Uniformitarianism and the Laramide Orogeny of the Wyoming Craton: The Present is the Key to the Past, and the Past…*

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Abstract

Seismic studies (COCORP, Deep Probe, and EarthScope BASE) have provided a better understanding of Laramide tectonism at deeper crustal levels. However, deformational mechanisms in the upper crust related to Laramide orogenisis remain unclear. Internal controls of Laramide tectonism in the upper crust have been proposed to be related to basement anisotropies, which may be linked to evolution of foreland arches at deeper crustal levels and structures seen at the surface. This study presents a structural and tectonic analysis of Precambrian anisotropies of the Wyoming craton and provides a hypothesis on the potential role of these features in Laramide orogenisis.

Anisotropies are generally oriented in three directions: north-northwest, west-northwest, and northeast. They have a complex and long history of deformation since the Precambrian, most recently, during the Laramide. This work provides evidence for development of long-lived Neoarchean zones of convergence dominantly directed from the southwest towards the craton forming north-northwest weakness zones, as shown from modern analogs. In addition, northeast-southwest-directed pure-shear compressional forces from convergence are postulated to have formed west-northwest- and northeast-trending anisotropies in the form of conjugate shears, again supported by modern convergence zone deformations.

It is proposed that these structures were reactivated throughout Laramide contraction, forming discrete zones of transpression that were displaced along a southwest- to northeast-directed Laramide deformational front. In the Wyoming transpressive zone,

west-northwest structures were displaced as reverse/left-lateral oblique-slip faults and, where connected, acted as lateral ramps facilitating major arch development along the north-northwest-trending structures. In the Montana transpressive zone, where north-northwest basement anisotropies are not present, reverse-sinistral slip occurred along west-northwest basement-seated faults without the associated vertical slip seen in Wyoming. Basement-seated faults are expressed at the surface as oblique, left-slip reverse faults (west-northwest deformational zones in Wyoming/Montana), high-angle right-slip faults (northeast deformational zones in Wyoming/Montana), and low-angle reverse faults/thrust faults (north-northwest arches generally only in Wyoming) that are interconnected in a convergent deformation system that likely includes the Black Hills. This deformation system is postulated to be a fundamental tectonic feature controlling formation of Laramide arches/uplifts of the Wyoming craton.

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Uniformatarianism and the Laramide Orogeny of the Wyoming Craton

The Present is the Key to the Past, and the Past…

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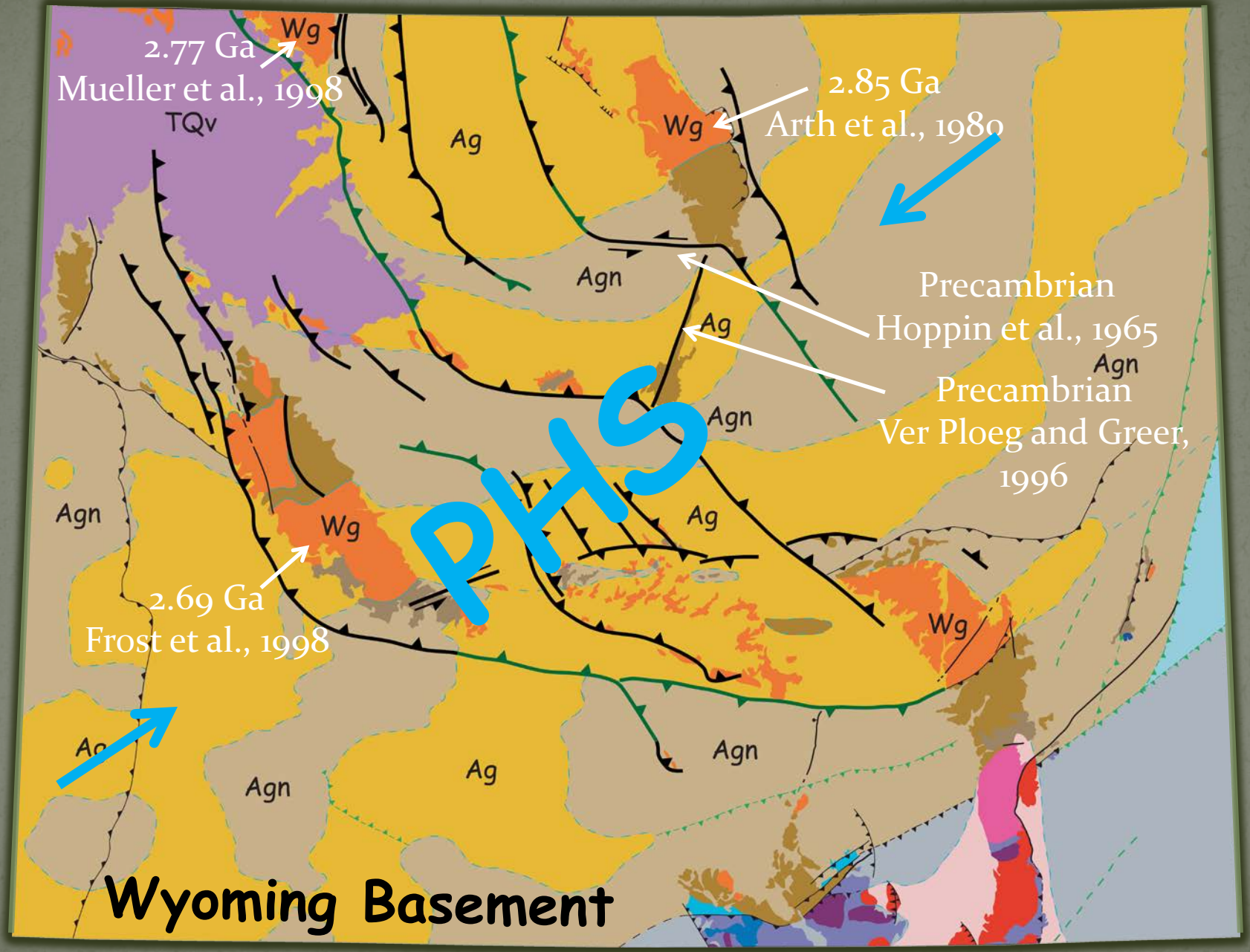
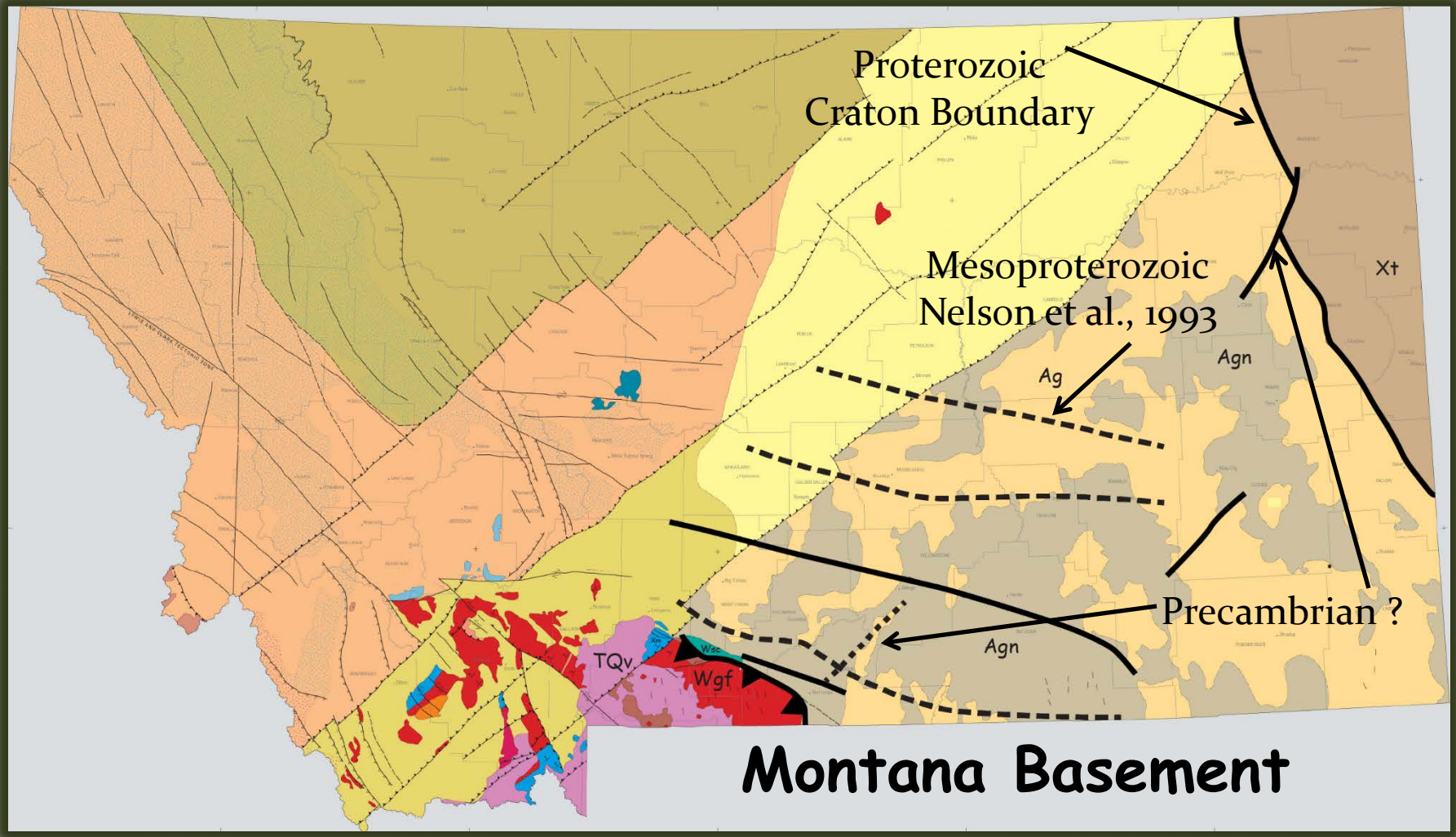
STUDY
AREA
ND
SD
MT
ID
NV
UT
WY
NE
CO

Hypothesis:

Laramide structures of the Wyoming craton formed in the Precambrian under a convergent tectonic regime and these basement structures were simply reactivated under a similar PHS during Laramide orogenisis



Sims et al., 2001



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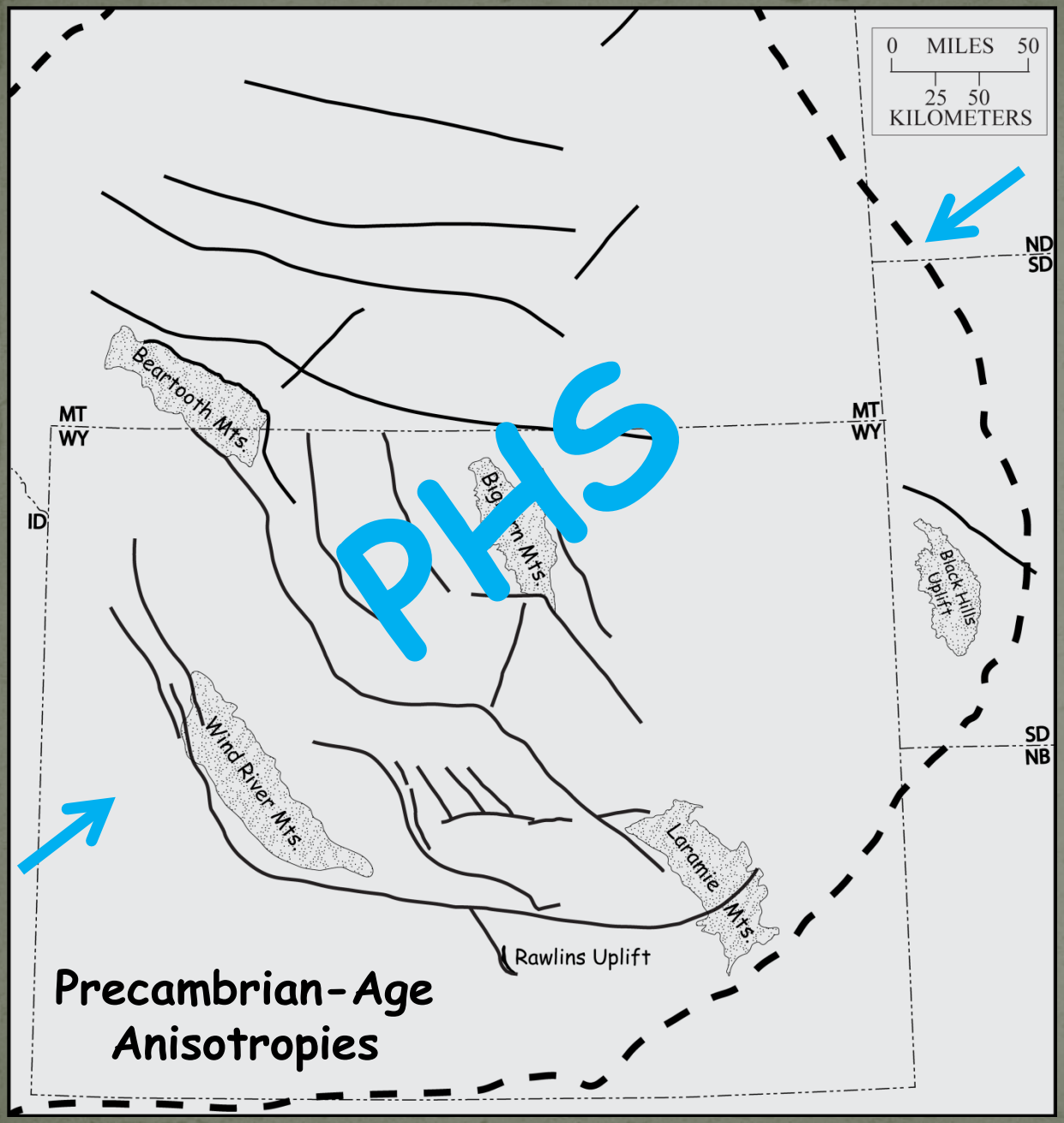
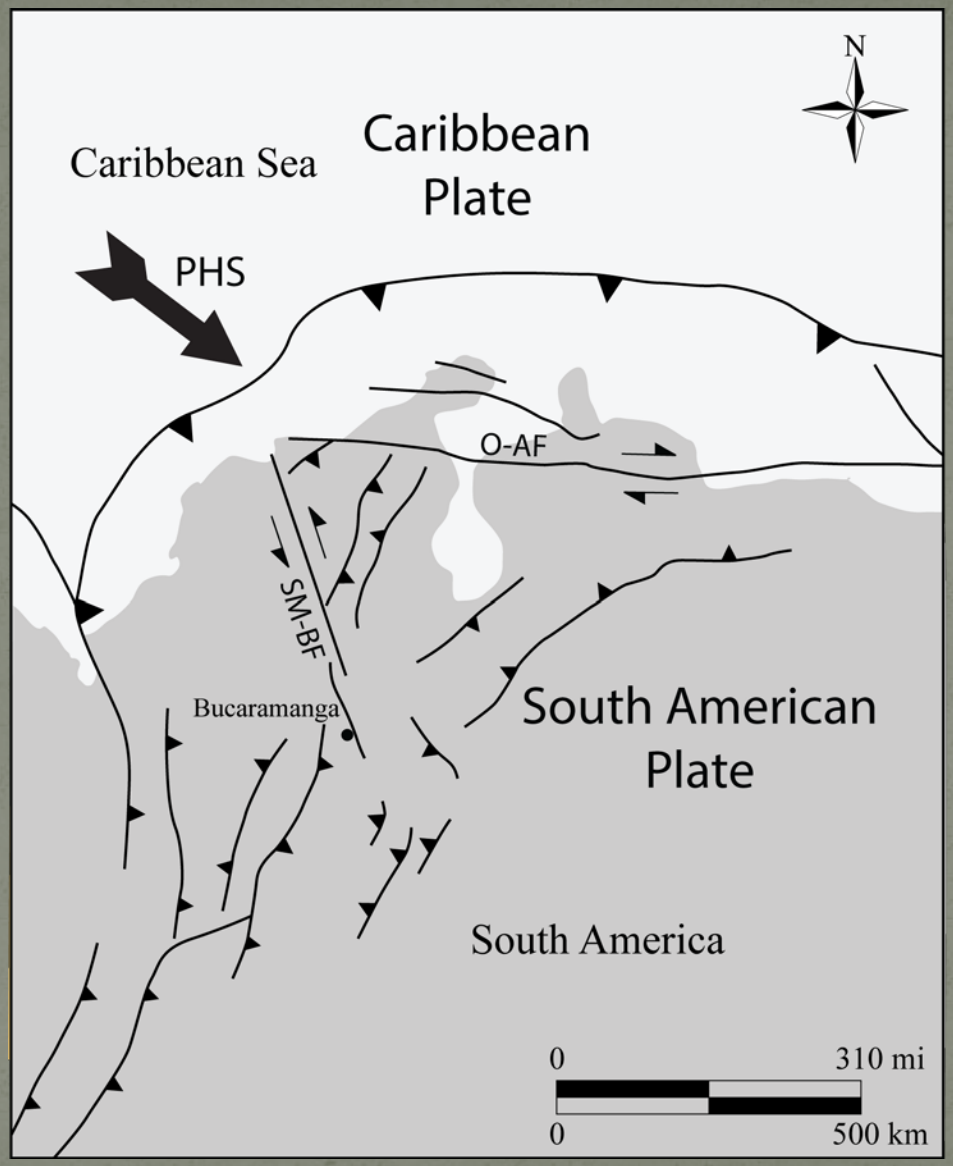


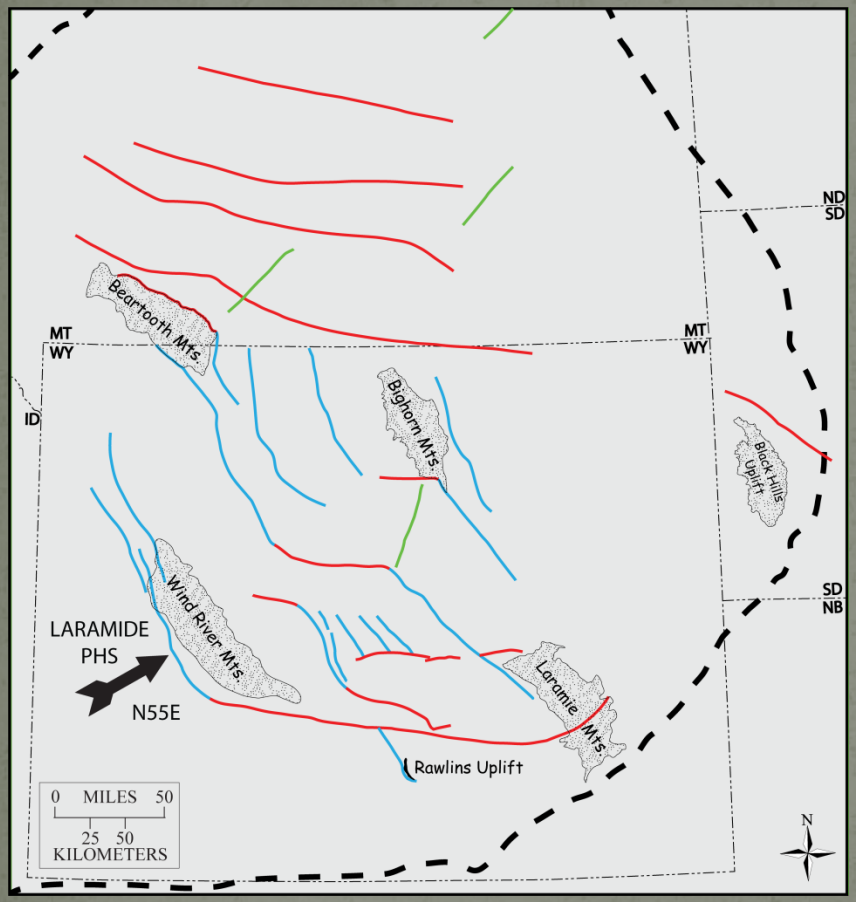
Modern Analogues ?

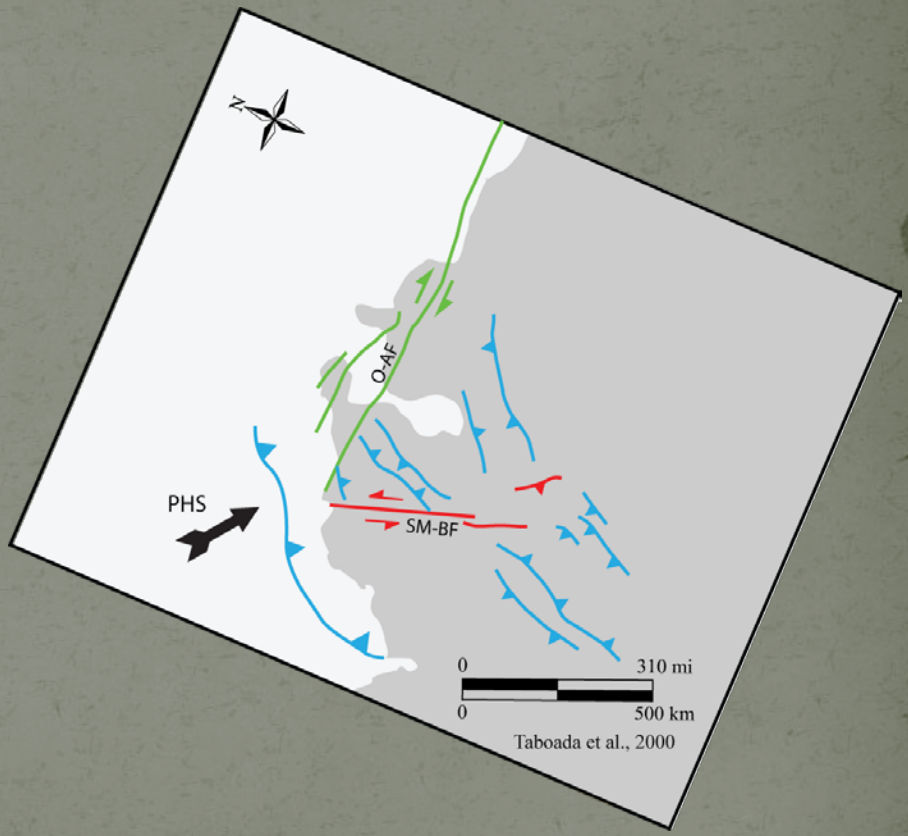
South America Analogue



Comparison to Precambrian Anisotropies of WC & Laramide Deformations ?

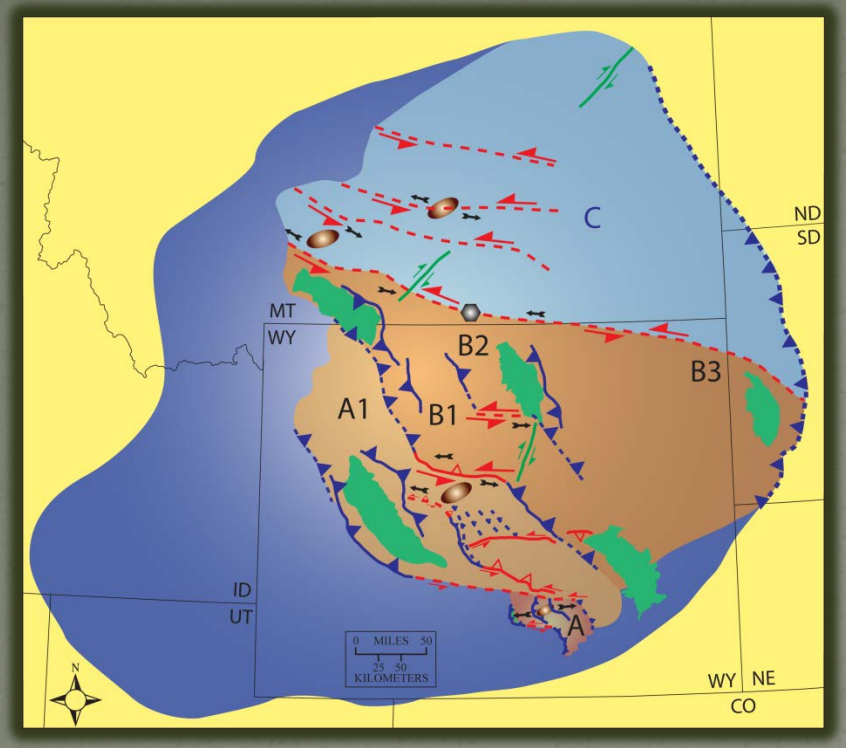
South America Analogue



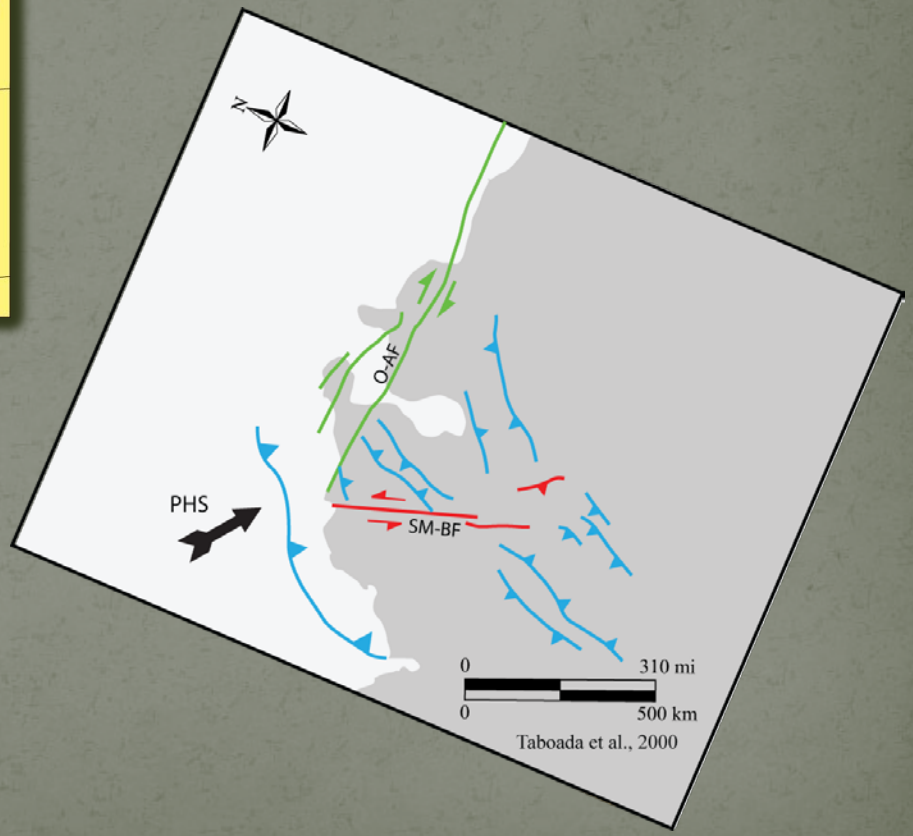


Precambrian-Age Anisotropies

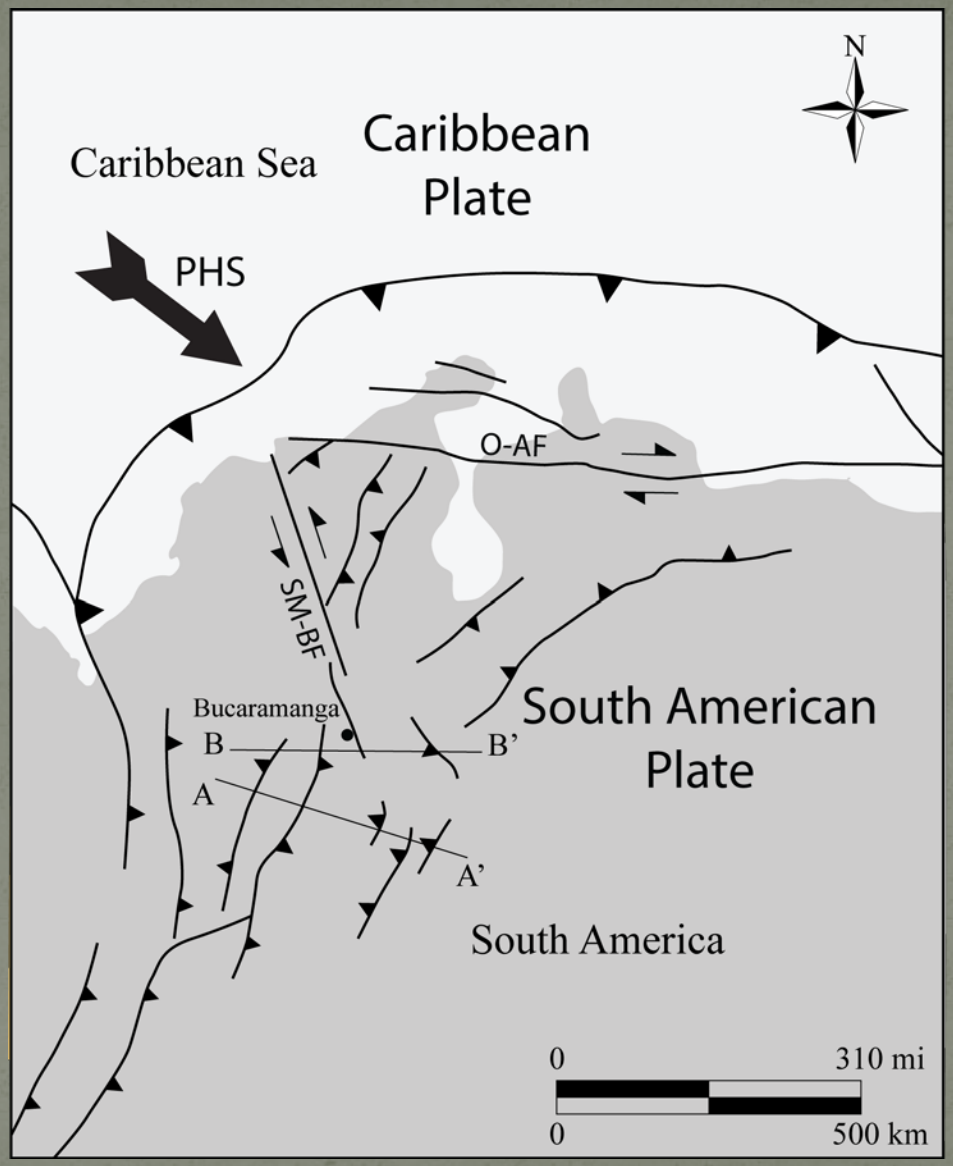
South America Analogue

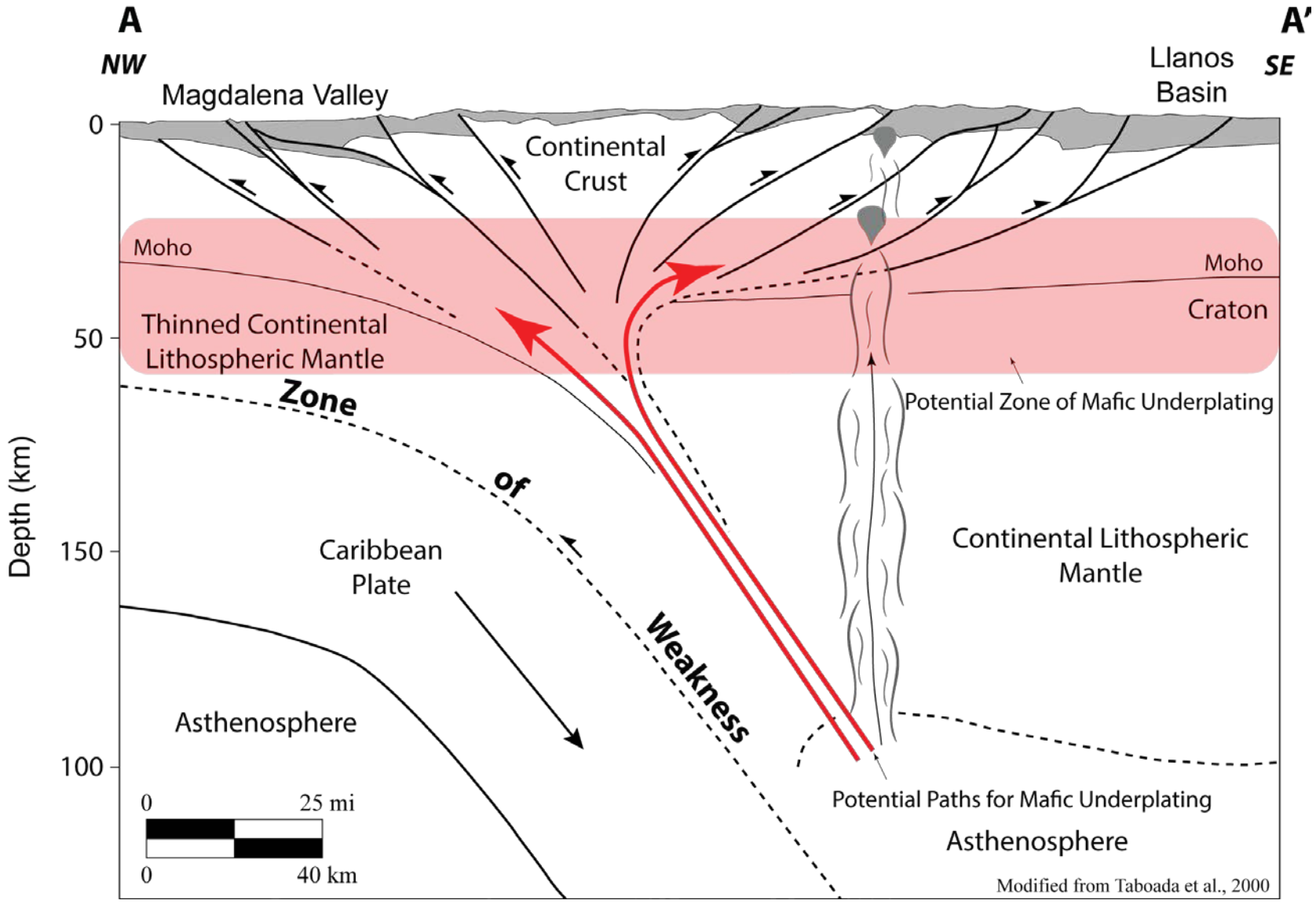


Laramide Deformations



South America Analogue Subsurface




A
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SE
Magdalena Valley
Llanos Basin
Continental Crust
Moho
Moho
Craton
Thinned Continental Lithospheric Mantle
Zone
of
Weakness
Potential Zone of Mafic Underplating
Continental Lithospheric Mantle
Caribbean Plate
Asthenosphere
Potential Paths for Mafic Underplating
Asthenosphere
Depth (km)
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25 mi
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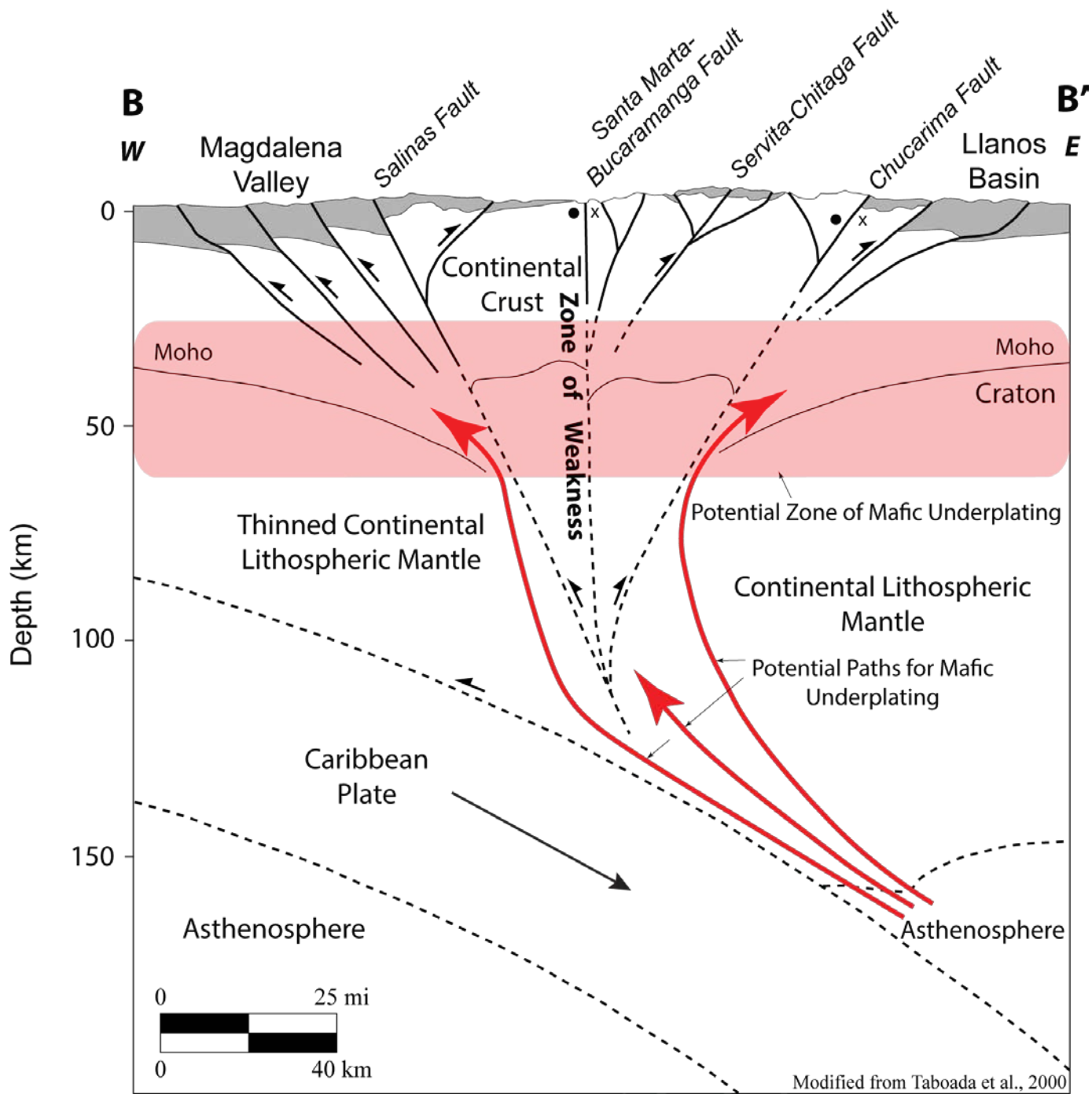
40 km
Modified from Taboada et al., 2000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Magdalena Valley
Salinas Fault
Santa Marta-Bucaramanga Fault
Servita-Chitaga Fault
Chucarima Fault
Llanos Basin
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Depth (km)
Continental Crust
Zone of Weakness
Moho
Moho
Craton
Thinned Continental Lithospheric Mantle
Potential Zone of Mafic Underplating
Continental Lithospheric Mantle
Potential Paths for Mafic Underplating
Caribbean Plate
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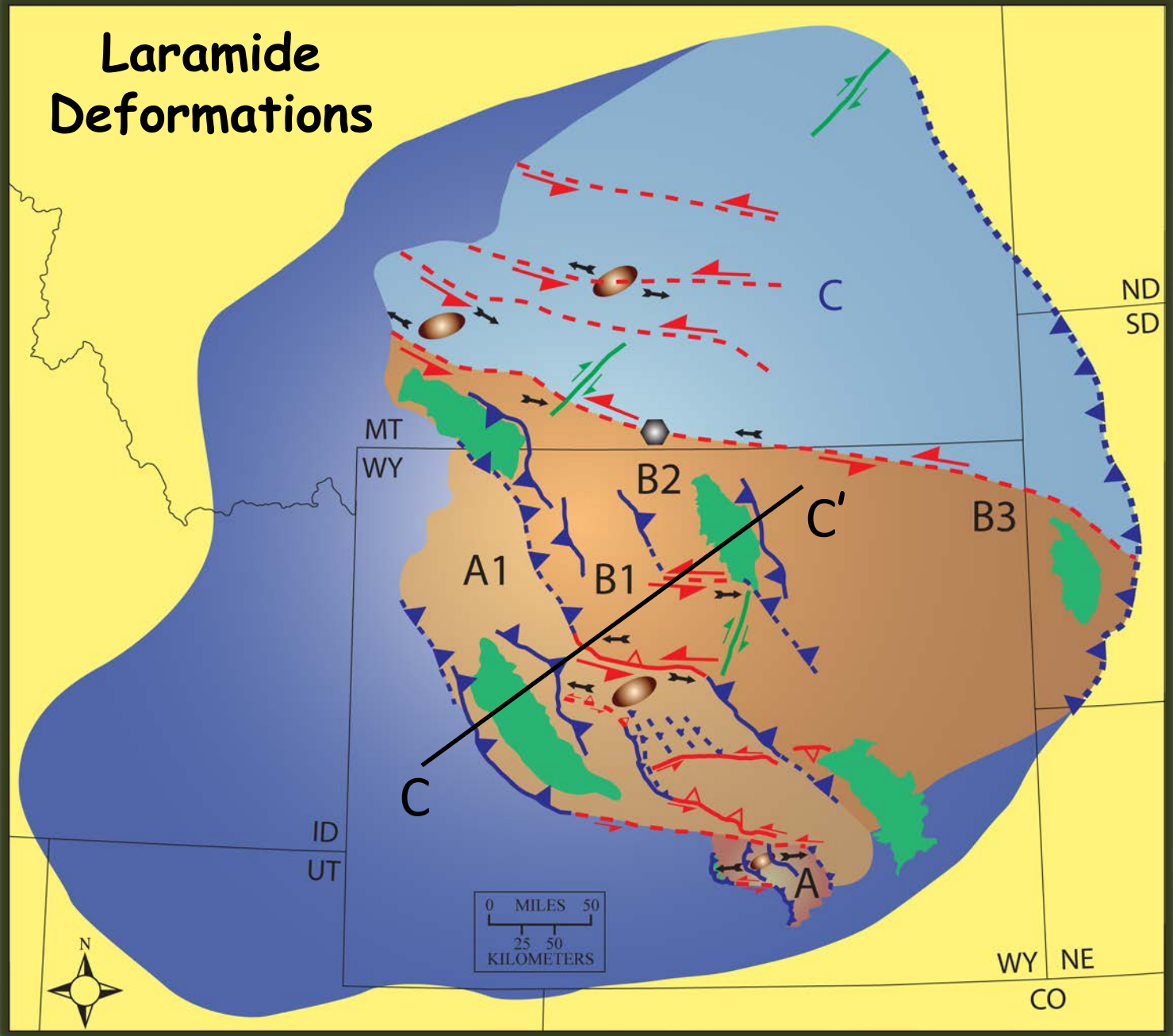
Modified from Taboada et al., 2000


Laramide
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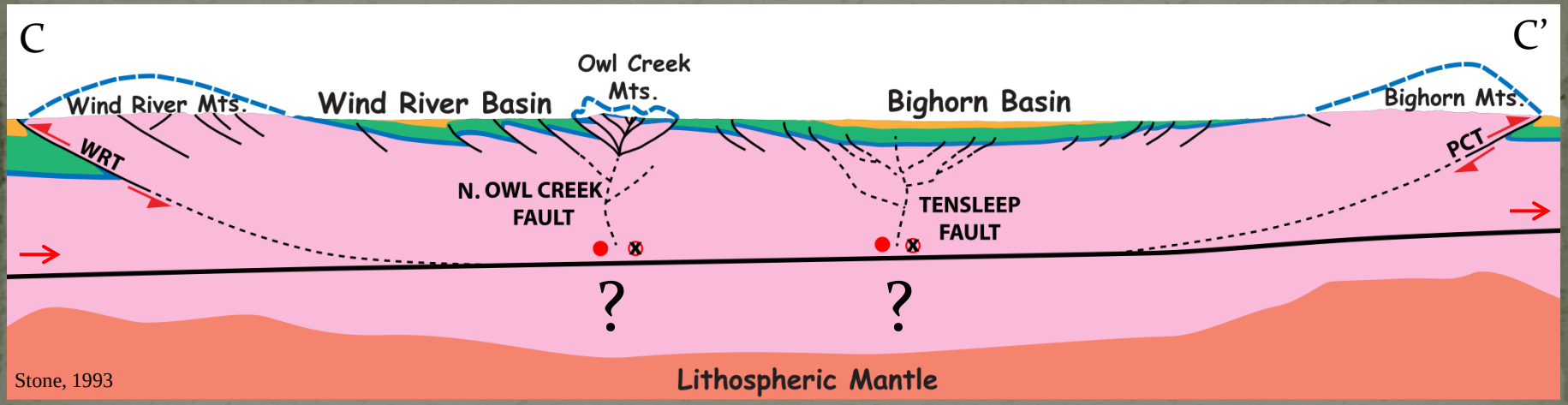
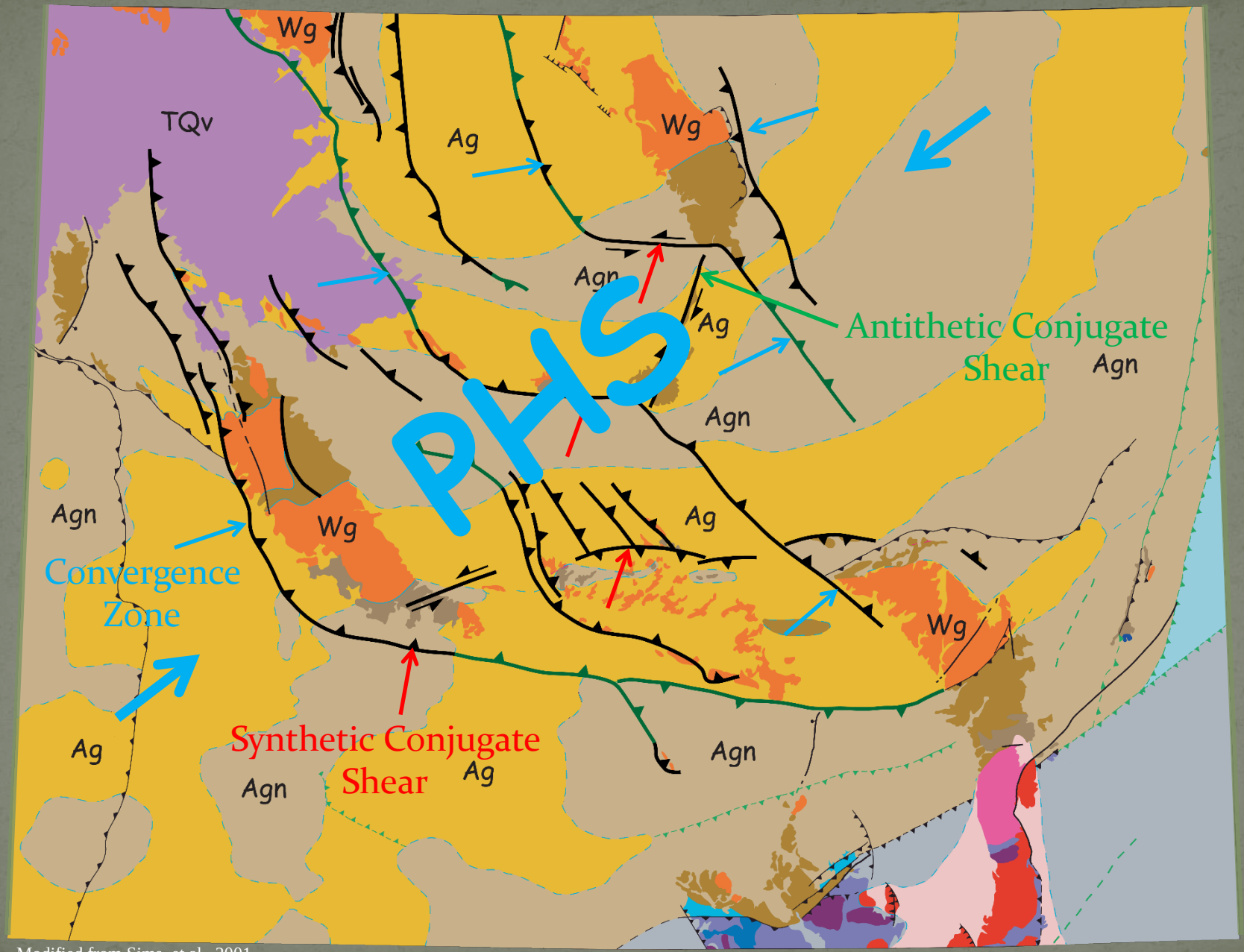
What do we know?

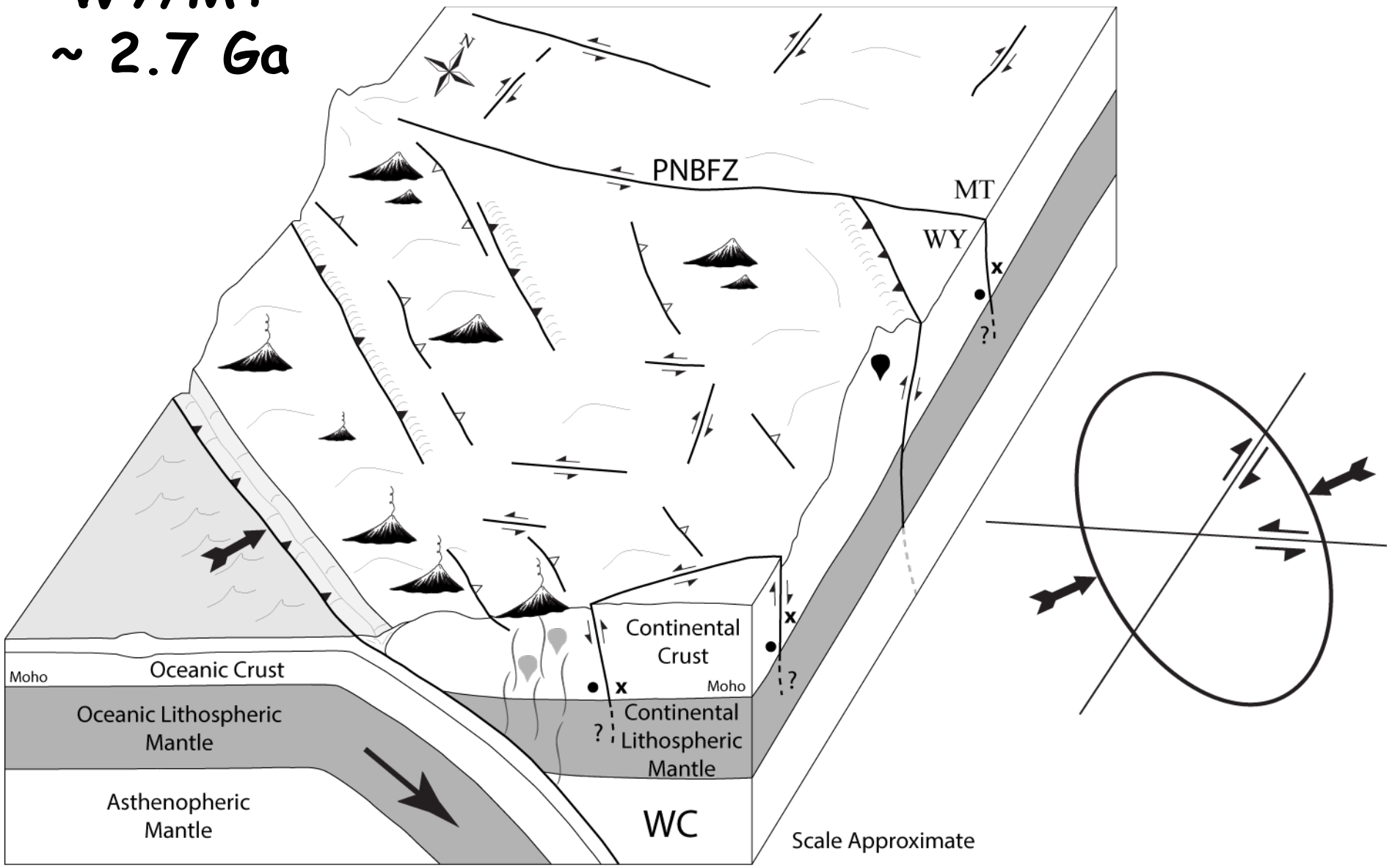
- Arch thrusts "**appear**" **to sole out** into mid-crustal transition zone
- Arch thrusts are "**connected**" via oblique-slip (sinistral/reverse) faults acting as **lateral ramps** facilitating horizontal thrust movement
- Possible **relationship** between upper mantle and basement anisotropies beneath arches/uplifts
  - For thrusts (= **Archean magmatic arcs**/subduction zones that have jumped and changed polarity through time; WRM/BHM)
  - For lateral ramps (= **?**)
    - = **synthetic conjugate shears** connecting Archean magmatic arcs/subduction zones?





Modified from Sims, et al., 2001

WY/MT
~ 2.7 Ga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Moho
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Mantle
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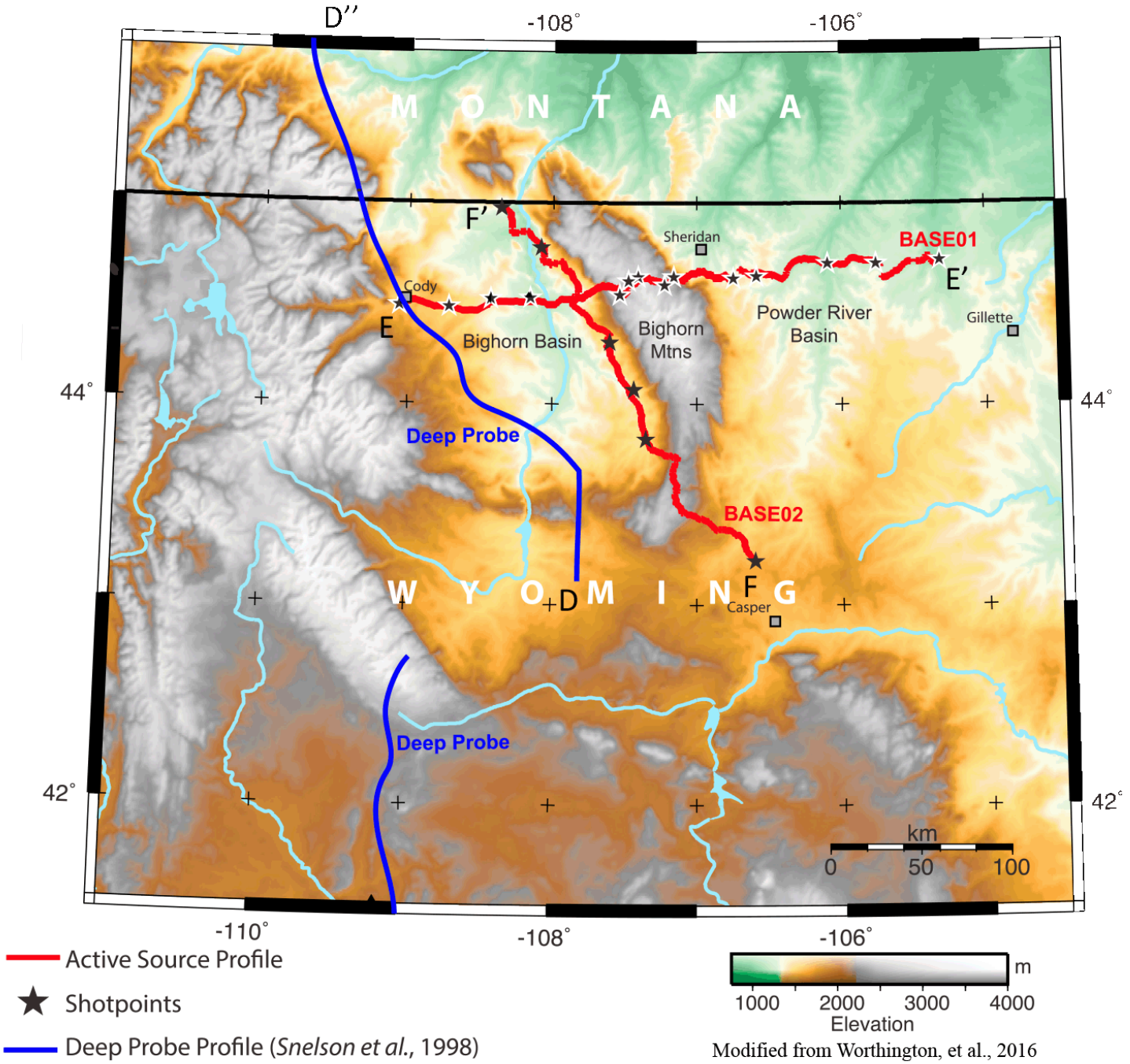
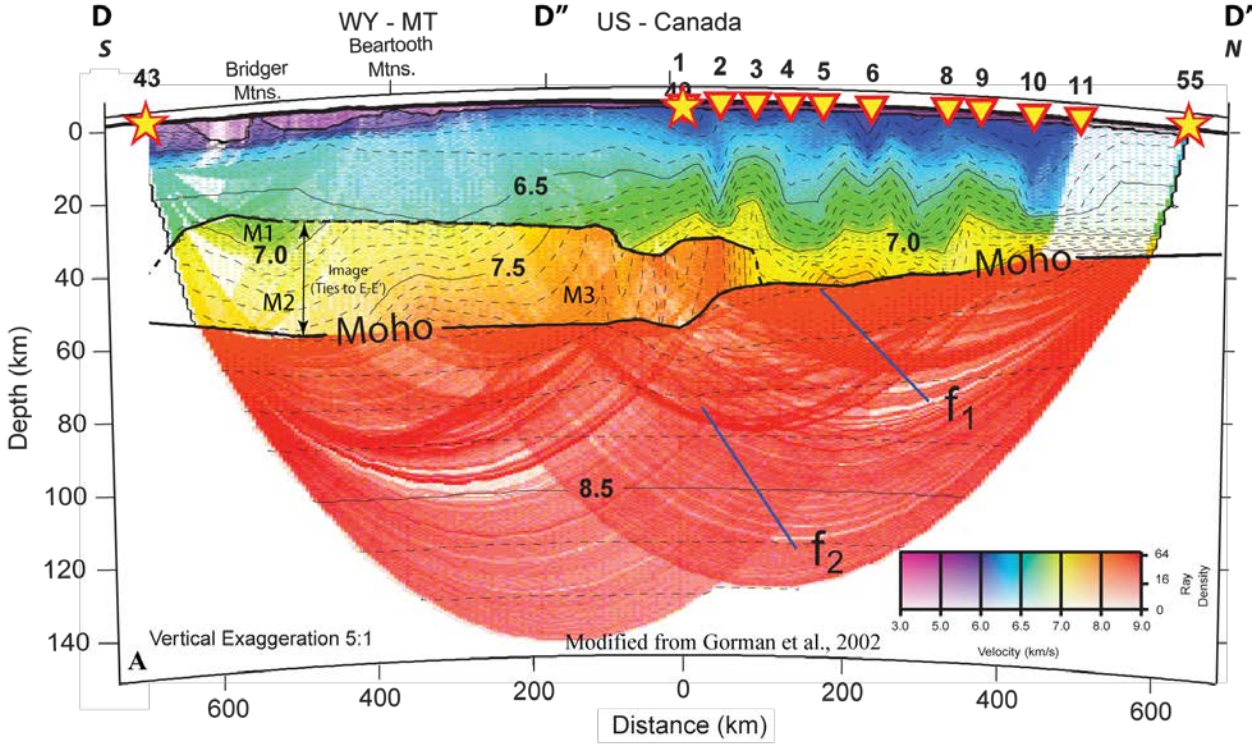
Scale Approximate



Modified from Worthington, et al., 2016

Deep Probe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Beartooth
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US - Canada
D′
N
Bridger
Mtns.
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3
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5
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8
9
10
11
55
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20
40
60
80
100
120
140
Depth (km)
6.5
7.0
7.5
8.5
M1
M2
M3
Image
(Ties to E-E′)
Moho
Moho
f_1
f_2
64
16
0
Ray
Density
3.0
5.0
6.0
6.5
7.0
8.0
9.0
Velocity (km/s)
Vertical Exaggeration 5:1
Modified from Gorman et al., 2002
A
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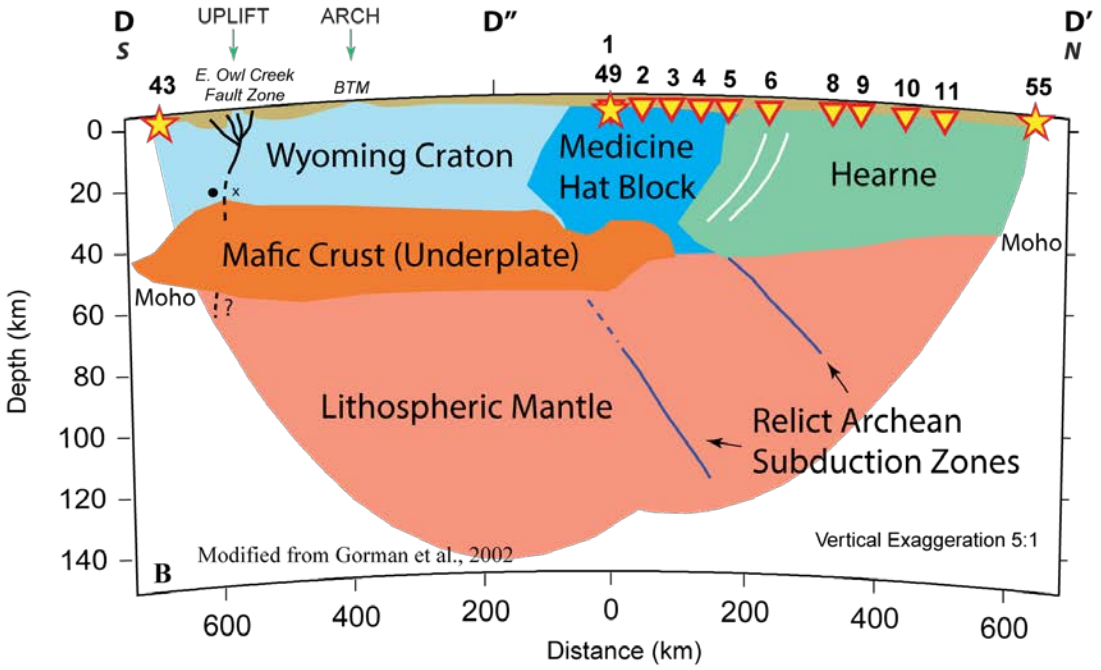
Distance (km)


D
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UPLIFT
ARCH
D″
D′
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43
E. Owl Creek
Fault Zone
BTM
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9
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11
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140
Depth (km)
Wyoming Craton
Medicine
Hat Block
Hearne
Mafic Crust (Underplate)
Moho
Moho
?
Lithospheric Mantle
Relict Archean
Subduction Zones
Vertical Exaggeration 5:1
Modified from Gorman et al., 2002
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200
400
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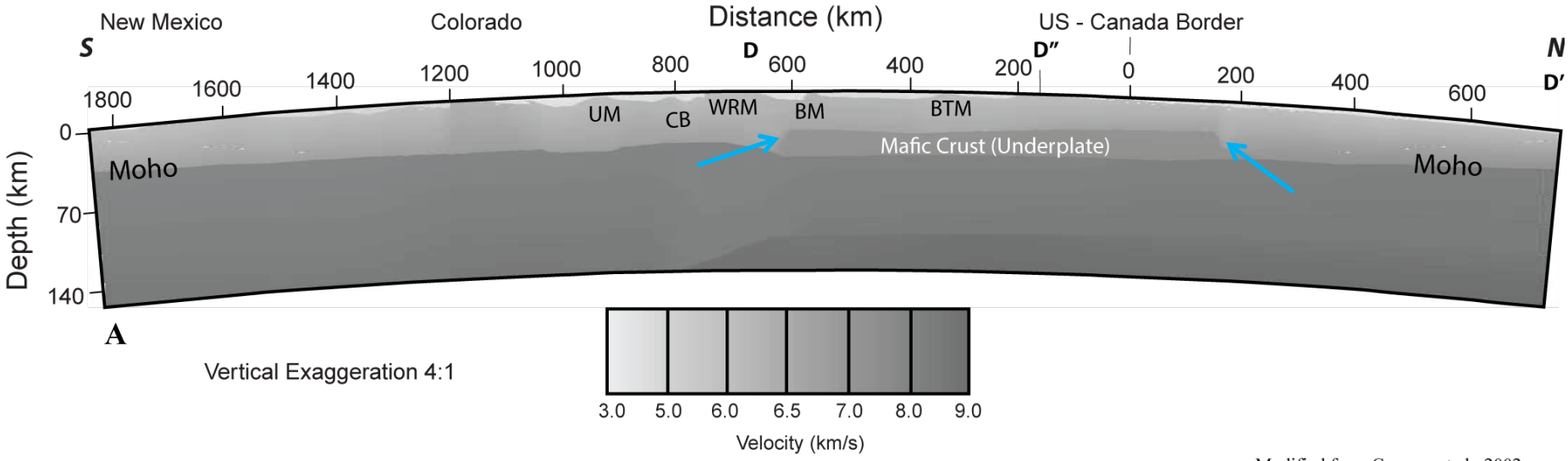
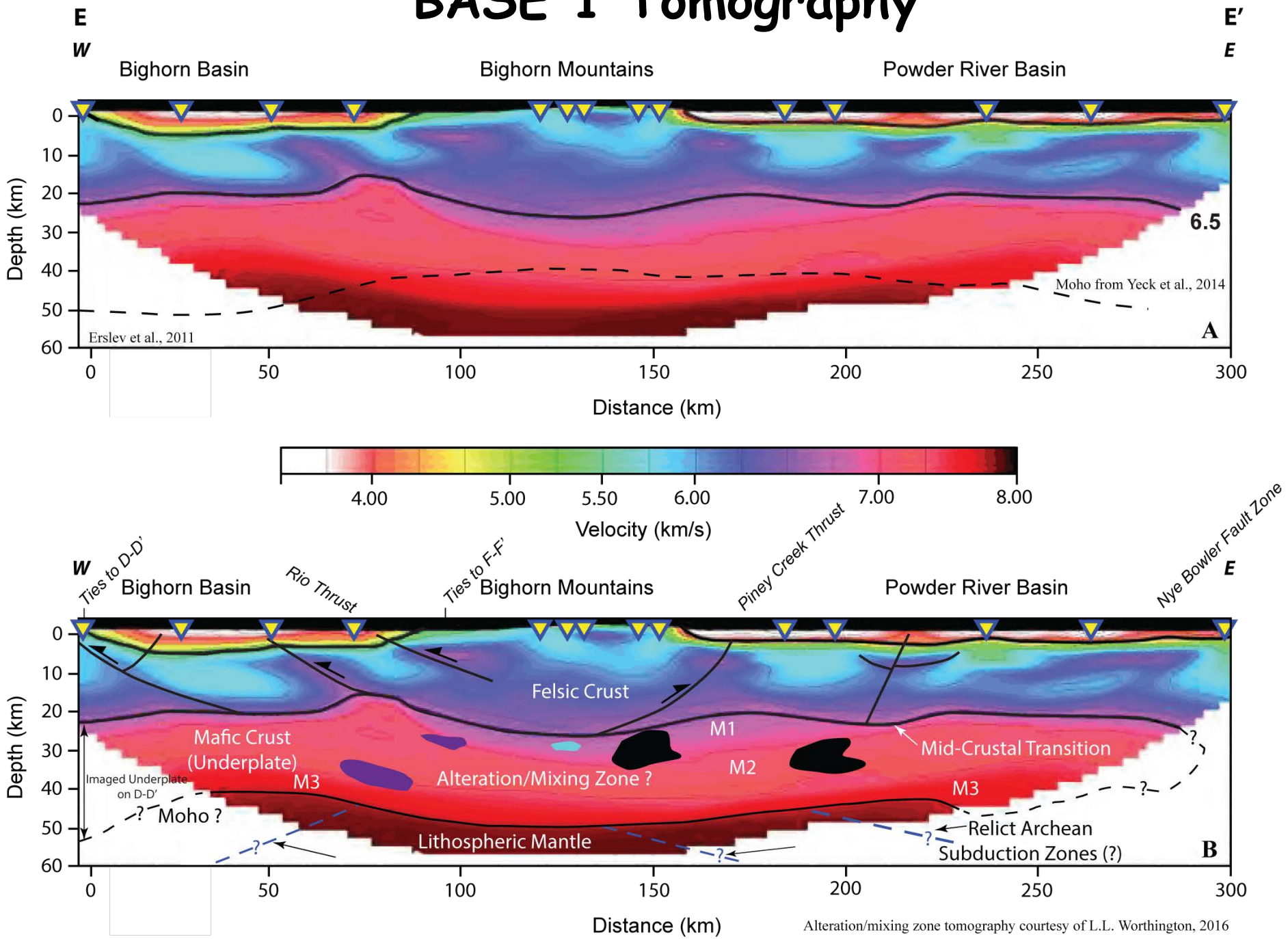
Distance (km)

Deep Probe Tomography



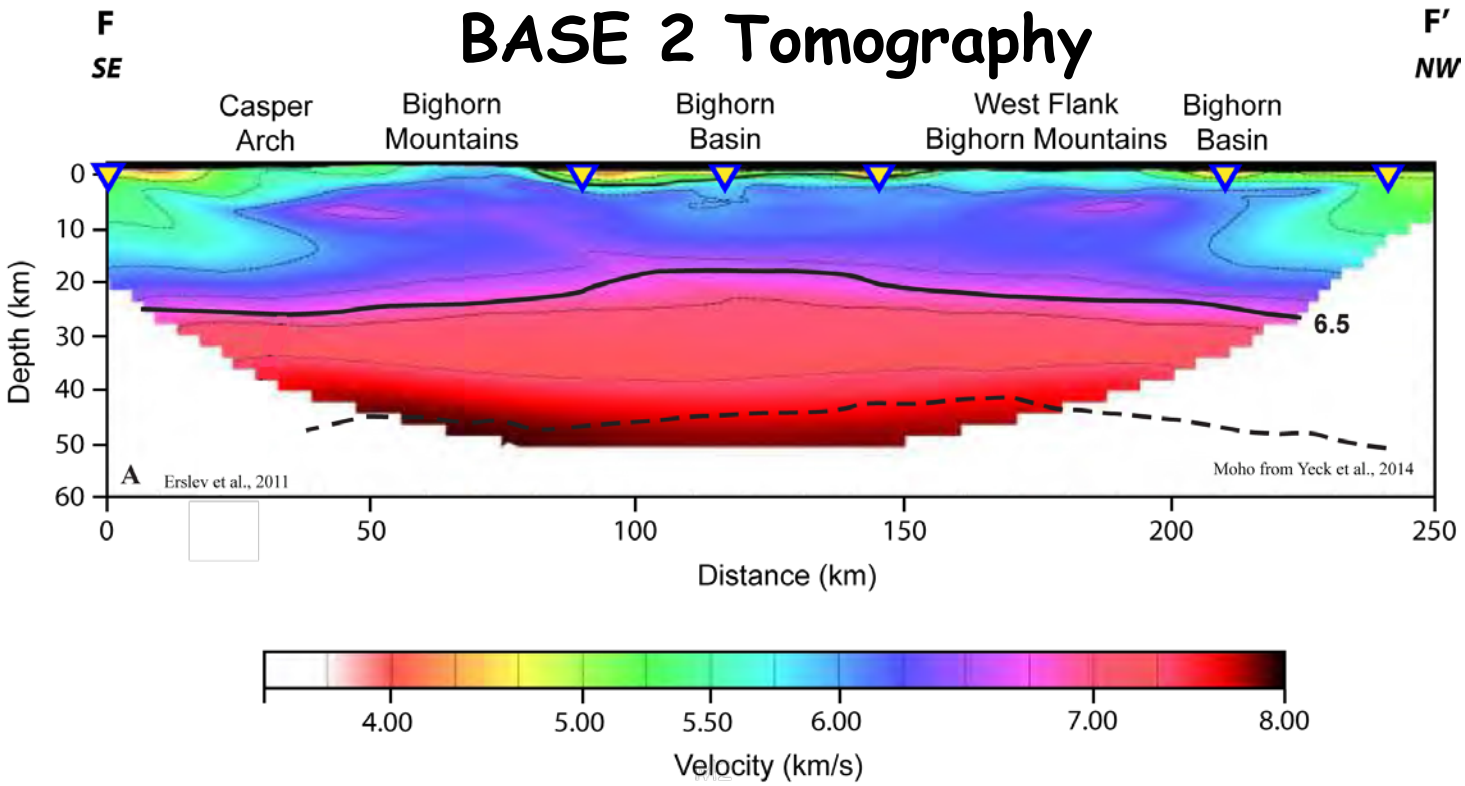
Modified from Gorman et al., 2002

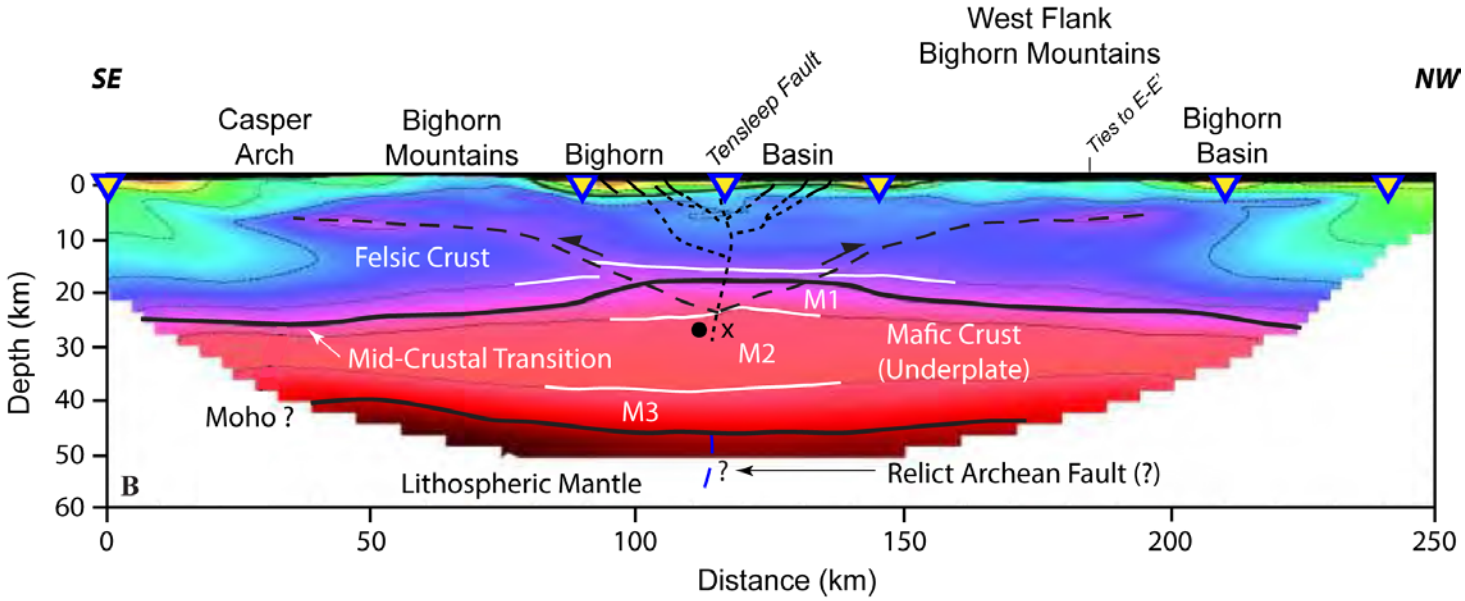
BASE 1 Tomography

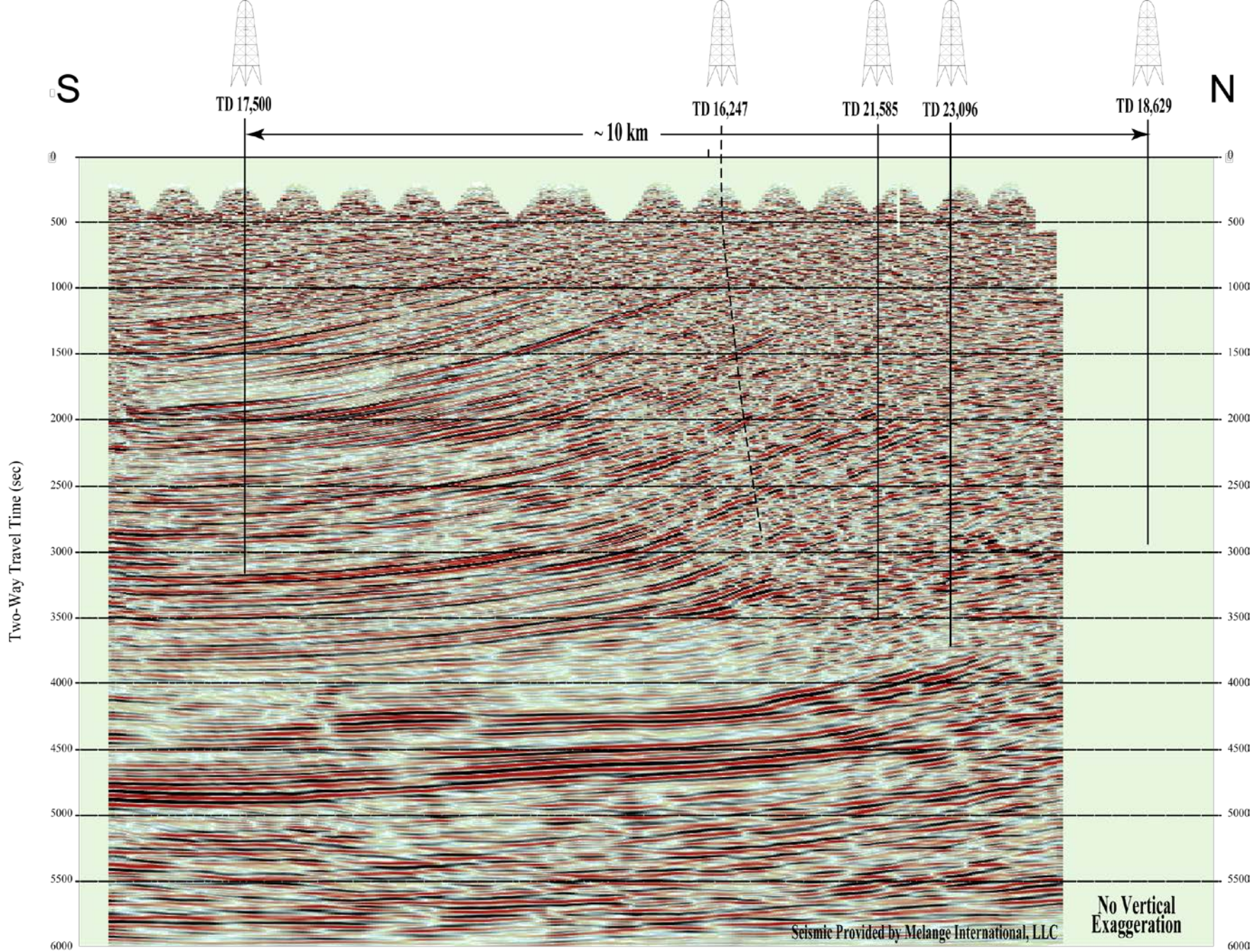


Alteration/mixing zone tomography courtesy of L.L. Worthington, 2016

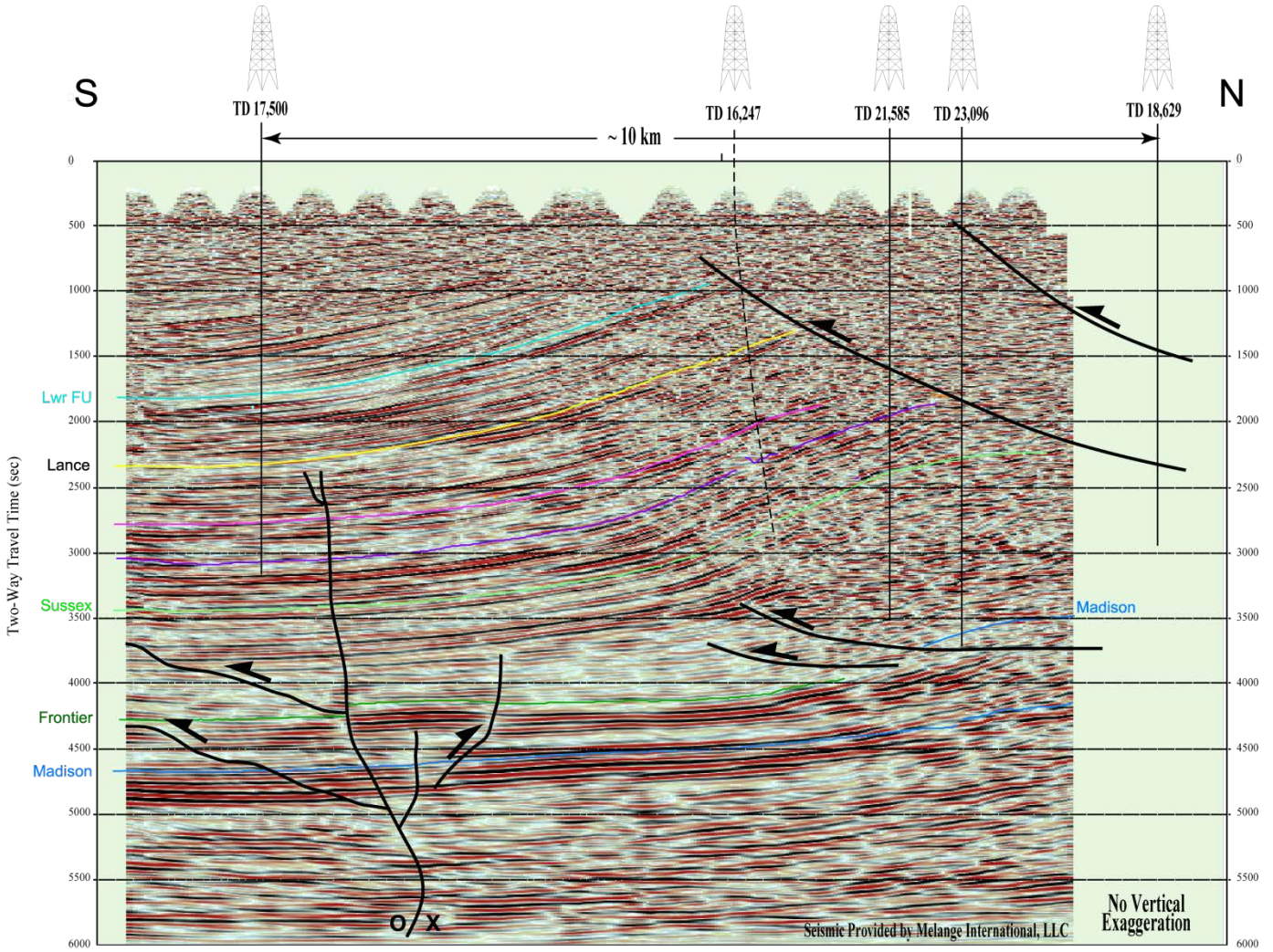
BASE 2 Tomography







Northern WRB/South Flank BM-Proprietary 3-D Survey



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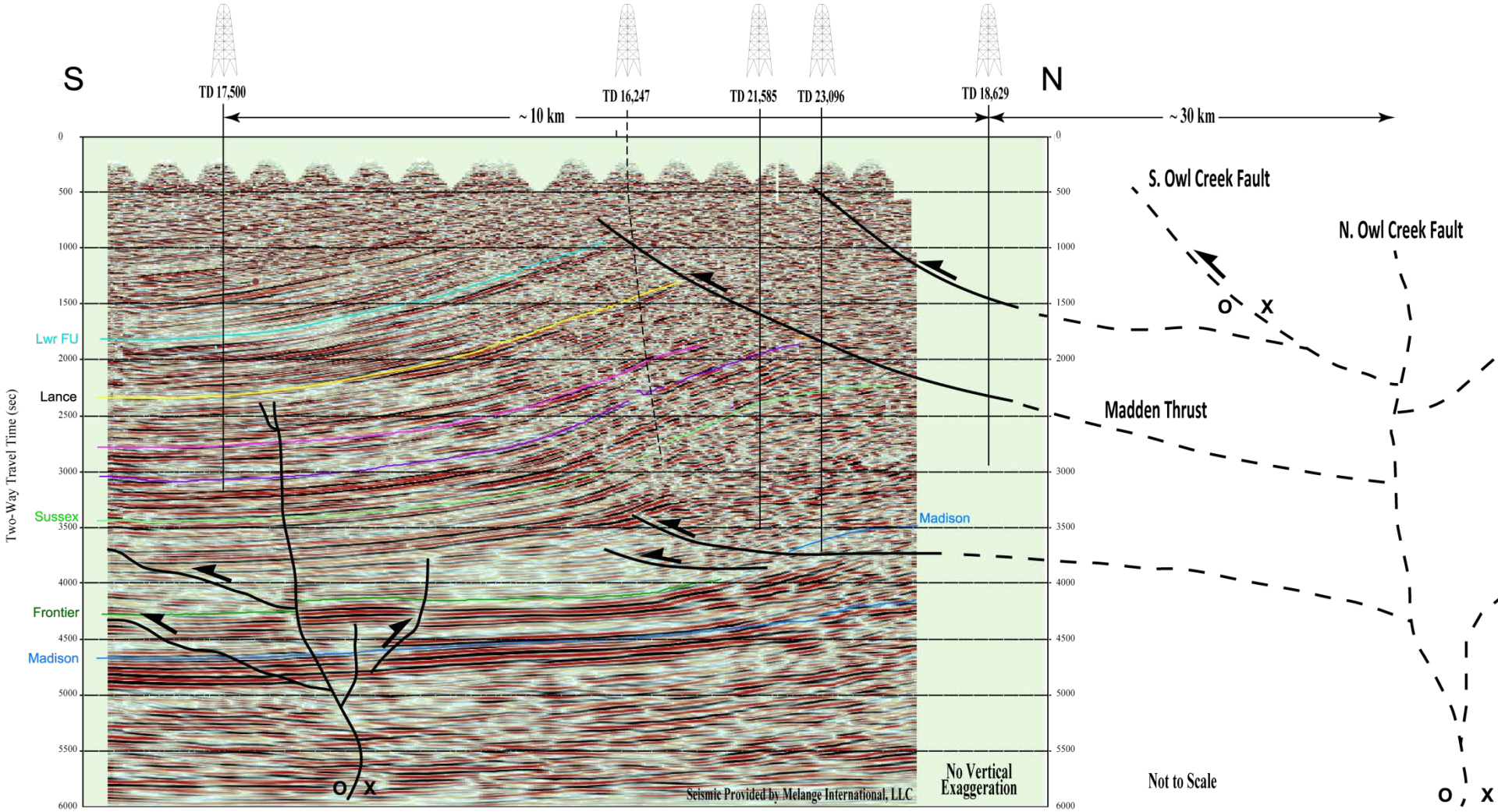
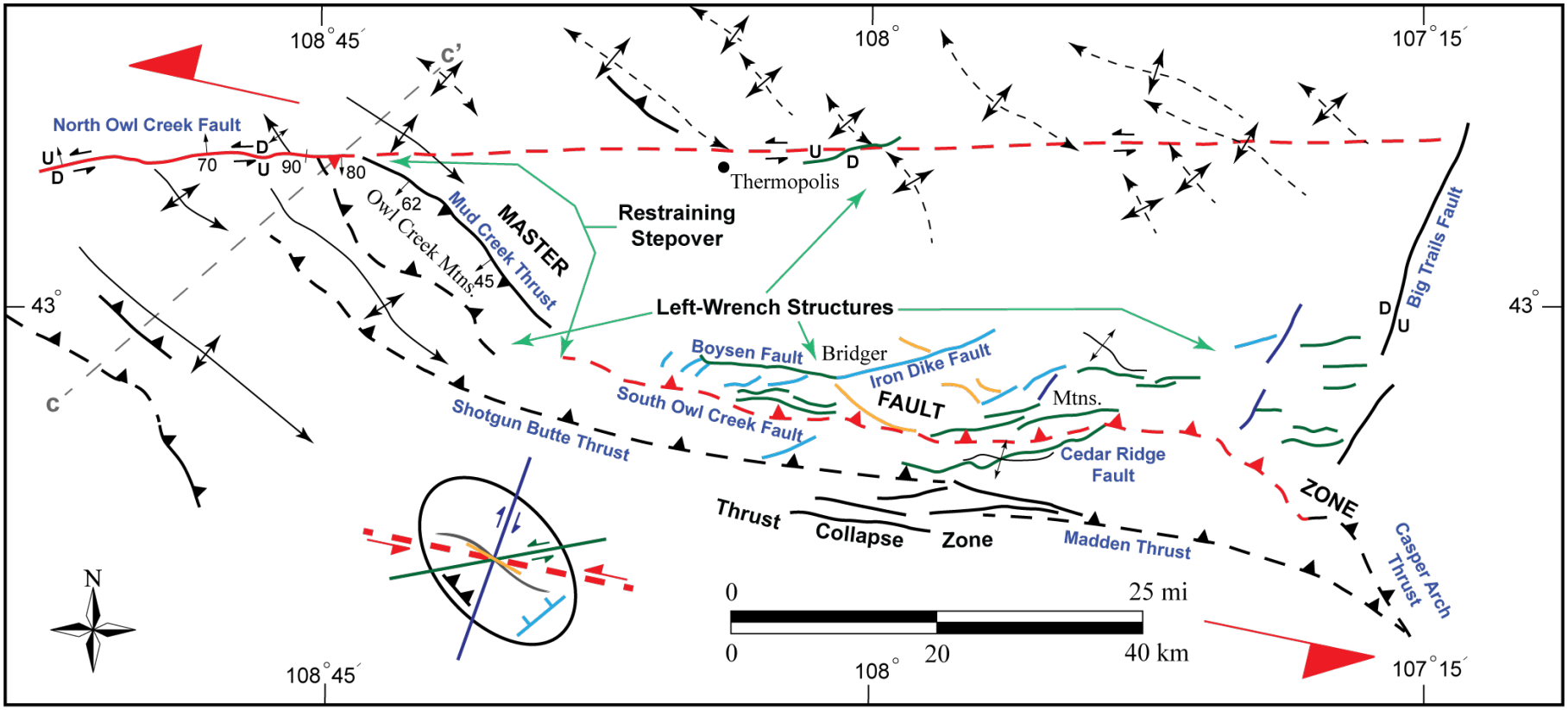
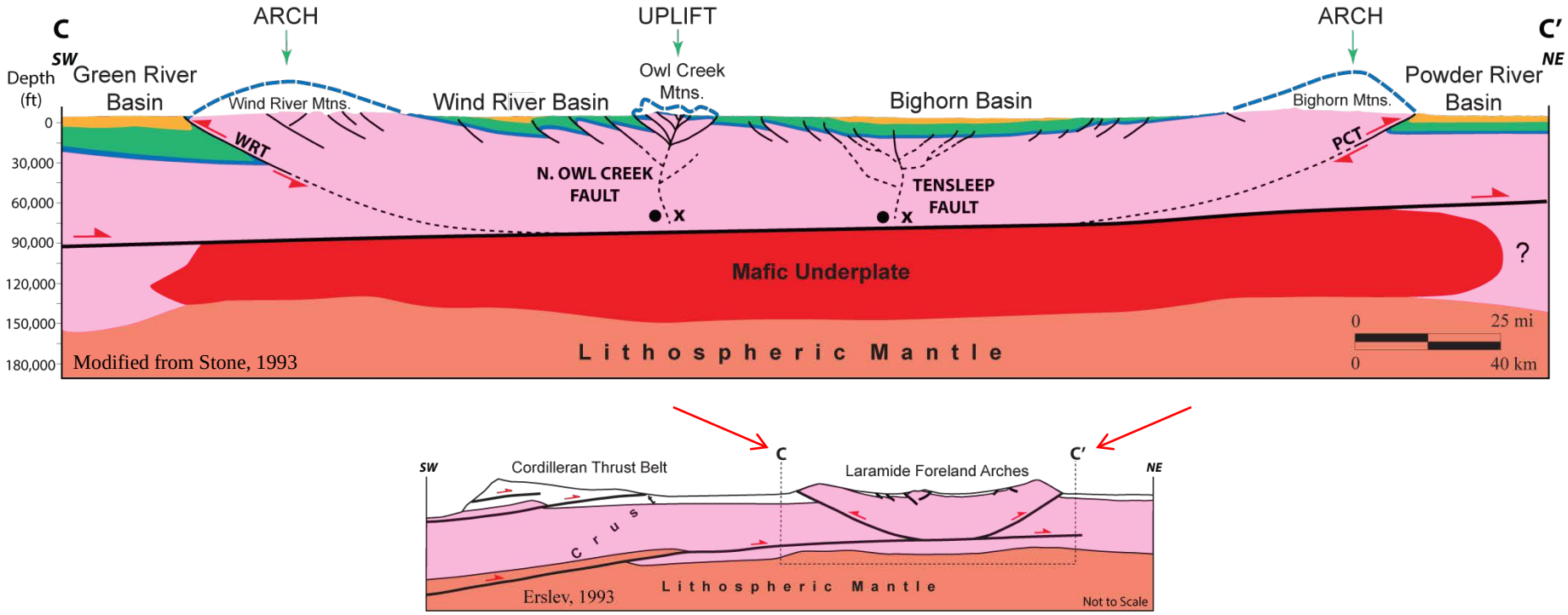


Northern WRB/South Flank BM-Proprietary 3-D Survey

Owl Creek Fault Zone

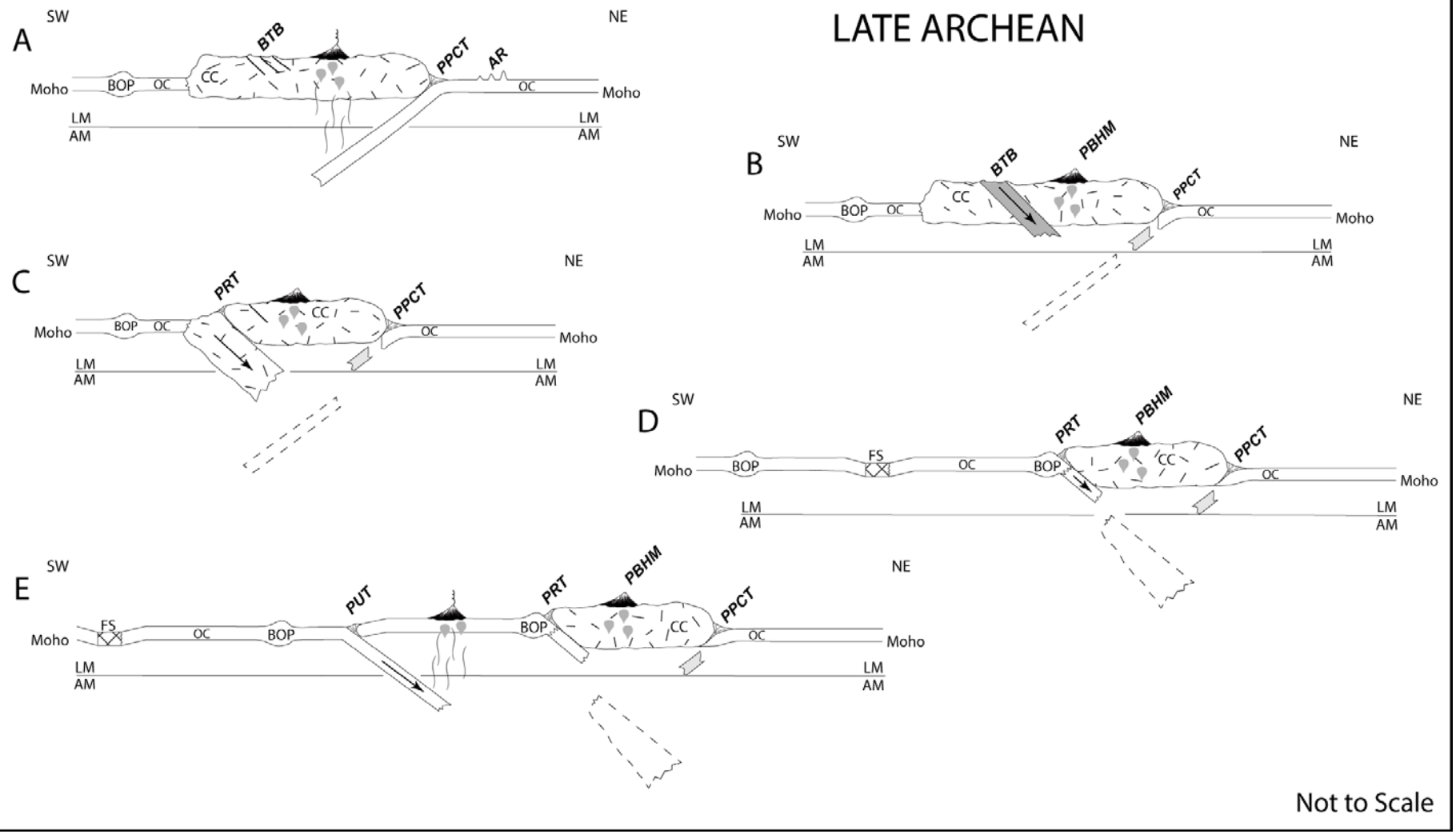


Tectonic elements from Love and Christiansen (1985), Ver Ploeg (1985), Paylor and Yin (1993), Thaden (1980a, 1980b), and Finn et al. (2010)

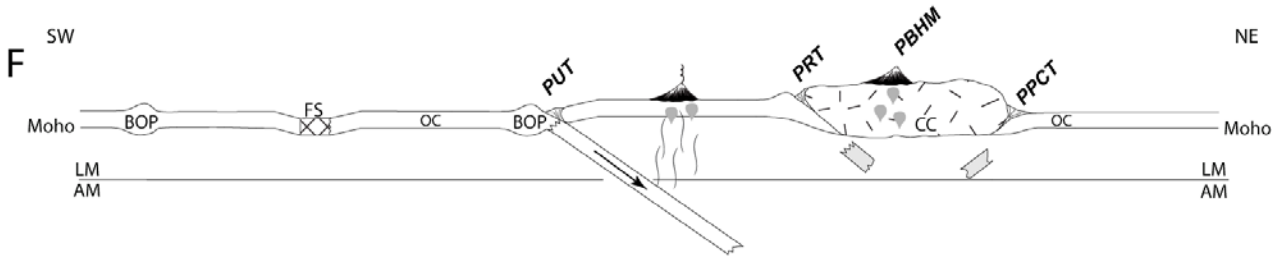


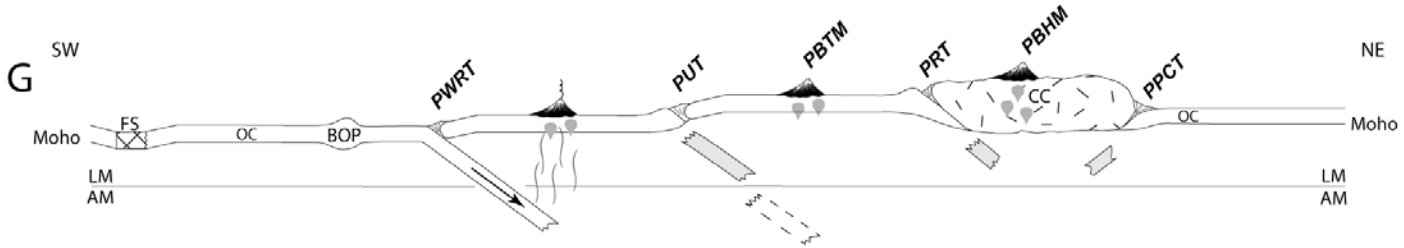
Convergent Deformation vs Crustal Detachment

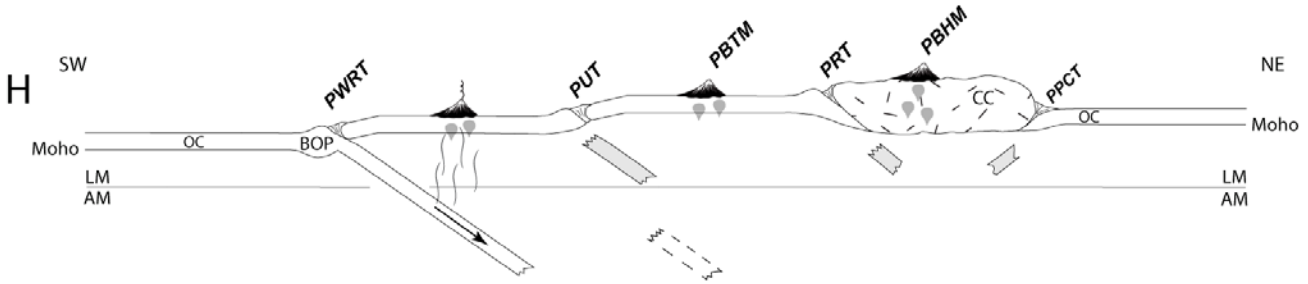
Convergence Zone Evolution



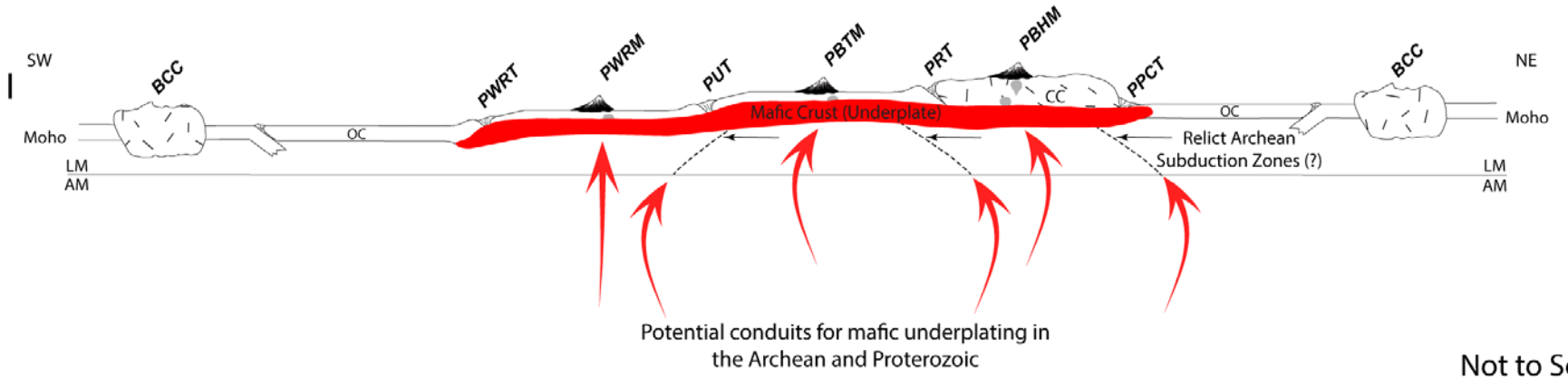
LATEST ARCHEAN





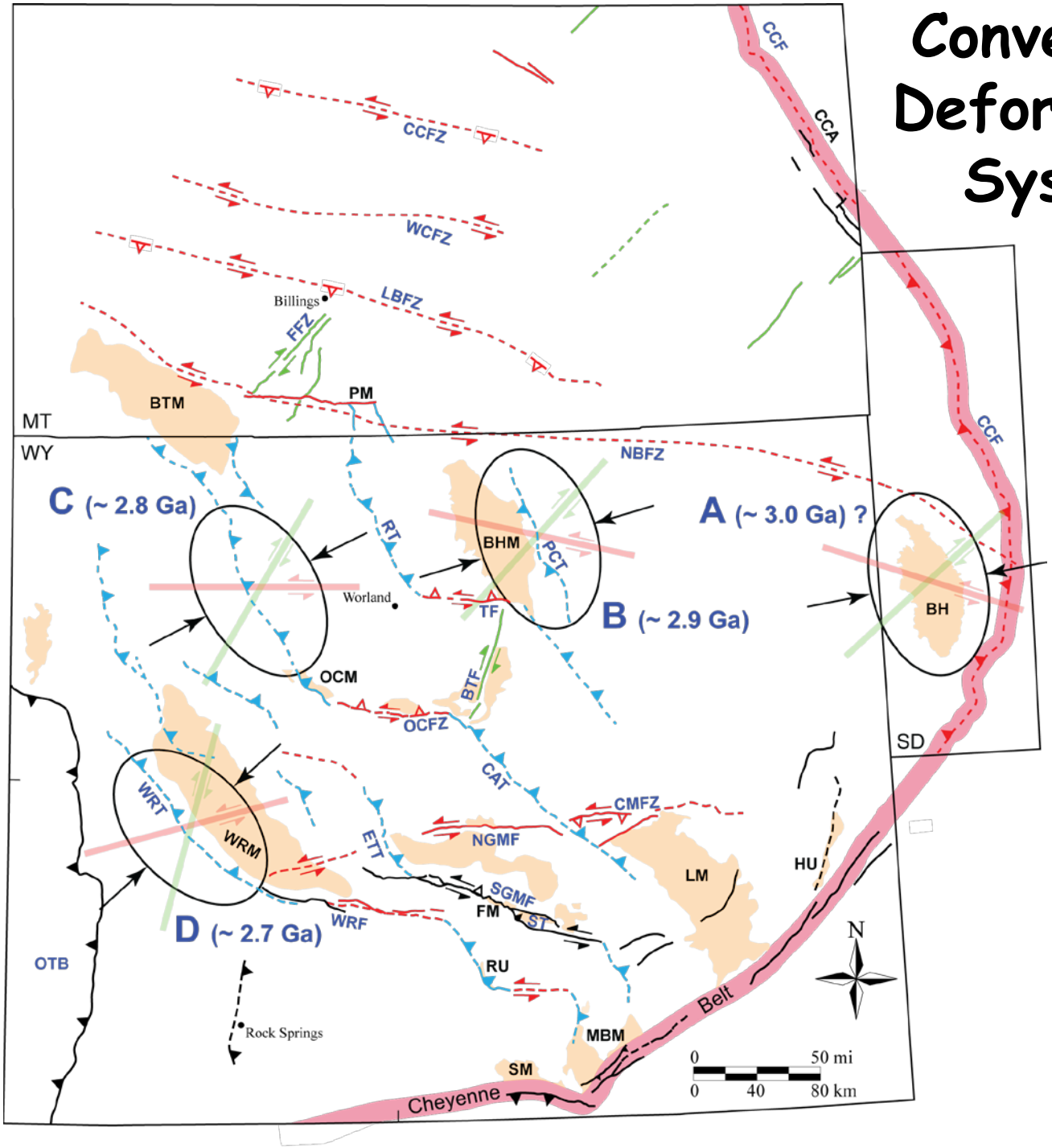


PROTEROZOIC



Not to Scale

Convergent Deformation System

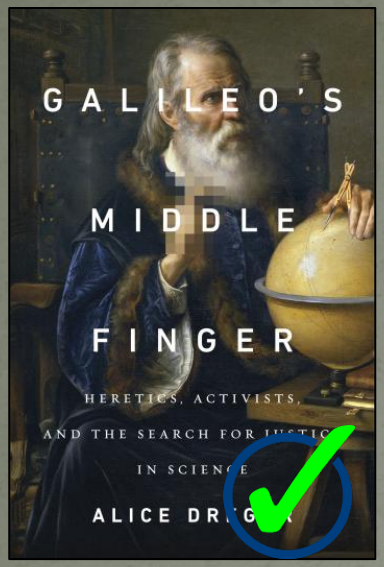


Summary

- Precambrian basement anisotropies **exist** across the Wyoming craton (N-NW , W-NW, NE)
- 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**

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 **incorporates ideas** from accepted/non-accepted models of Laramide orogenesis and requires minimal explanations for the various Laramide structures seen across the craton
- **= UNIFYING CONCEPT**



All Truth Passes Through Three Stages

1. Ridicule
2. Violently Opposed
3. Accepted as being self-evident

Arthur Schopenhauer