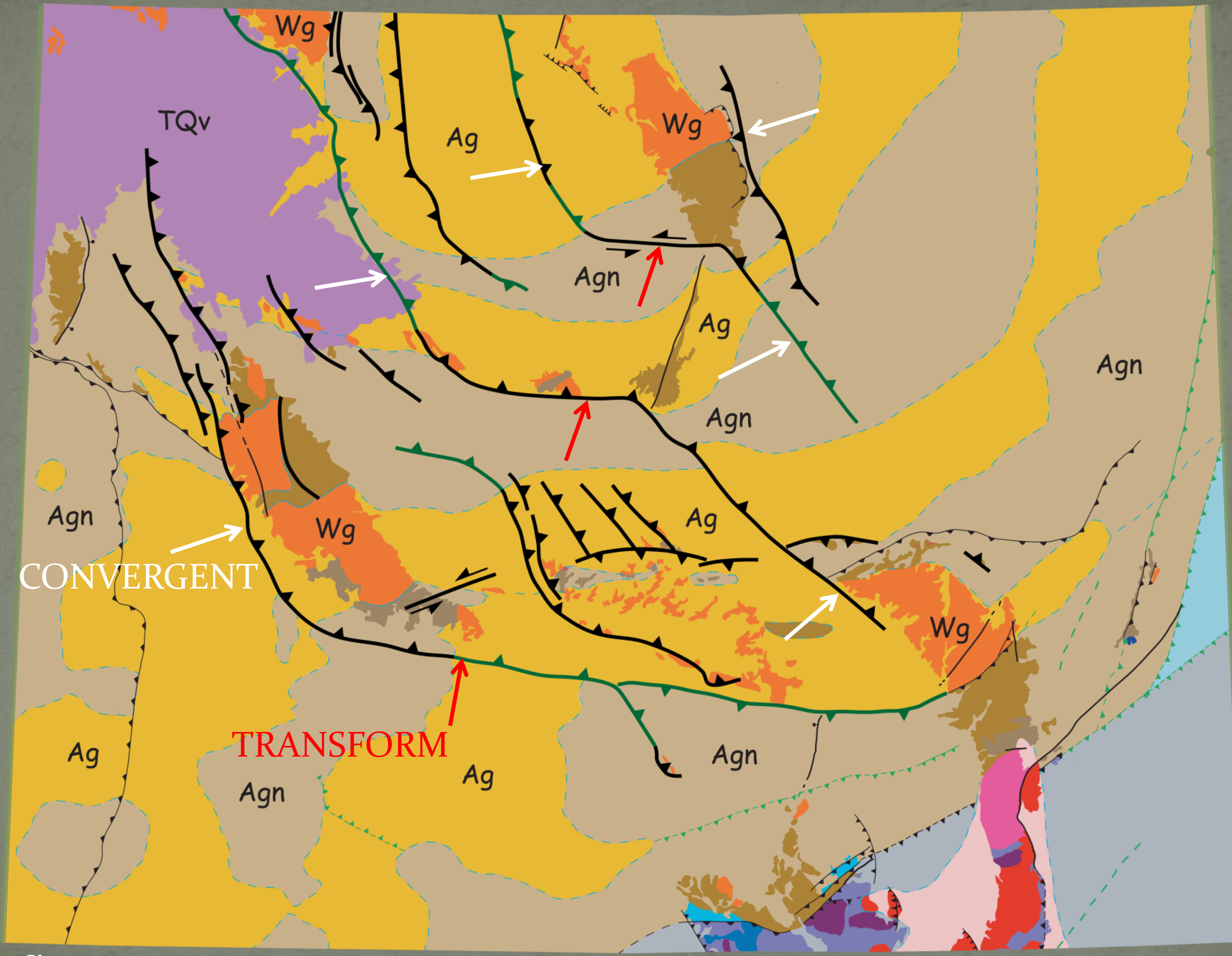


Modified from Stone, 1987 and Yeck, et al., 2014

Chicken or the Egg?

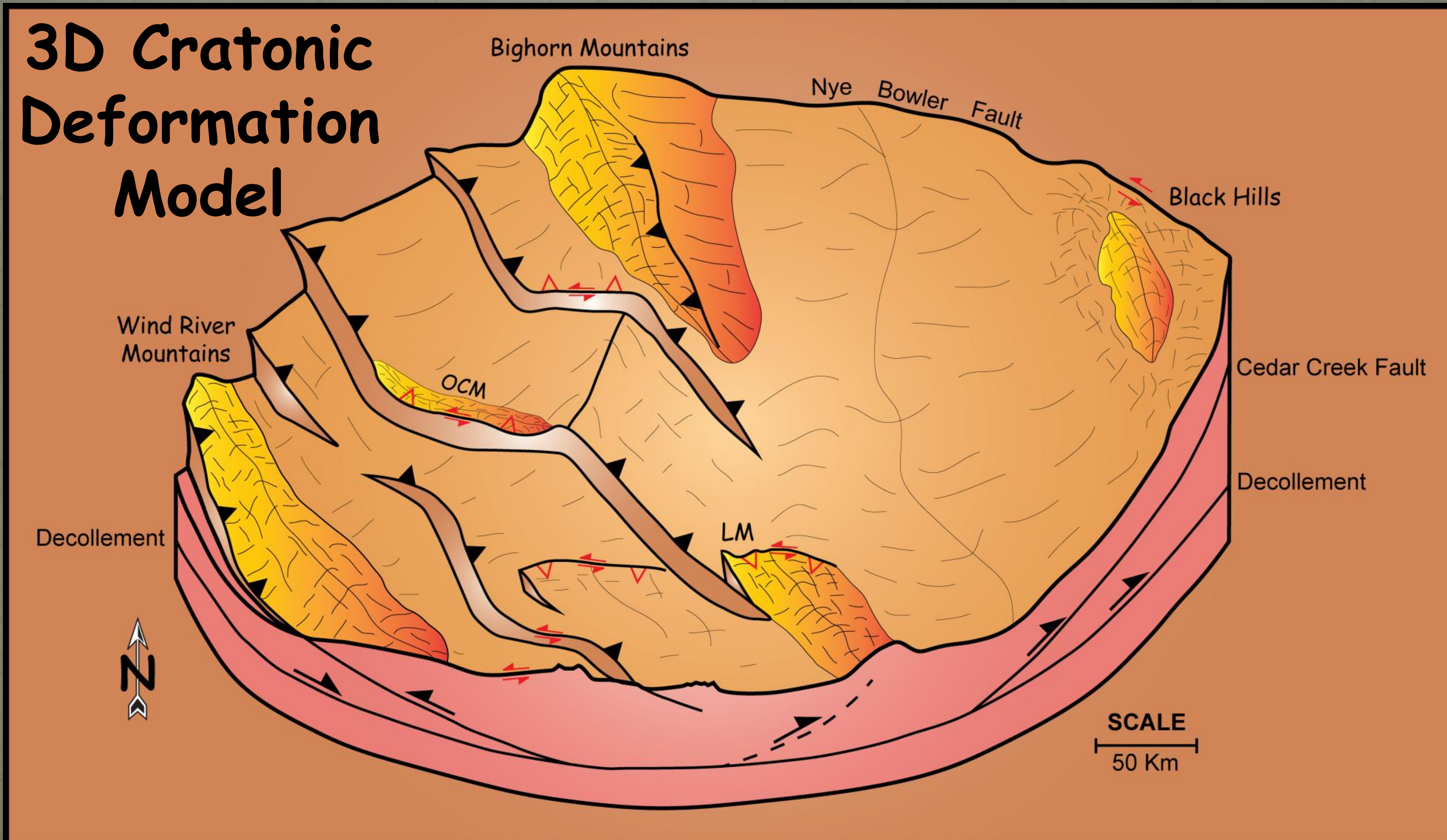
- Arch thrusts **sole out** into mid-crustal detachment zone
- Arch thrusts are **"connected"** via oblique-slip (sinistral/reverse) faults acting as **lateral ramps** facilitating horizontal thrust movement
- Possible **relationship** between upper mantle and basement anisotropies beneath uplifts
  - For thrusts (= **Archean magmatic arcs**/subduction zones; WRM)
  - For lateral ramps (= ?)
    - = **transform faults** connecting Archean magmatic arcs/subduction zones?





Sims, 2001

North-Central Wyoming-Late Eocene



Summary

- Precambrian basement anisotropies **exist** across the Wyoming craton (N-NW and W-NW)
- These anisotropies **correspond well** to surface structures
- Evidence of **left-shift** on the W-NW faults is **ubiquitous** across the craton
  - In **Wyoming**, where W-NW faults "**connect**" with N-NW structures, these faults facilitate Laramide thrusting as **sinistral, reverse-slip lateral ramps**
  - In **Montana**, N-NW basement anisotropies are not present; therefore, deformation is confined to **sinistral deformation zones** (transpressional)
- Basement anisotropies appear to be related to:
  - **Convergent plate margins** during the **Archean** (WY)
  - **Cratonic rift zones** during the **Proterozoic** (MT)
  - **Proterozoic craton boundary** (SD and MT)

Summary Con't

- Orientation of basement anisotropies were conducive to **reactivation under NE-SW directed PHS** during the Laramide
- The orientation of these features and deformation history create the **"symmetry"** observed across the Wyoming craton
- Further studies on the **left-shift zones** need to be conducted to understand mid- to lower-crustal/upper mantle relationships **= DRIVER**
- This cratonic model is **consistent with accepted models** of Laramide orogenesis and requires minimal explanations for the various Laramide structures seen across the craton


THANK YOU!