Inherited Structural Fabrics and the Impact on Oblique-Slip Faults in the South Texas Laramide Foreland*

Christopher Zahm[1], Gordon A. Smith[2], and Andrea Nolting[3]

Search and Discovery Article #30467 (2016)**
Posted October 17, 2016

*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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Abstract

The extent of a compressional orogenic event is often determined by the last folds or faults toward the hinterland. However, the stress conditions which allow for compressional deformation are gradational into the "undeformed" stable craton resulting in a zone of high horizontal stress beyond the mapped front. This zone is of tremendous importance in petroleum systems as this can become the unconventional reservoir "sweet spot" in the basin. The orientation of faults should be predictable given knowledge of the shortening direction. However, inherited pre-existing fabric can influence the orientation and intensity of the younger deformation. South Texas has experienced many of the major tectonic events that define the southwestern US including PC-Cambrian rifting, orogenic uplift in the Penn and E. Permian associated with the Marathon-Ouachita Orogeny, Triassic-Jurassic rifting, compressional folding in the Tertiary Laramide Orogeny, and extensional rift fault development in the Neogene during Basin and Range rifting. Boundaries that define the deformation associated with these events overlap and can be difficult to discern. A well exposed road cut north of Sanderson, Texas contains significant oblique extensional faults (rake 5-25 deg) with NW (315) and NE- (020) oriented faults. However, satellite imagery over the exposure reveals that only a few of the faults are visible linear elements in satellite images. Scaling back from the outcrop, more than 30,000 mappable fractures/faults define a 60-km wide zone between the last Laramide fold and the stable craton. When exposed, the faults within this zone have limited offset (most are less than 3 m, subseismic resolution) because of their oblique offset. Fault and fracture orientations vary along this zone due to the fabric of older, Paleozoic subsurface structures. Observation of slickensides, massive sparry calcite development, and fault damage zones suggest that the NW faults are shearing along distributed faults which allows for significant extensional opening of the NE fault sets. No element in outcrop honors "ideal" orientations, likely a result of the reactivation of inherited Paleozoic structural fabric. Much work remains to fully characterize the zone of faulting ahead of the so called "Laramide Front" but outcrops provide valuable insight into the hierarchy of fracture development expected in similar age rocks along orogenic fronts in both surface and subsurface systems.

Selected References

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Presented at AAPG Calgary June, 2016

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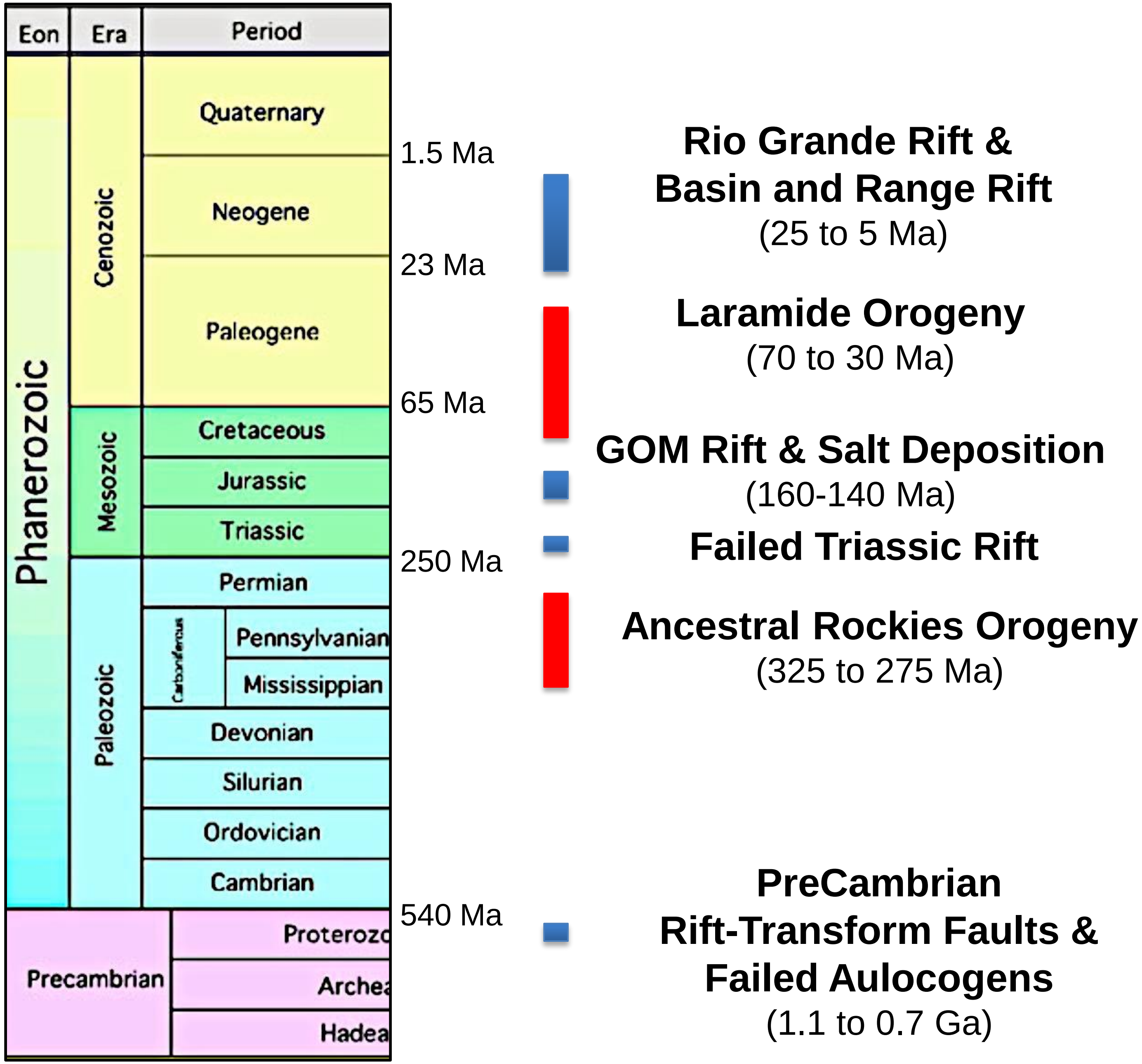
Relevance of study

- The space between detectable foreland deformation (i.e., folds and large faults) and the undeformed craton is not well defined, but numerous small faults develop as pre-existing structures are reactivated during orogenic compression

- The occurrence and frequency of the faults and fractures has relevance to key South Texas basins, but likely exists in most foreland systems

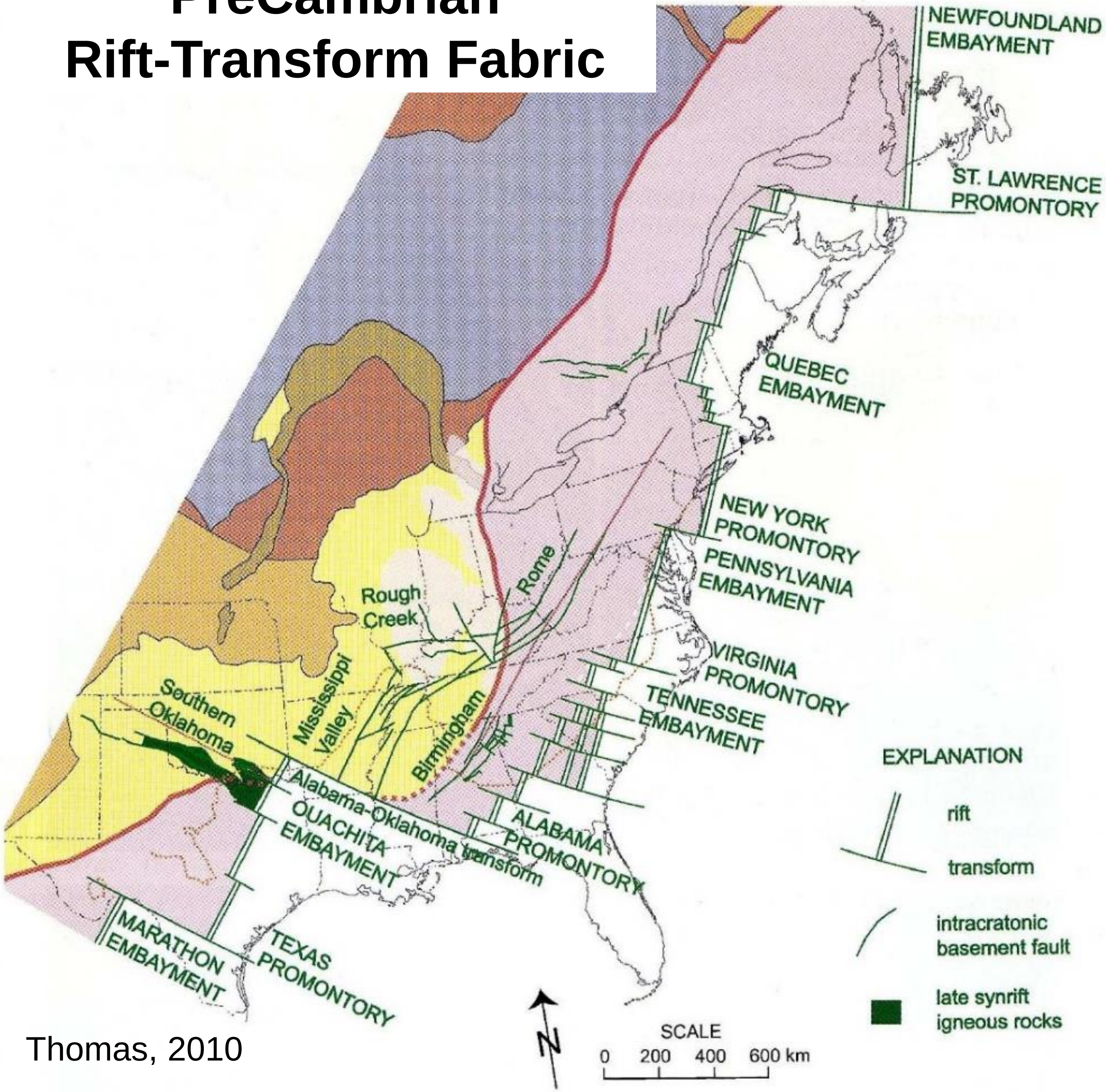
Tectonic Events Chart

- Several major tectonic events within South Texas-Northern Mexico area
- Early rift-transform faults establish the “fabric” which controls younger tectonic elements and subsequent basin development
- Younger elements record complexity of multiphase deformation from the P-C basement fabric

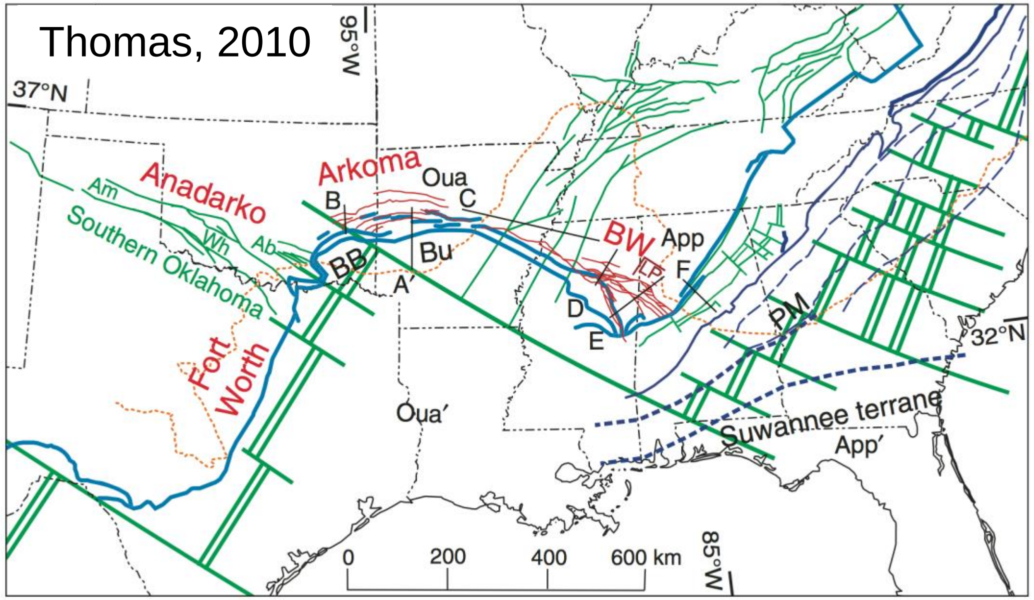


Rifts
Orogens

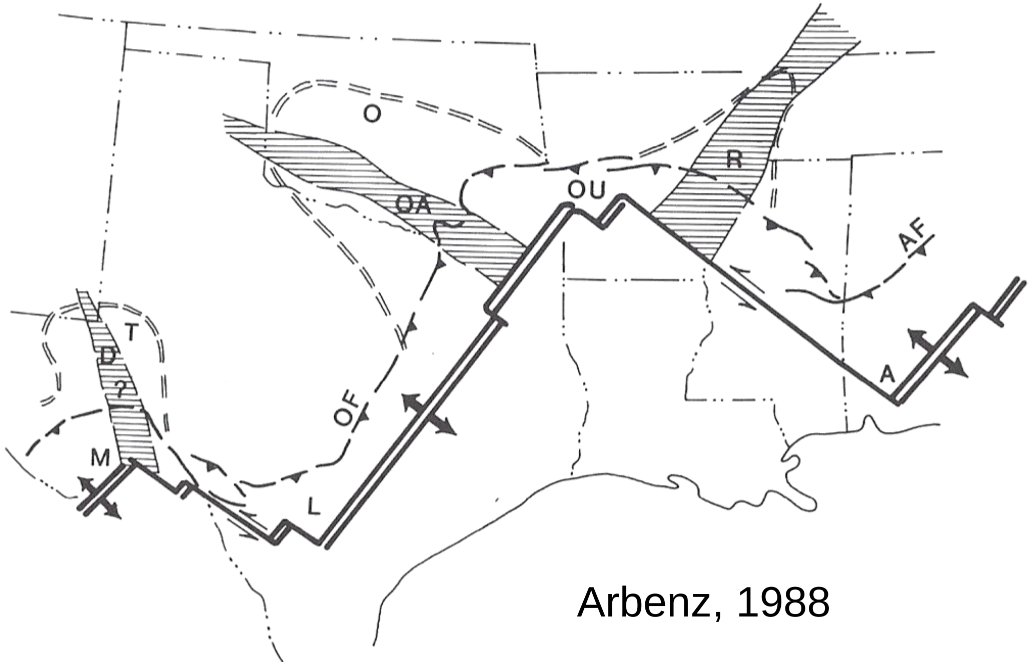
PreCambrian Rift-Transform Fabric



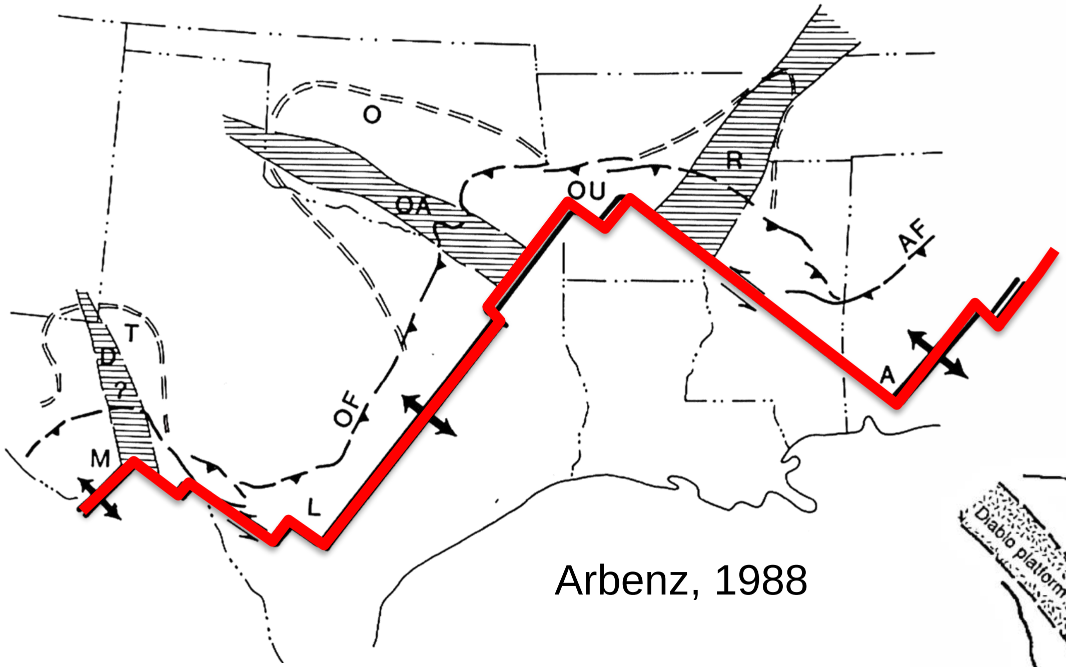
Thomas, 2010



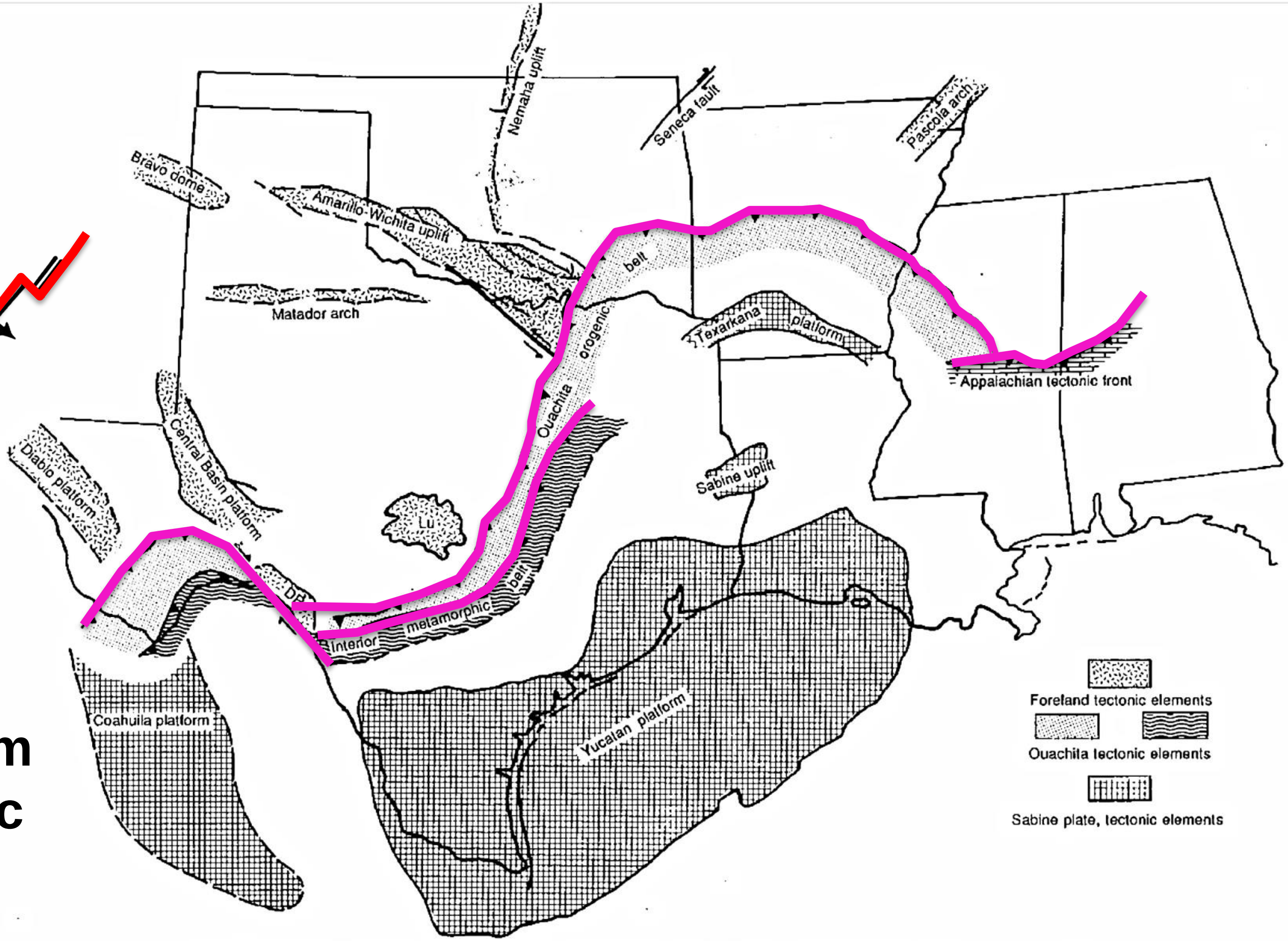
Thomas, 2010



Arbenz, 1988



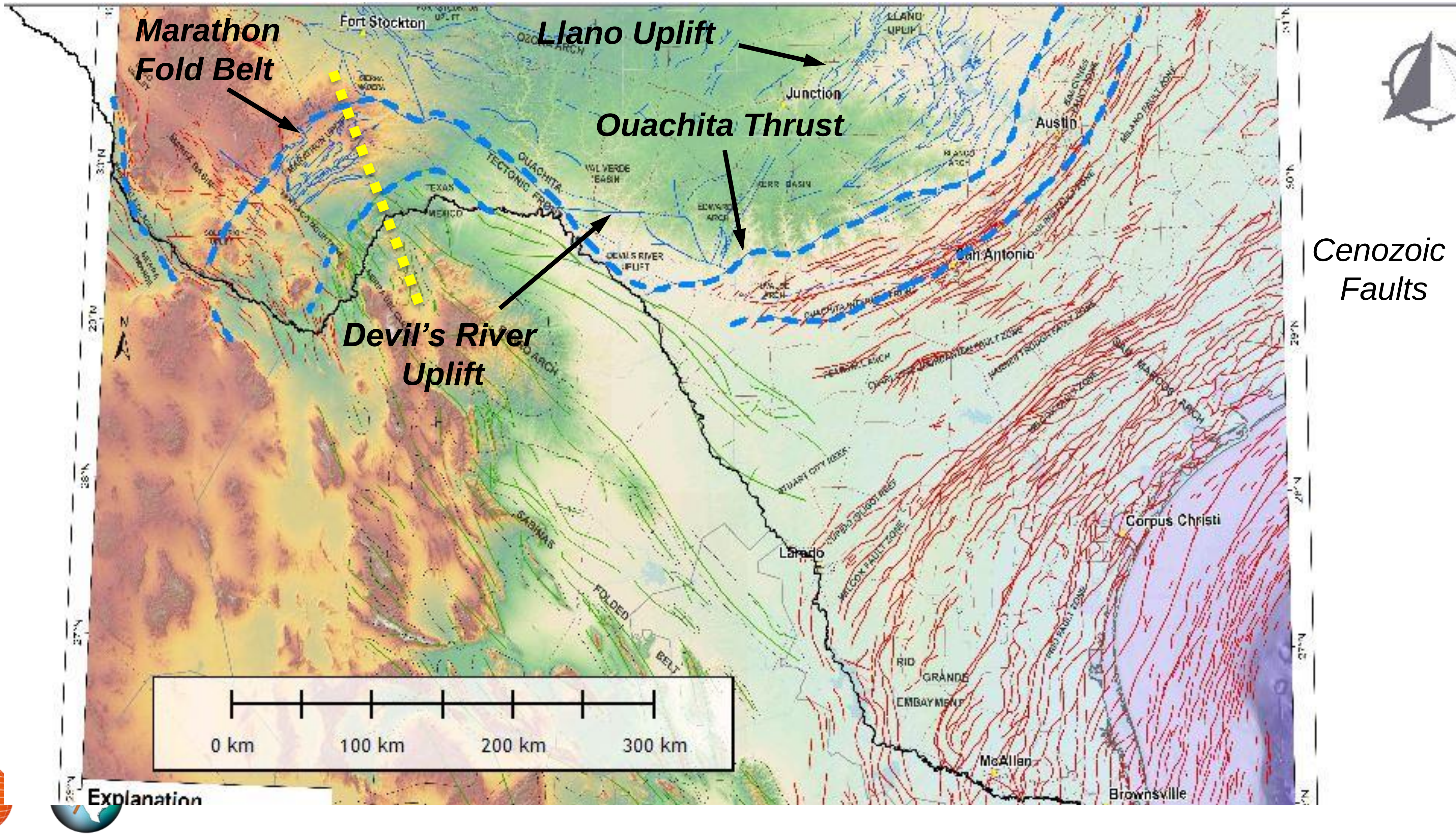
Arbenz, 1988



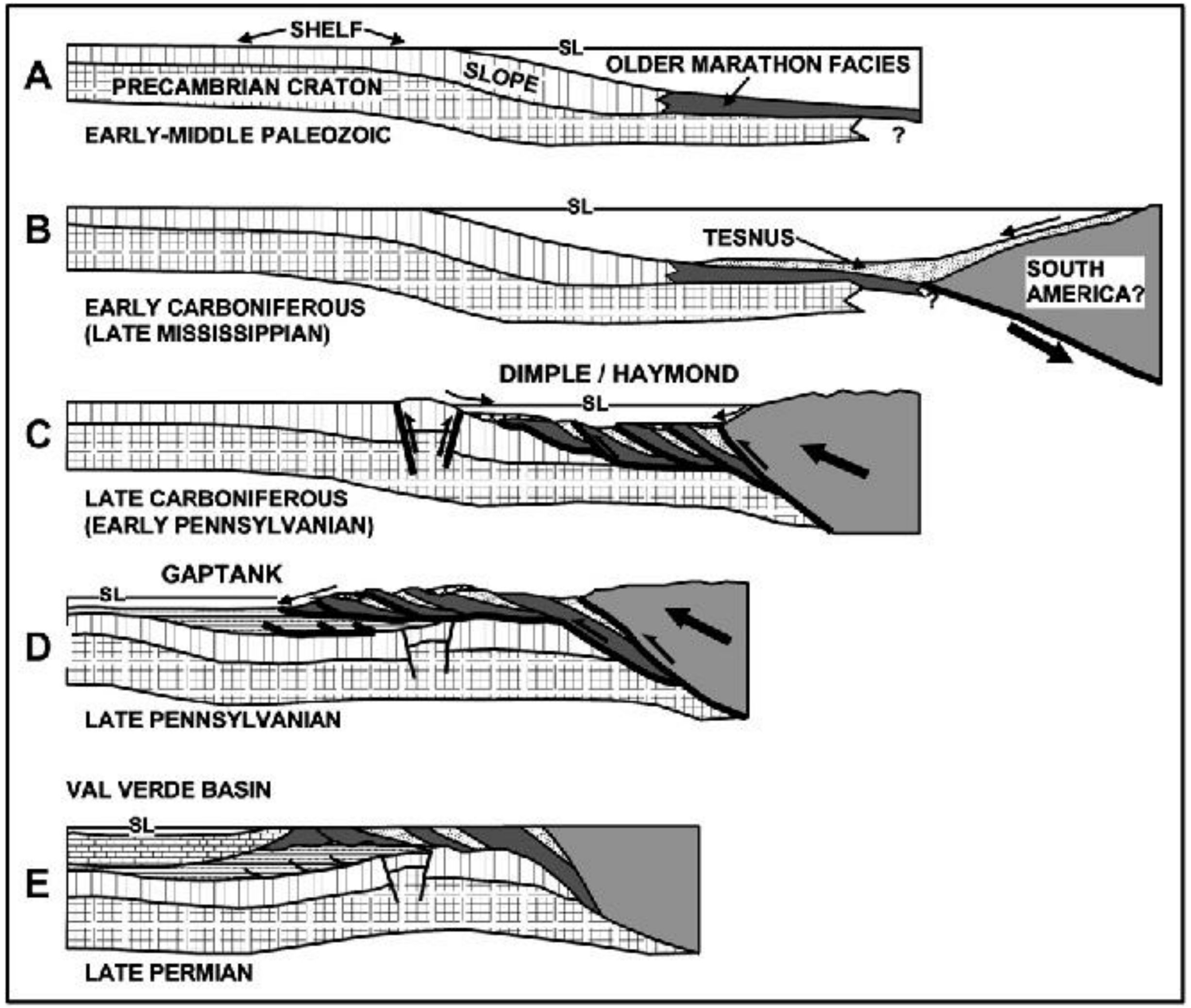
P-C to Cambrian Rift-Transform fabric reoccupied by Paleozoic Ouachita Orogeny

Arbenz (1988) compiled from King (1975), Pindell (1985), and Handschy and others (1987)

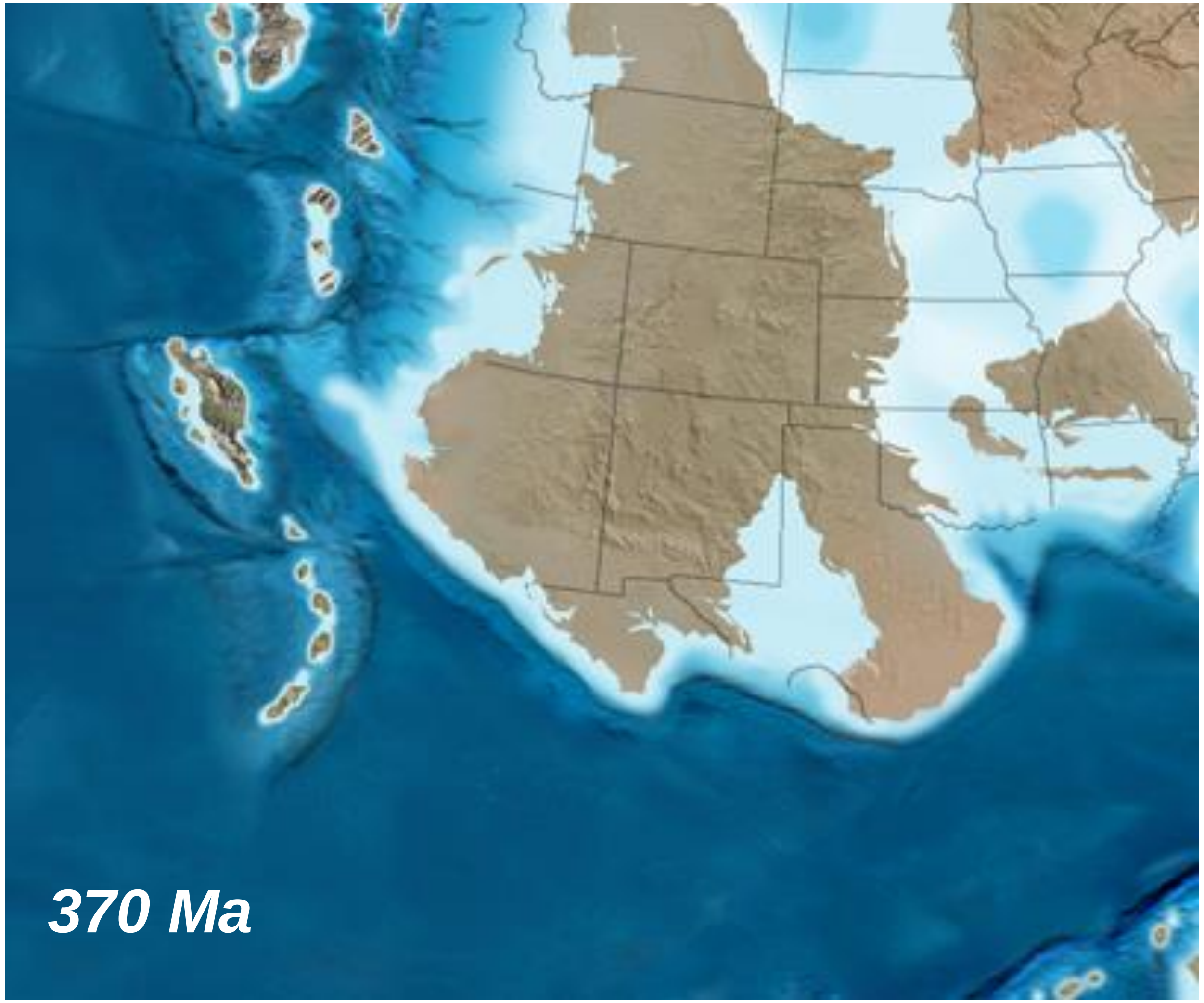
Paleozoic Tectonic Elements of South Texas-Northern Mexico



Late Carboniferous to Early Permian Ancestral Rocky Mountains (ARM) Orogeny

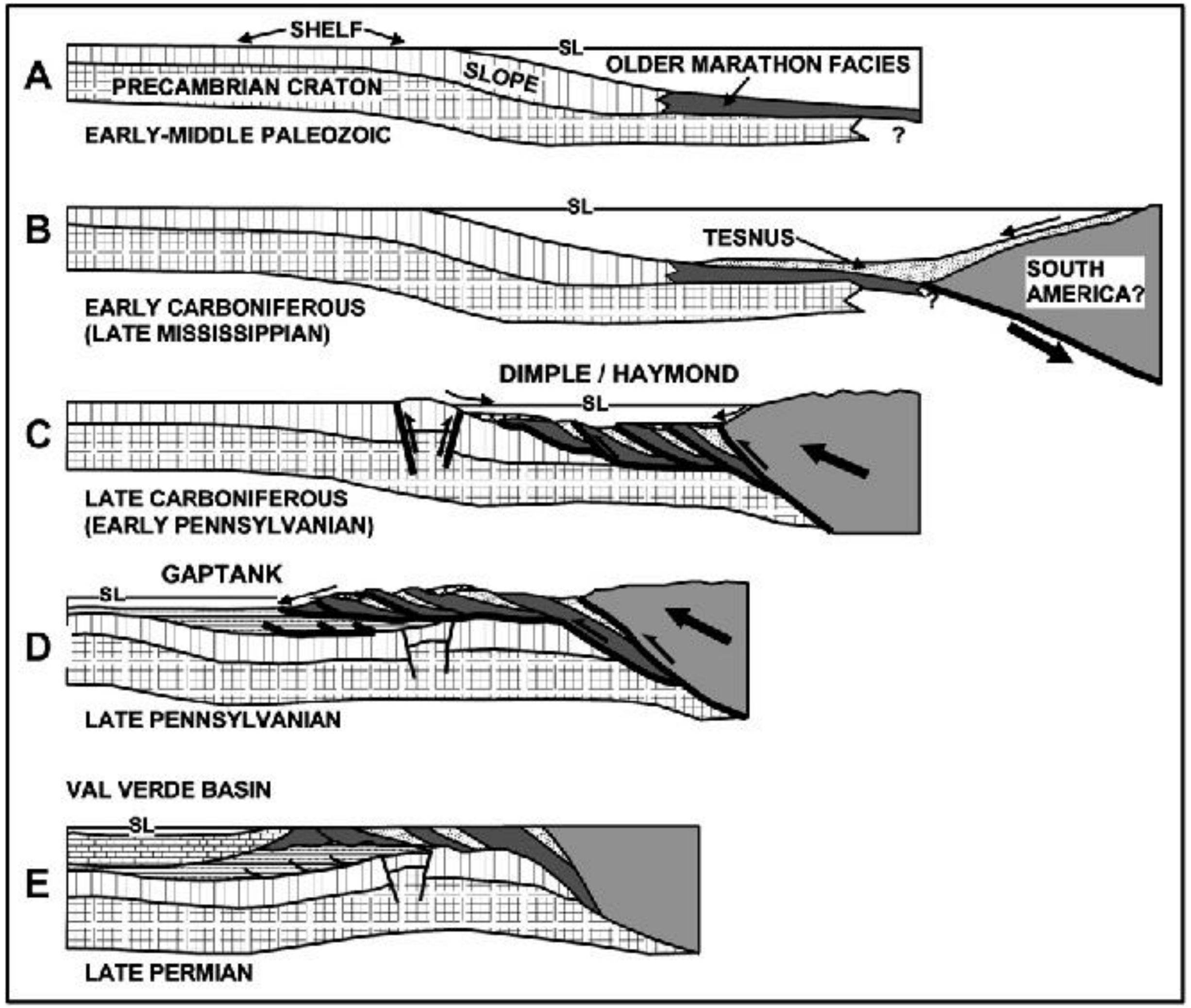


Hickman and others (2009)

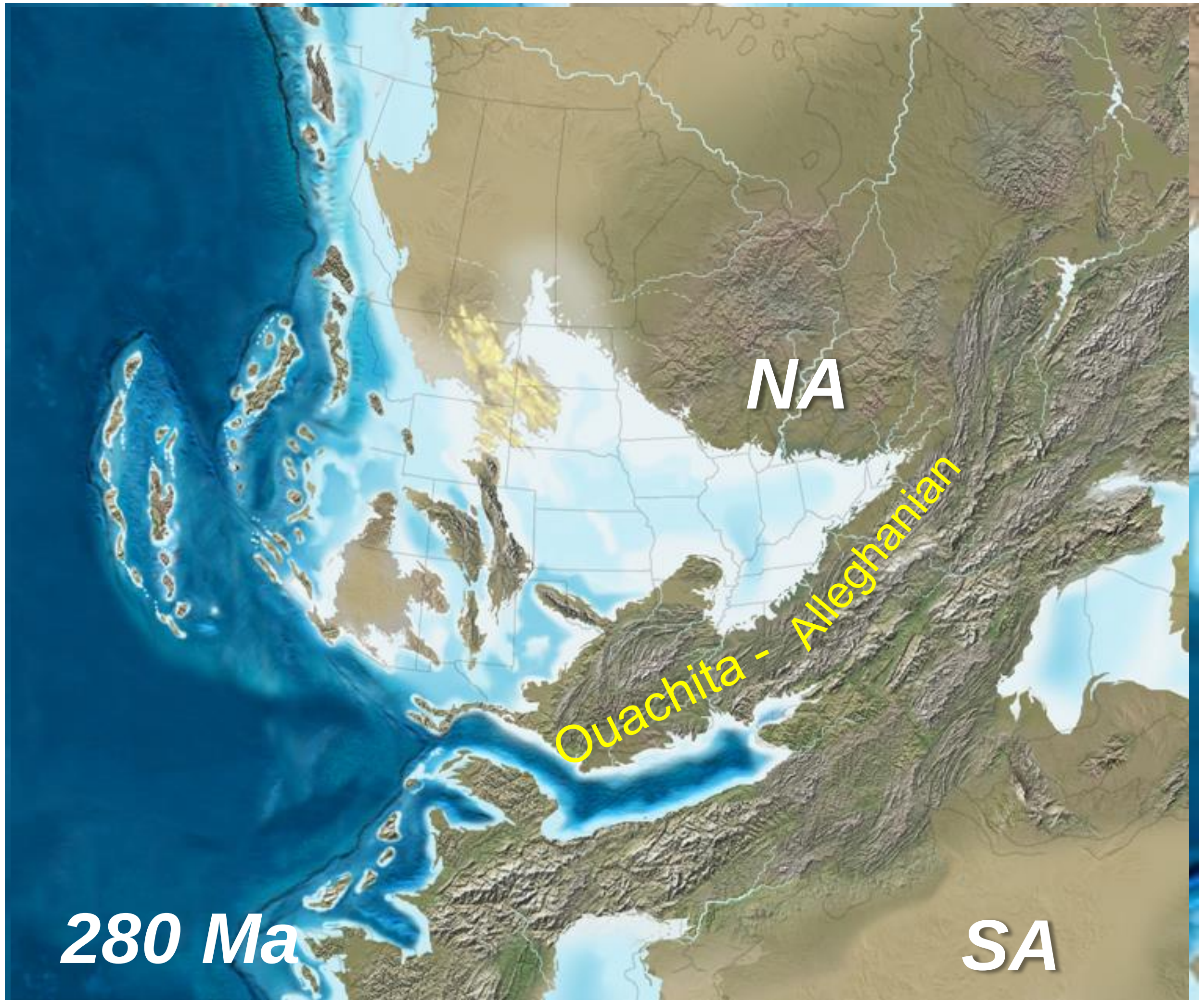


Blakey Paleogeography

Late Carboniferous to Early Permian Ancestral Rocky Mountains (ARM) Orogeny

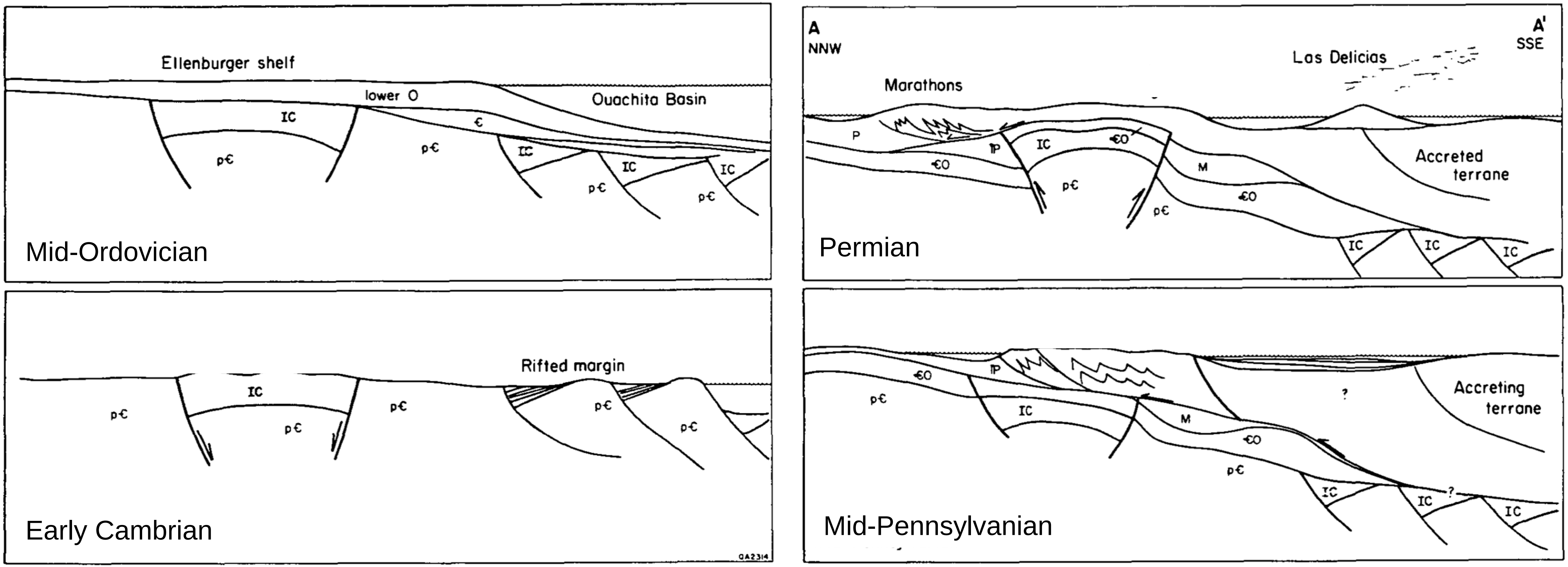


Hickman and others (2009)

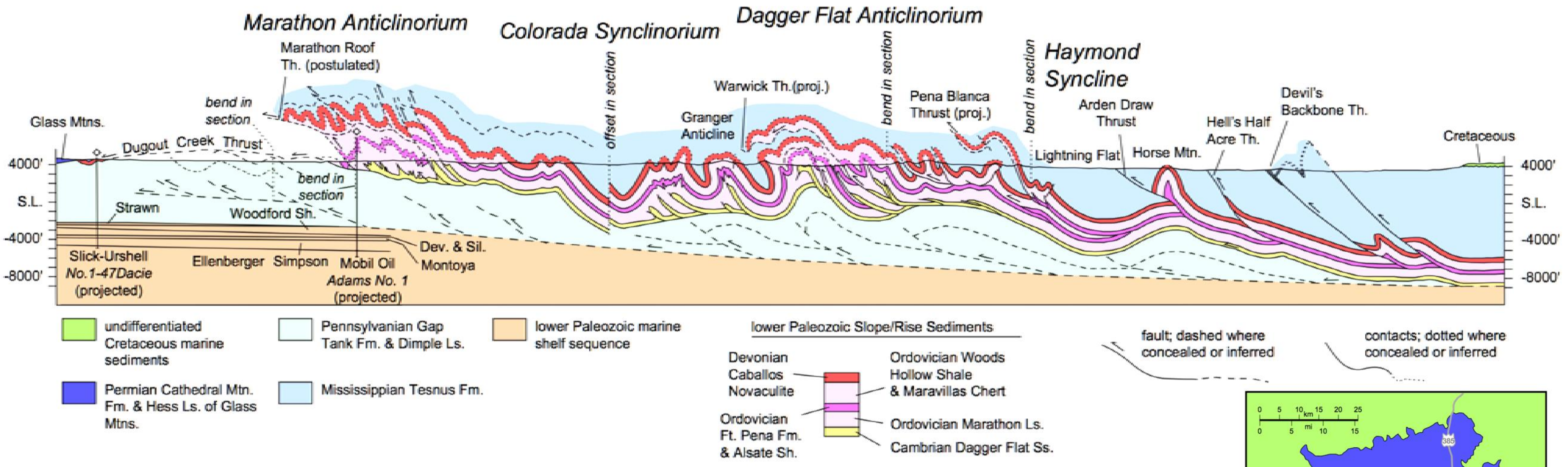


Blakey Paleogeography

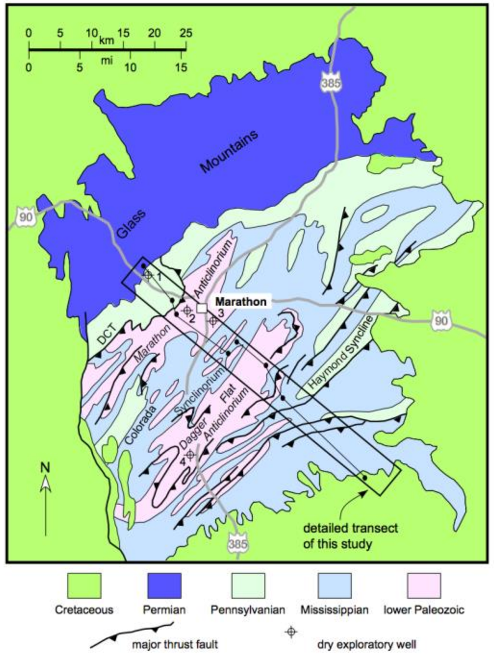
Paleozoic Tectonic Basement Inversion and Thin-Skinned Detachment – Ewing (1984)



Thin-Skinned Paleozoic (ARM) Compressional Folding – Marathon Fold Belt



Hickman (2009)



Tectonic Events Chart

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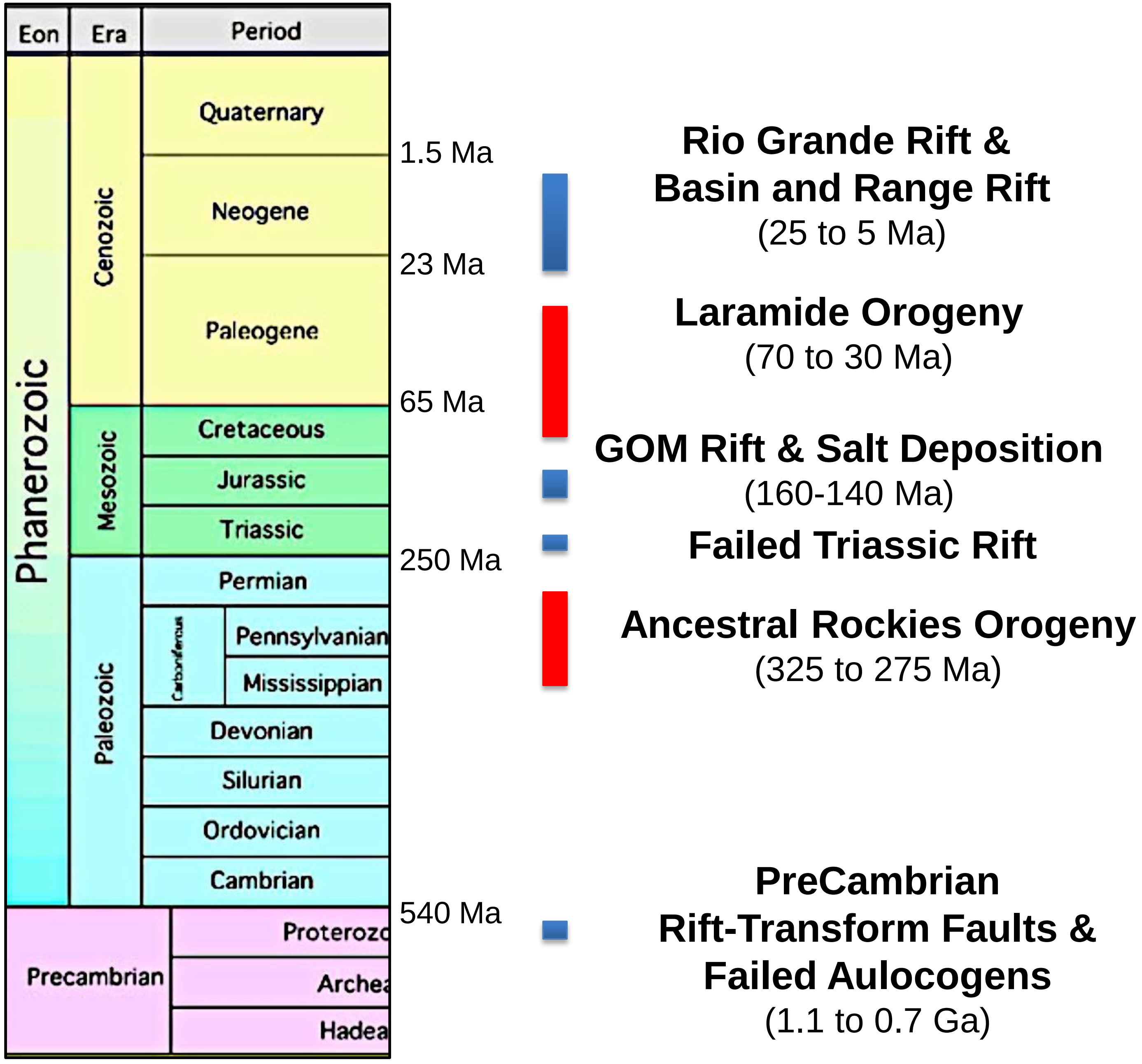
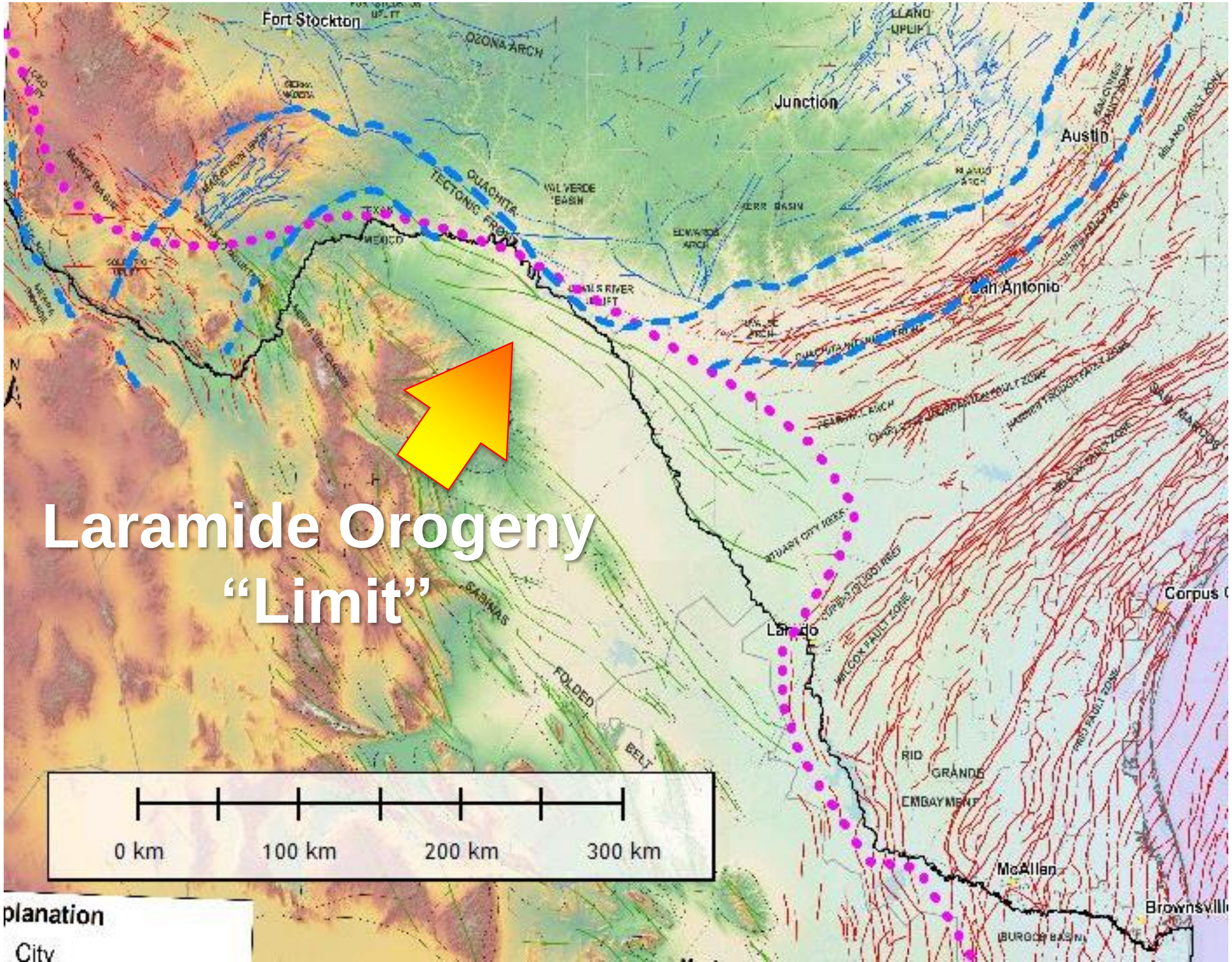


Rifts

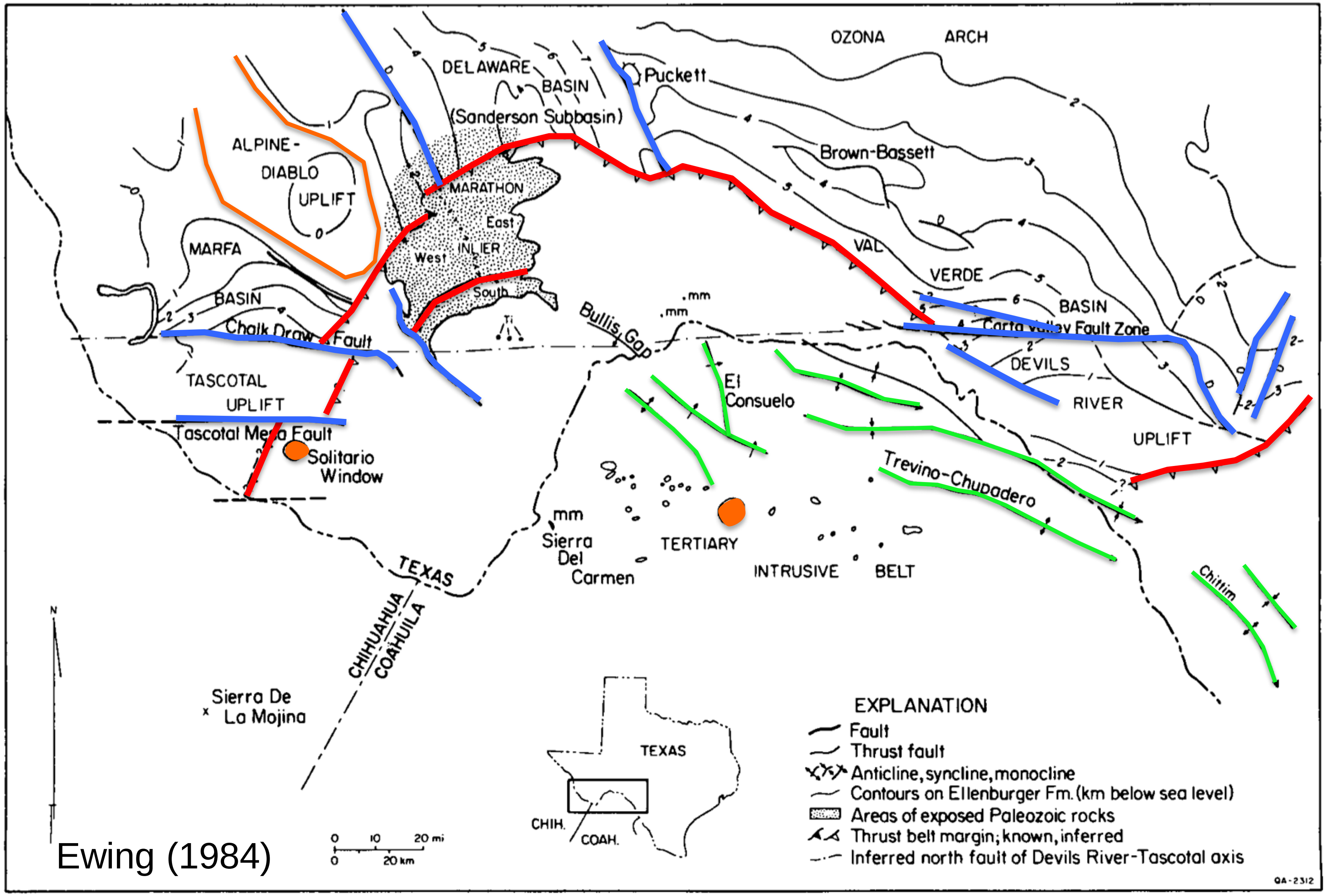
Orogens

Cretaceous-age Folds and Faults, Laramide Orogeny – Northern Mexico



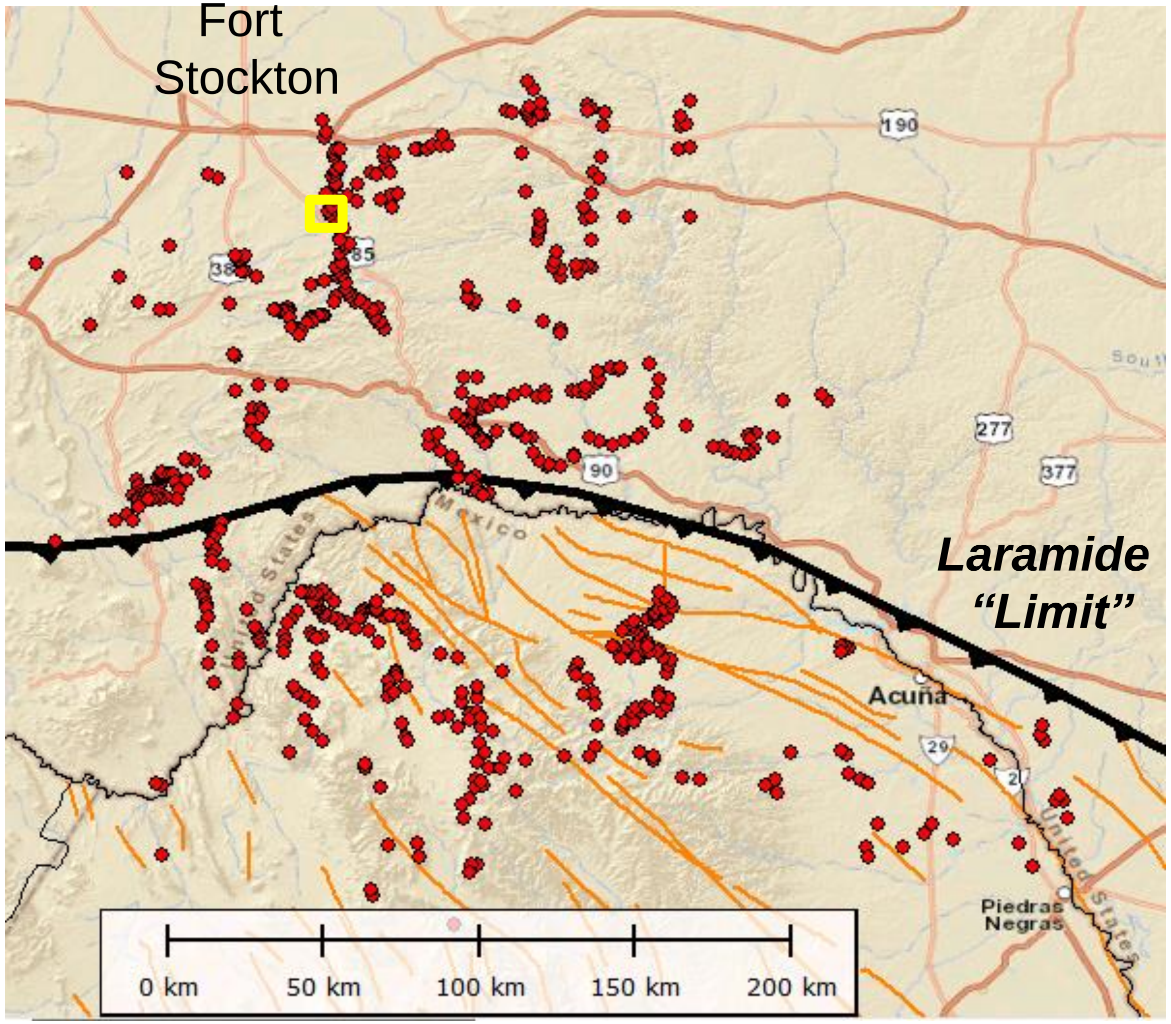
Tectonic Elements of South Texas

- Oldest P-C Basement Elements (blue)
- Paleozoic ARM Elements (red)
- L. Cretaceous Laramide Elements (Green)
- Neogene Rift Elements (Orange)

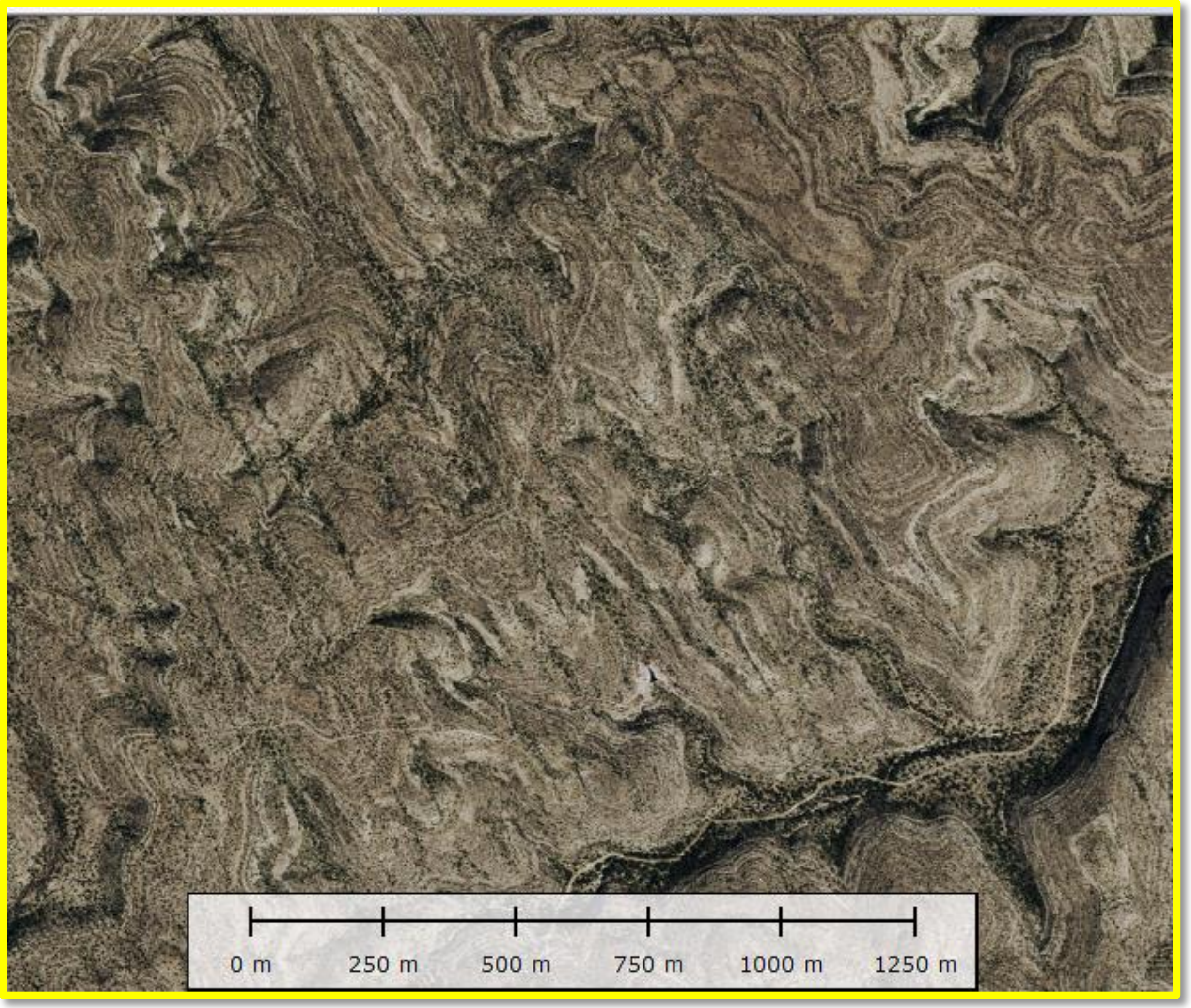


Ewing (1984)

Late Cretaceous Outcrop Exposure with Small Faults

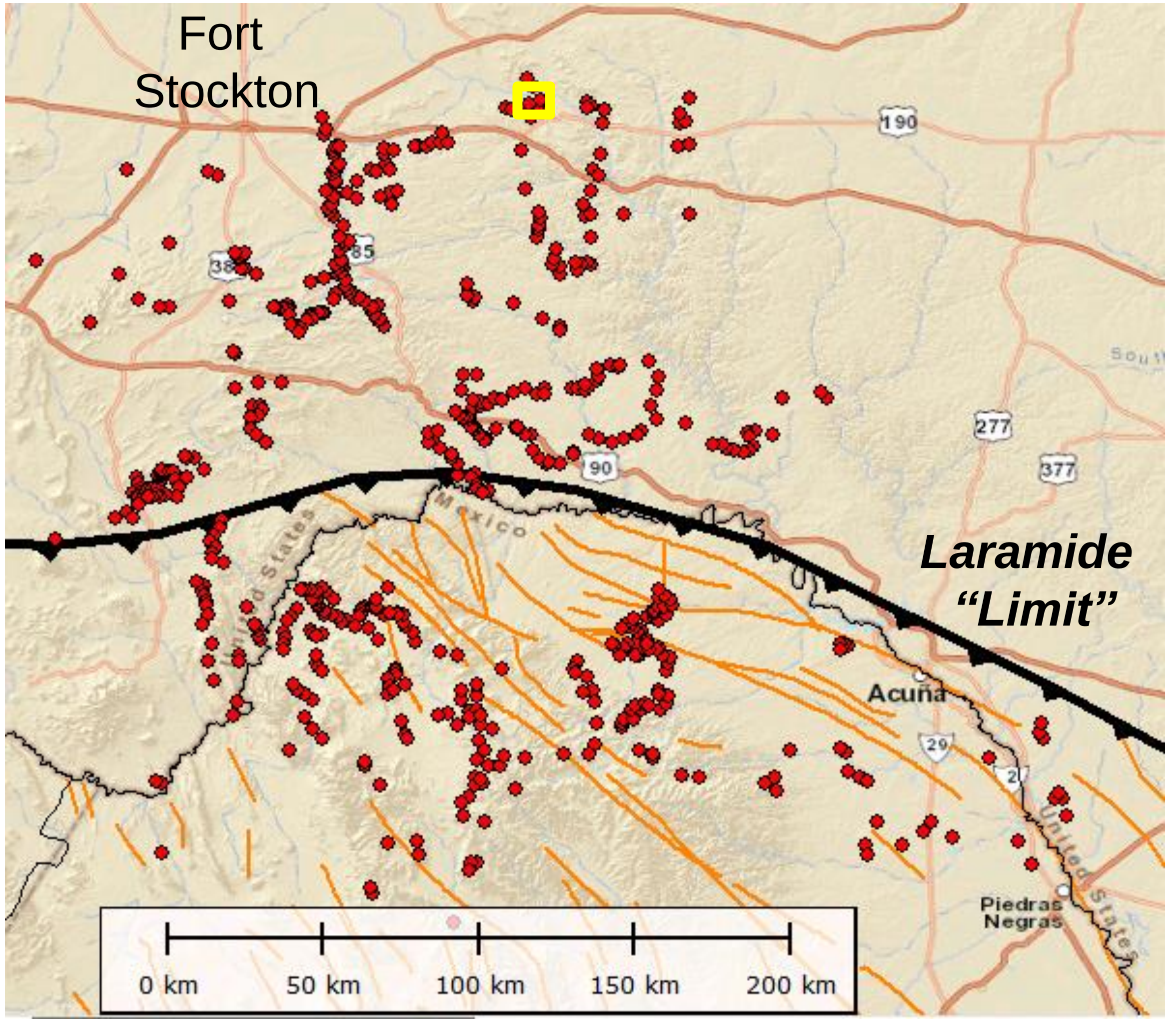


Location of exposed faults in outcrop



NNW Orientated Faults

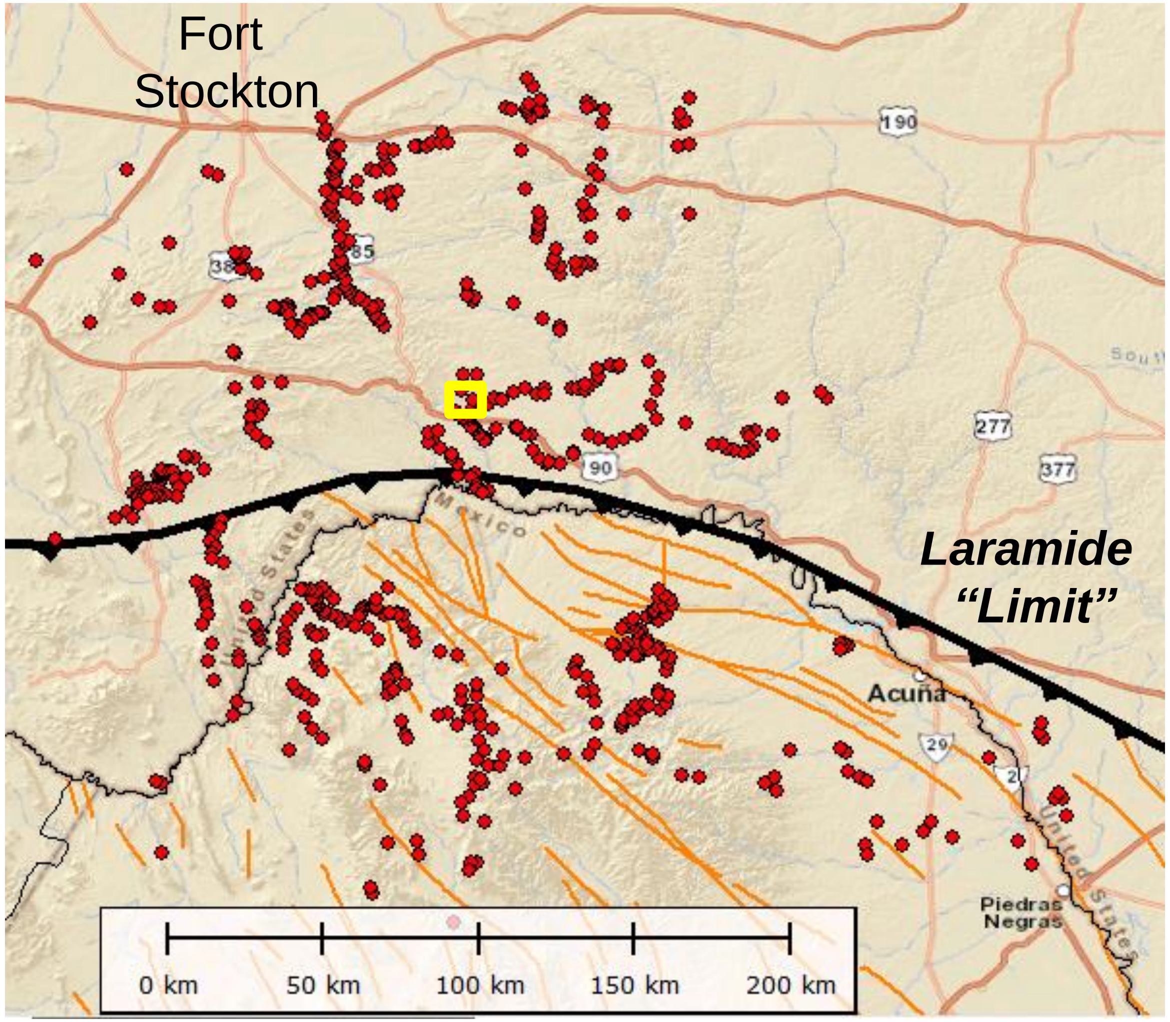
Late Cretaceous Outcrop Exposure with Small Faults



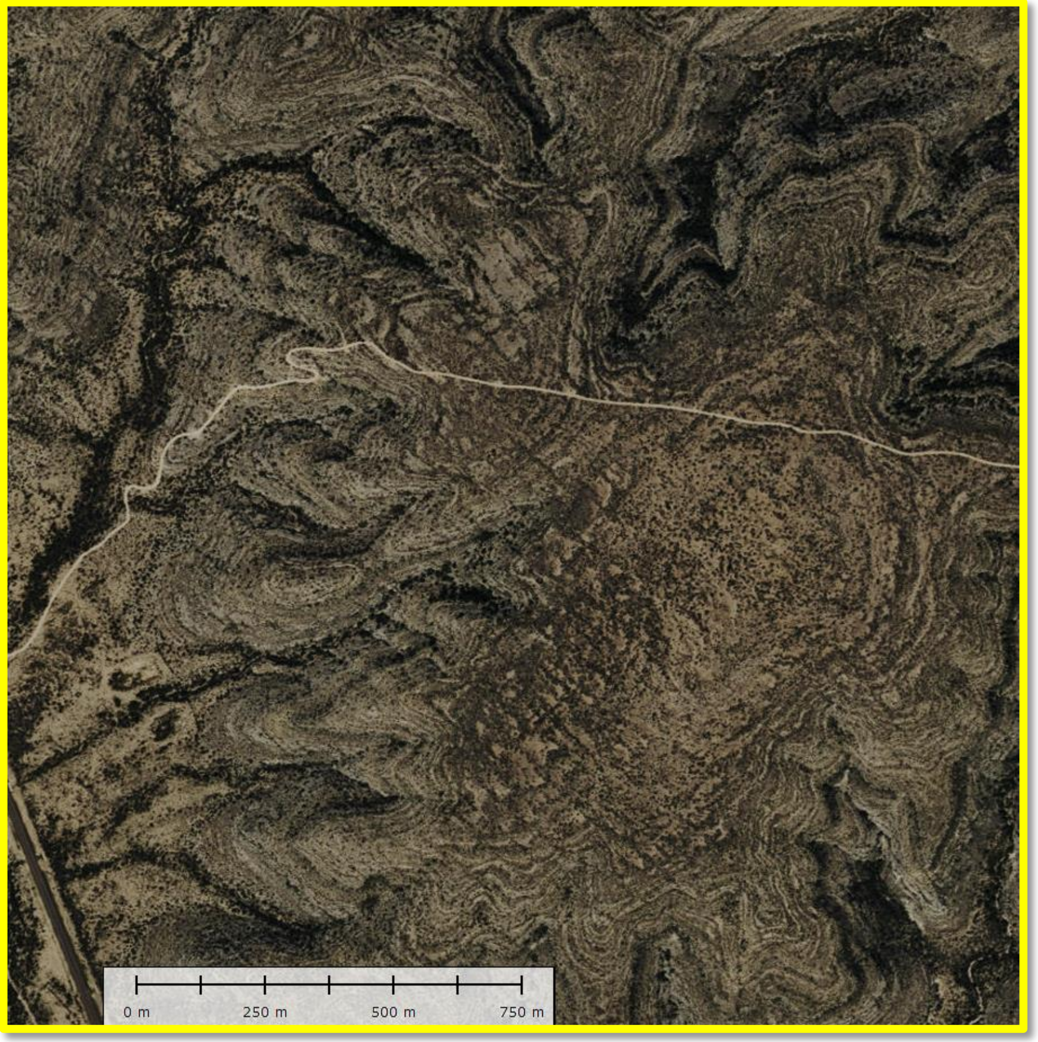
Location of exposed faults in outcrop

North-Orientated Faults

Late Cretaceous Outcrop Exposure with Small Faults

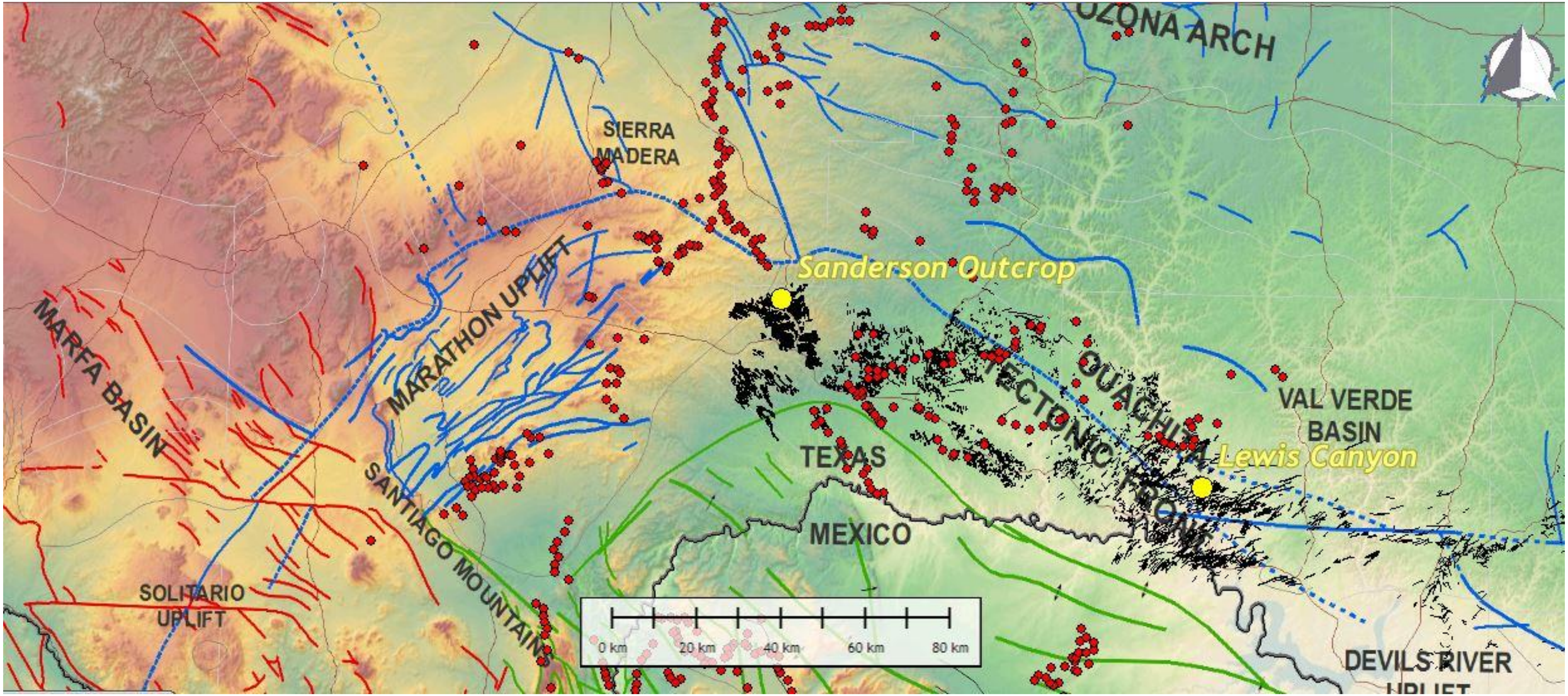


Location of exposed faults in outcrop

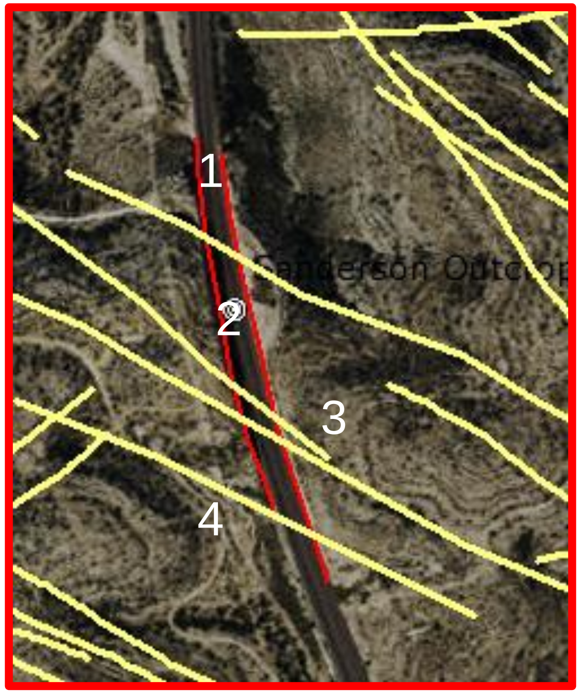


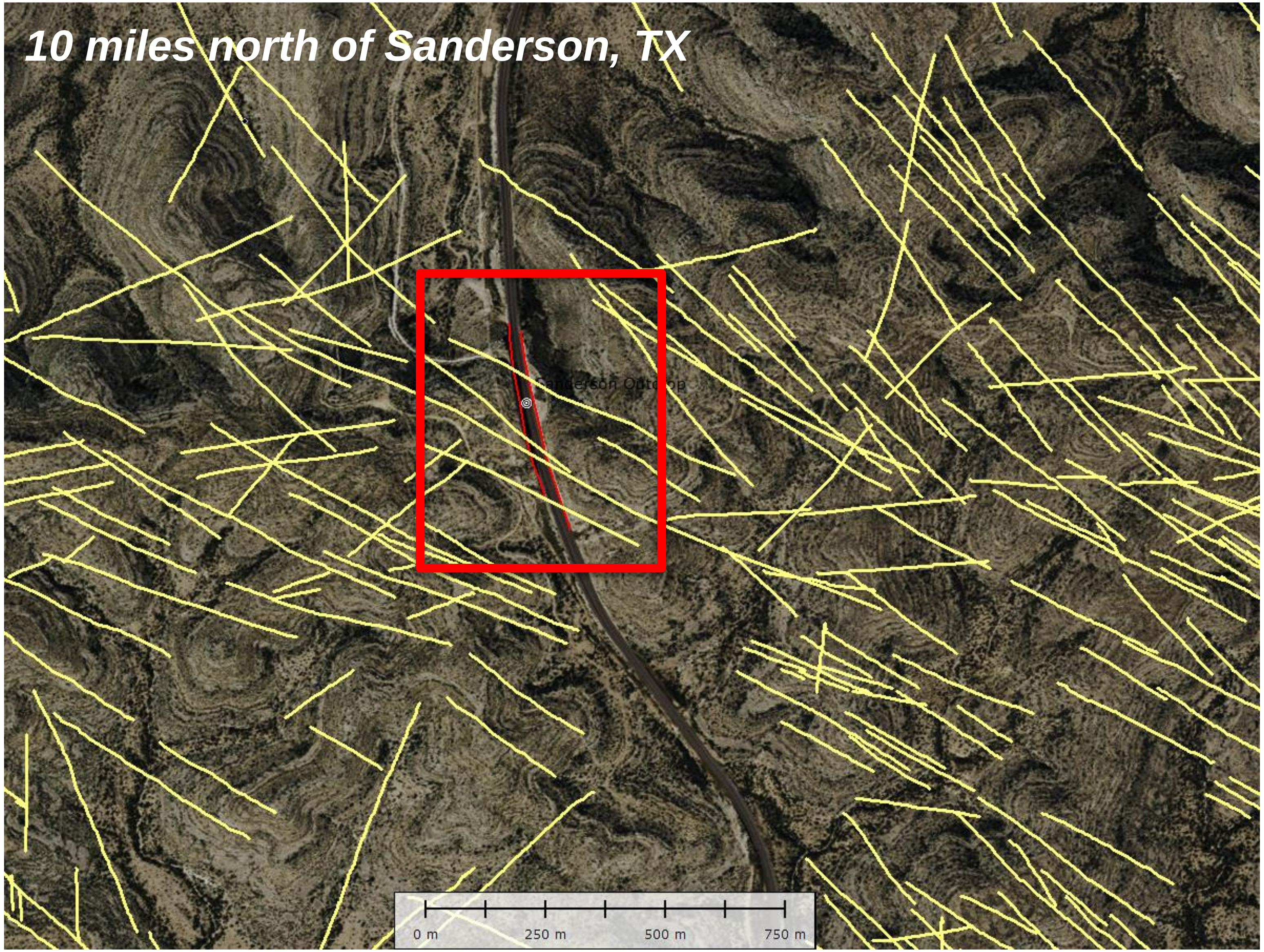
NW-Orientated Faults

Mapped Faults Exposed in Late Cretaceous Carbonates

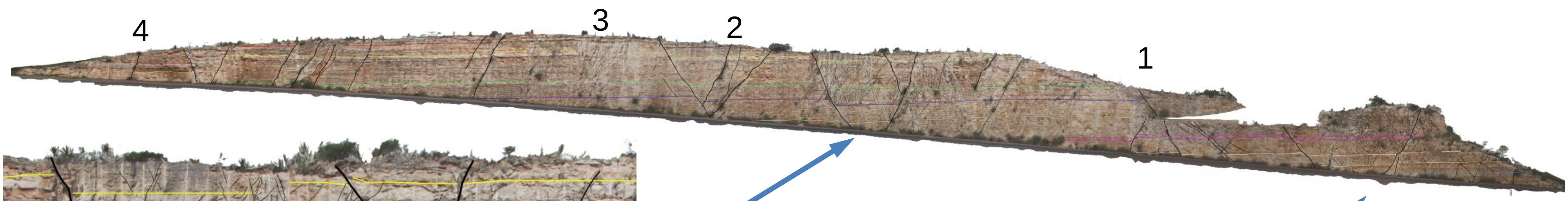


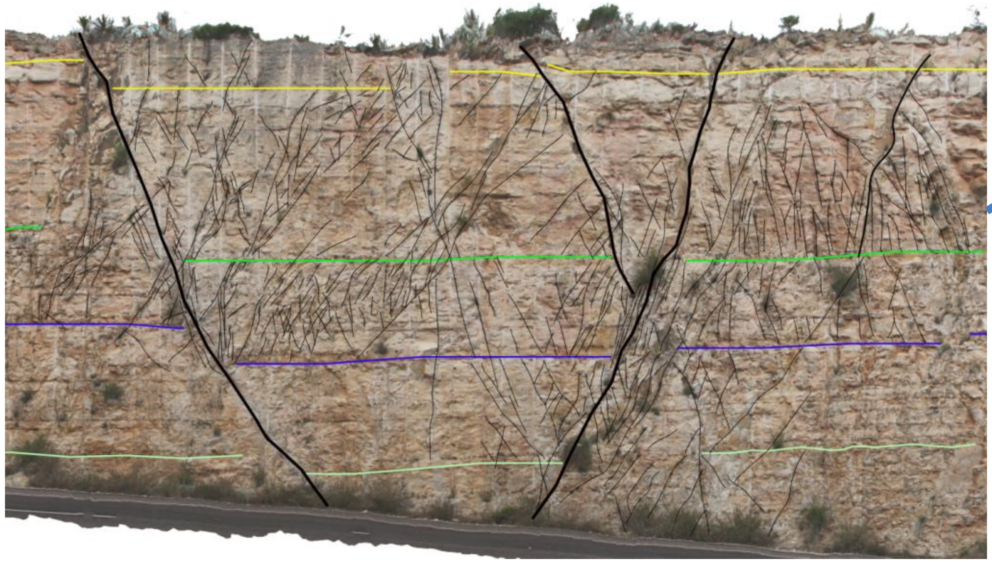
Are these features really faults?



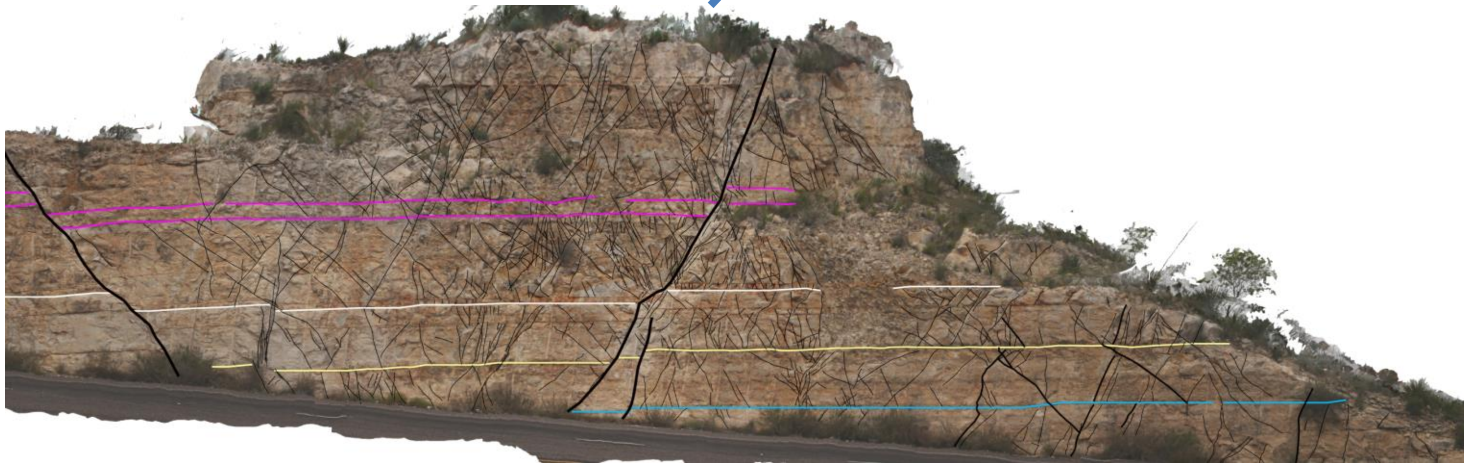


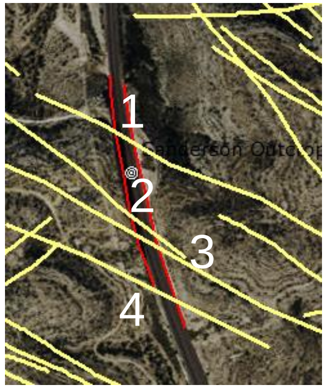
Oblique Extensional Slip Faults Exposed in Roadcut



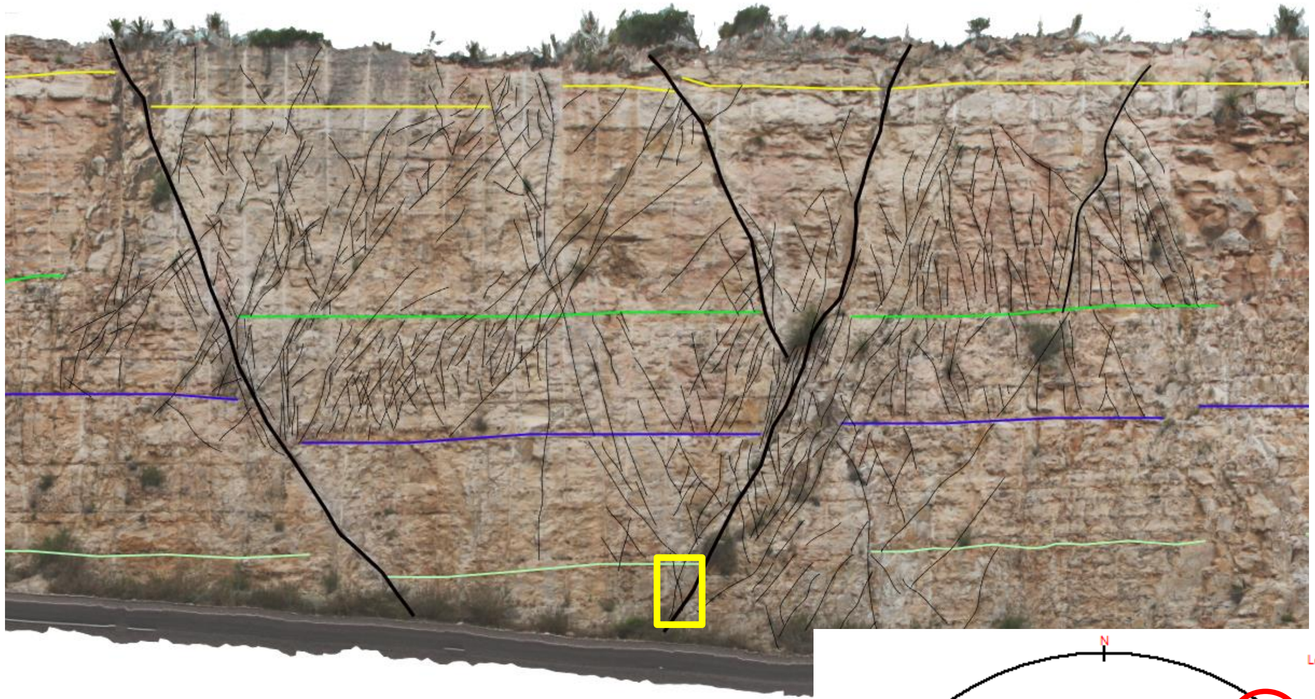


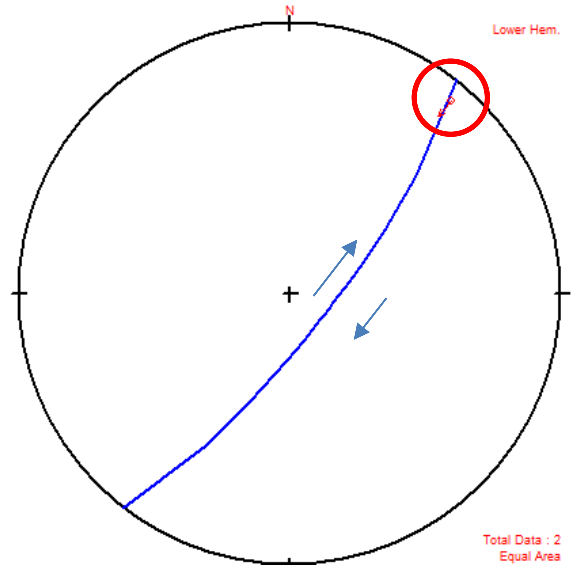
Total outcrop length is ~375 m
(oriented NNW to SSE)





Compressional Deformation: Oblique-Slip Faults (Low Rake Angles)





- Orientation is NE (038)
- Dip is high (78)
- Rake is low (8)
- Right-lateral fault

Compressional Deformation: Oblique-Slip Faults (Low Rake Angles)

Compressional Deformation: Vertical Stylolites

NE-oriented fractures

- Greater oblique extensional offset
- Significant calcite spar within growing void
- Multiple episodes of opening, calcite precipitation and slip (both extensional and low angle oblique
- More frequent fracture intensity halos

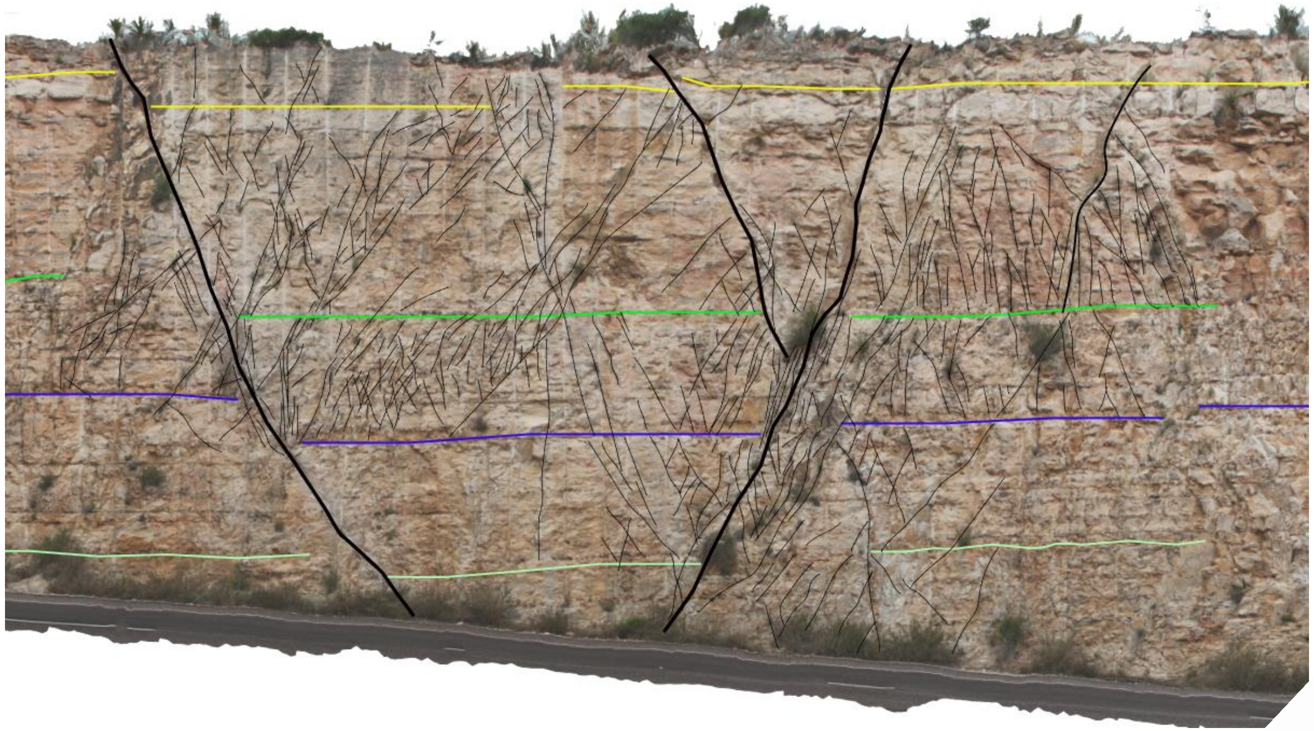
NW-oriented fractures have

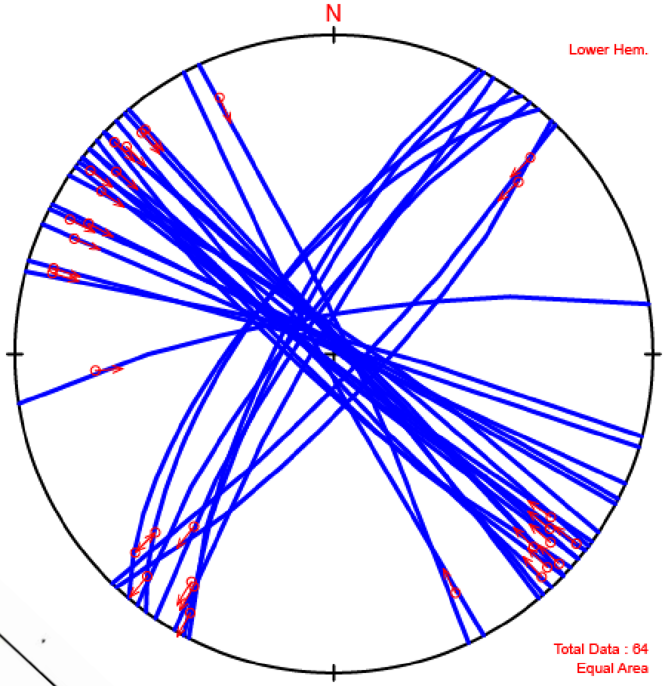
- Limited offset slip
- Limited calcite spar
- Lower intensity of secondary fractures
- Higher frequency of occurrence

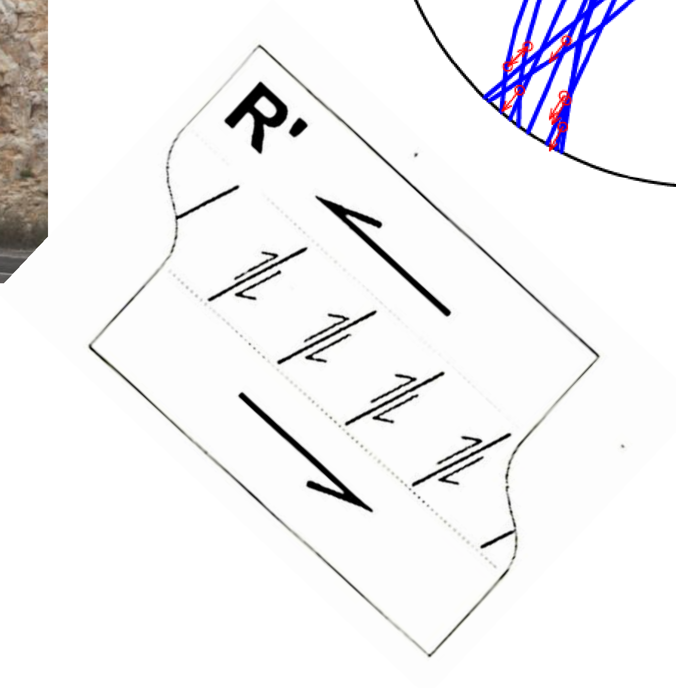
Compressional Deformation: Oblique-Slip Faults (Low Rake Angles)

NE Fault

NW Fault

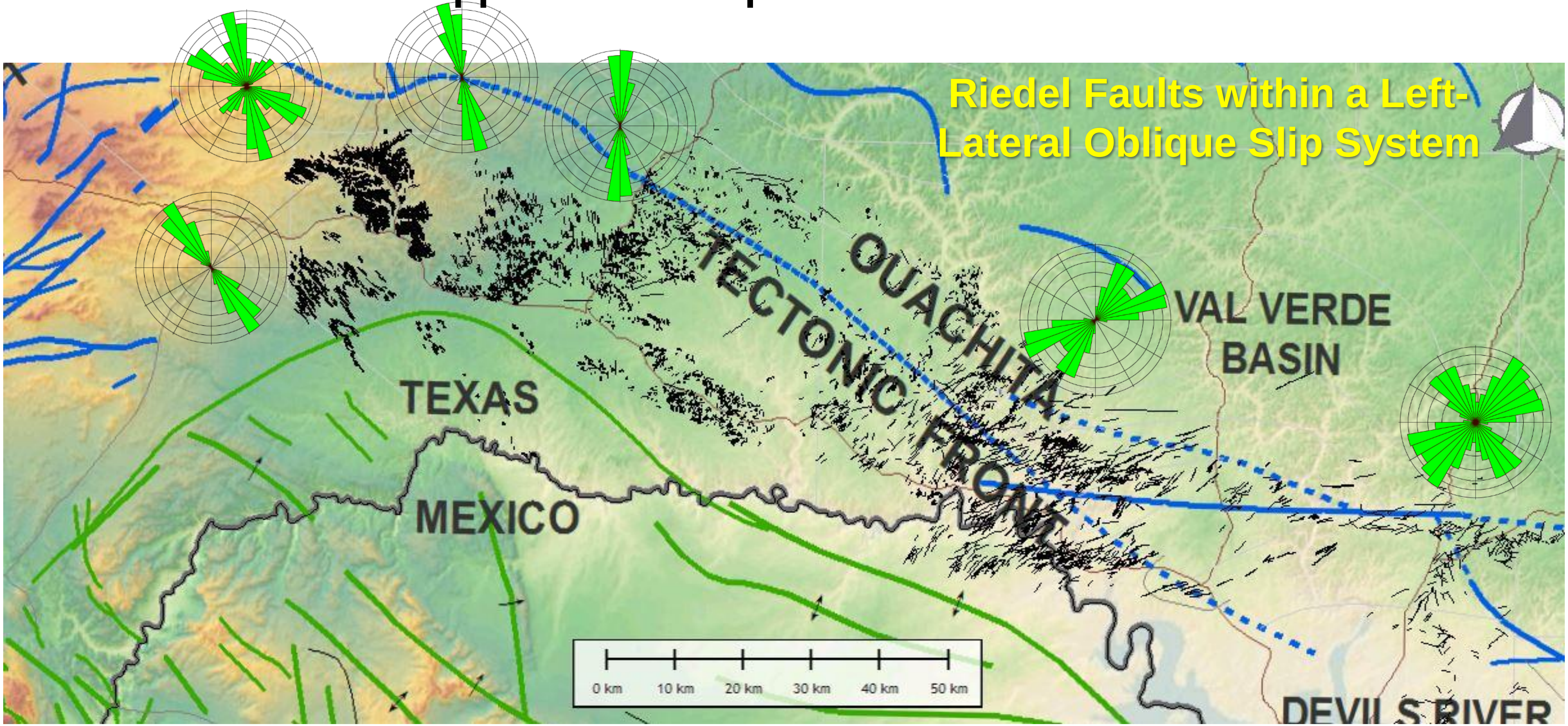






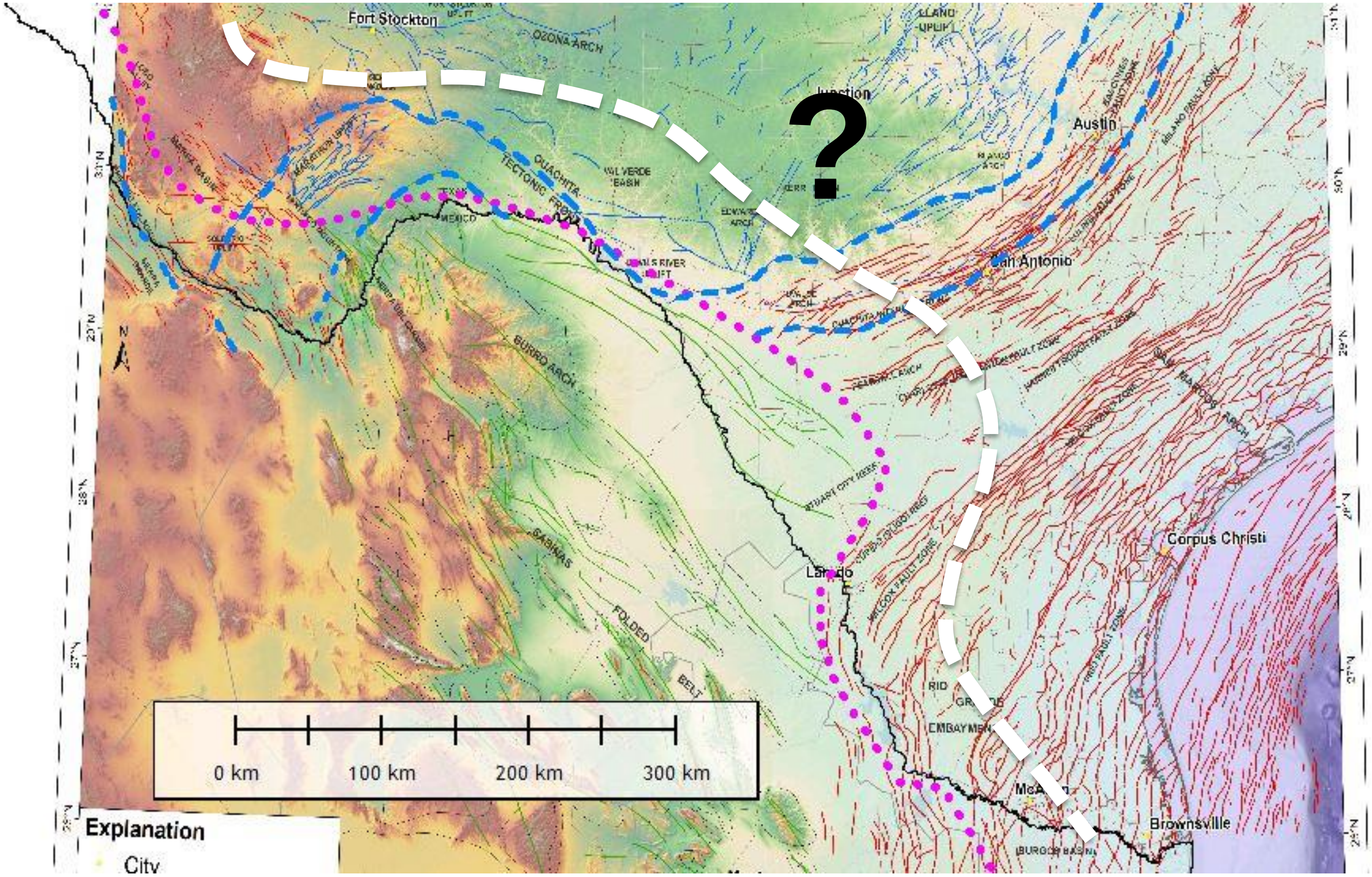
Left-Lateral, Oblique-Slip Faults

Orientation of Mapped Faults Exposed in L. Cretaceous Carbonates



- Cretaceous faults reflect Pre-Cambrian to Paleozoic basement structural elements
- Thin-skinned fold belt has little to no effect on orientation preference

Where is the brittle deformation "limit" of an orogeny in when pre-existing faults are present?



Conclusions

- The brittle deformation “limit” in the orogenic forelands may represent a broad zone (10-100s km) with significant deformation

- Pre-existing structures or “tectonic inheritance” plays a critical role in concentrating brittle fault and fracture elements in orogenic foreland

- Faults that develop have little vertical offset, but very high concentrations (100s m spacing) and significant fault-related fracture zones

- Consideration of these fault and fractures systems are critical to understanding permeability heterogeneity in subsurface reservoirs

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