Small Faults, Big Damage Zones — An Example of Fault-Related Fractures and Dissolution Collapse in a Ramp Crest Carbonate System, Lower Pecos River Canyon, Texas*

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Abstract

Fractures that develop in faulted carbonate strata, especially faults of less than 5 m offset, are problematic for reservoir characterization due to detection difficulty in the subsurface. This study documents an outcrop example of fracture development and dissolution collapse along faults with minor offset. The outcrop exposure along the Lower Pecos River is unique in many ways, but most striking is that carbonate strata containing faults are continuously exposed for more than 60 miles. This provides an opportunity to study progressive fracture development from minor, mechanically-bound fractures culminating in brecciated faults and dissolution collapse zones.

Lewis Canyon lies along the Lower Pecos River Canyon exposing three upper Albian (Cretaceous) high frequency sequences. A single high frequency sequence consists of transgressive systems tract (TST) dominated by mud-rich facies containing low-relief chondrodontid clam mounds capped by radiolitid rudist rudstones and bafflestones. TST bed thickness is variable ranging from 15 cm to 2 m within the mounds. Highstand systems tract (HST) facies consist of accumulated lower shoreface grainstones that are 10-15 m in thickness. Variability in thickness and facies types creates a heterogeneous architecture with higher fracture intensity in the thin-bedded TST compared to the grainstones of the HST. This relationship is pervasive in outer zones greater than 100 m from exposed faults. Fracture intensity increases as proximity to the fault increases up to 2 meters where significant brecciation is common.

Faulting along the outcrop area is a result of Laramide compressional tectonics that created compressional folds in northern Mexico. Folding is not observed along the Pecos River Canyon. Rather, Laramide reactivation of Ouachitan-age reverse faults creates oblique slip on the preexisting basement faults and secondary faults associated with oblique slip. Scale of outcrop exposure and minor fault offset, make this a great locality to improve understanding of the interaction of stratigraphy, fracture, and faulting at a scale that is most problematic to reservoir characterization.

Selected References

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Kerans, C., 2002, Styles of Rudist Buildup Development along the Northern Margin of the Maverick Basin, Pecos River Canyon, Southwest Texas: GCAGS Transactions, v. 52, p. 501-516.

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Lehmann, C., D.A. Osleger, and I. Montanez, 2000, Sequence Stratigraphy of Lower Cretacous (Barremian-Albian) Carbonate Platforms of Northeastern Mexico: Regional and Global Correlations: Journal of Sedimentary Research, Section B: Stratigraphy and Global Studies, v. 70/2, p. 373-391.

Leonard, R.C., 1977, A comparison of fracture patterns and post Paleozoic structural features on the southern Edwards Plateau, Texas: GSA Abstracts with Programs, v. 9/1, p. 58.

Wilcox, R.E., T.P. Harding, and D.R. Seely, 1973, Basic Wrench Tectonics: AAPG Bulletin, v. 57/1, p. 74-96.

Woodcock, N.H. and C. Schubert, 1994, Continental strike-slip tectonics *in* P.L. Hancock, (ed.) Continental Deformation: Pergamon Press, New York, New York, p. 251-263.

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An Example of Fault-Related Fractures and Dissolution Collapse in a Ramp Crest Carbonate System, Lower Pecos River Canyon, Texas

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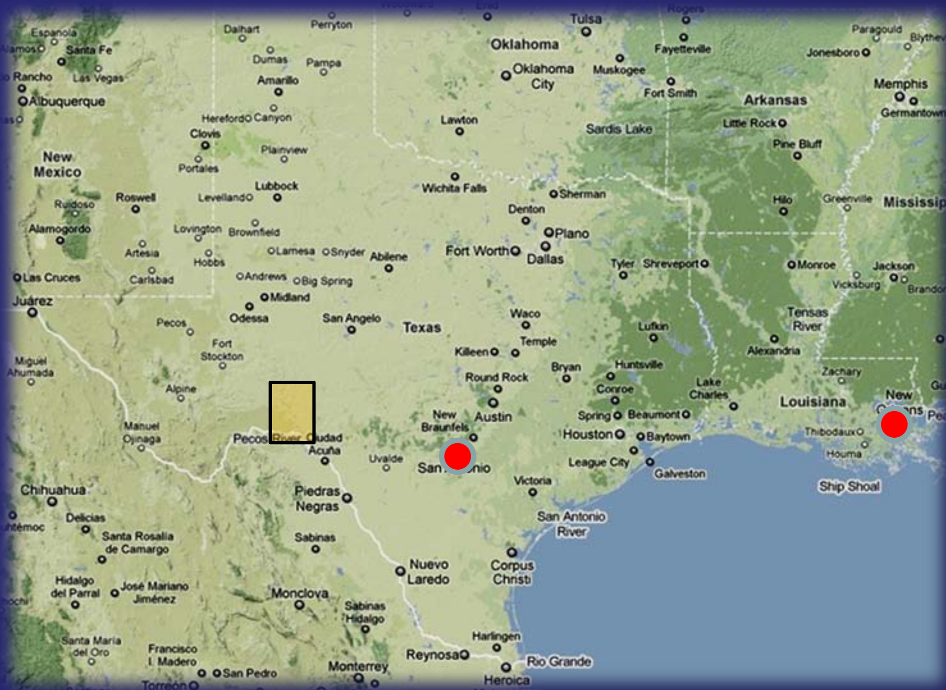
The University of Texas at Austin

April 2010, AAPG Annual Convention, New Orleans, LA

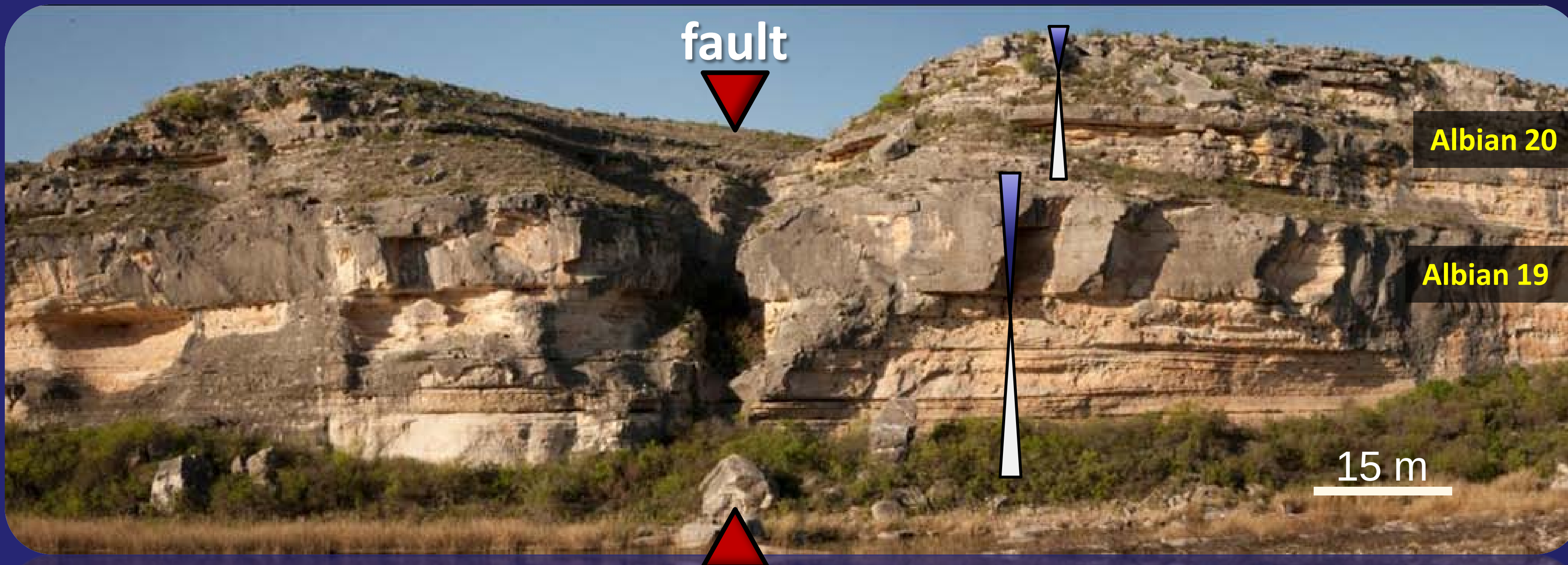
Is it really faulted?



700 miles west of New Orleans
250 miles west of San Antonio

- 60+ miles of continuous exposure (>20 mile dip direction).
- Correlation of the same Late Albian packages possible throughout the entire interval.
- Less that 1° regional stratigraphic dip.

Sub-Seismic Detection of a Fault Zone



- Fault zones in outcrop have limited vertical offset which allows for lateral correlation of stratigraphic units over ten's of miles.

Reservoir Characterization Significance

- Fractures that develop by reactivation of pre-existing tectonic elements can be significant, yet in this example remain undetectable by most seismic surveys (and even geologists in the field).

- These undetected fractures represent reservoir heterogeneities that may result in anomalous permeability corridors or thief zones, complicating enhanced recovery efforts.

Overview

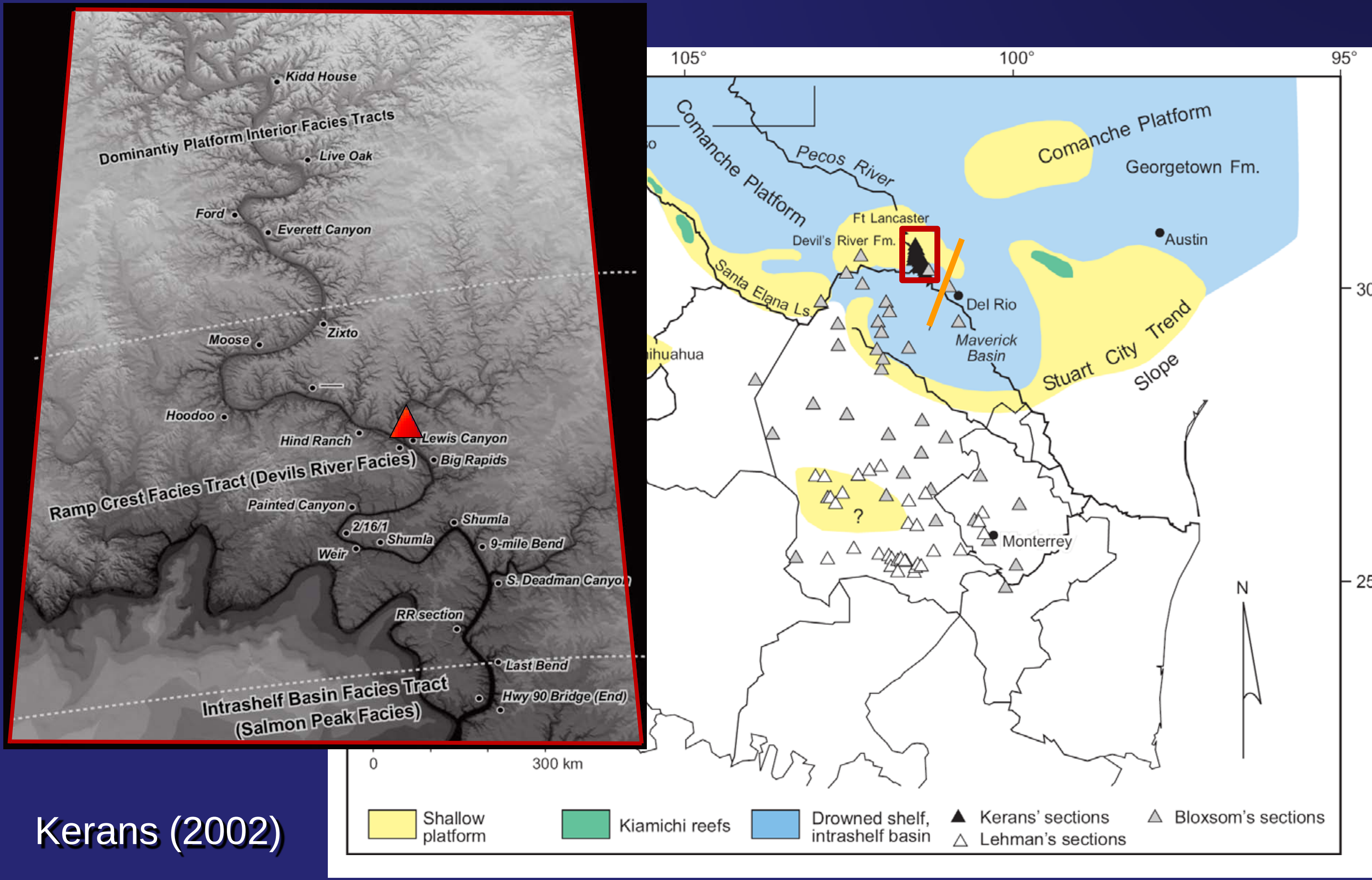
Review the stratigraphic and tectonic framework of the Lower Pecos River and Devil's River Uplift

Revisit the oblique-slip model for secondary fractures

Illustrate quantified fault damage zones to highlight the interplay of stratigraphy and structure

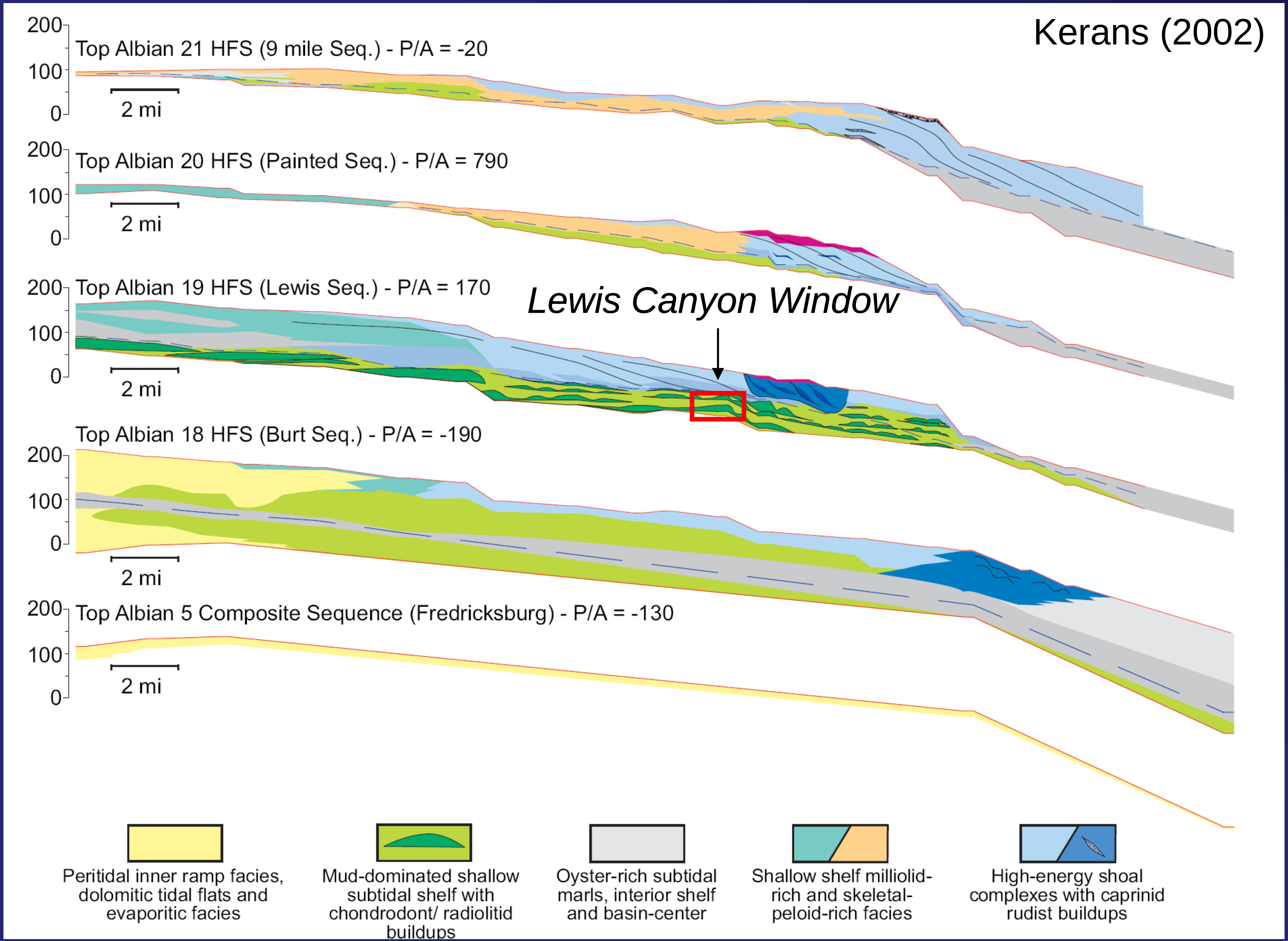
Describe karst collapse related to intersection fault elements

U. Albian, Washita Group (Edwards Equivalent) Segovia / Devil's River / Salmon Peak Fm.

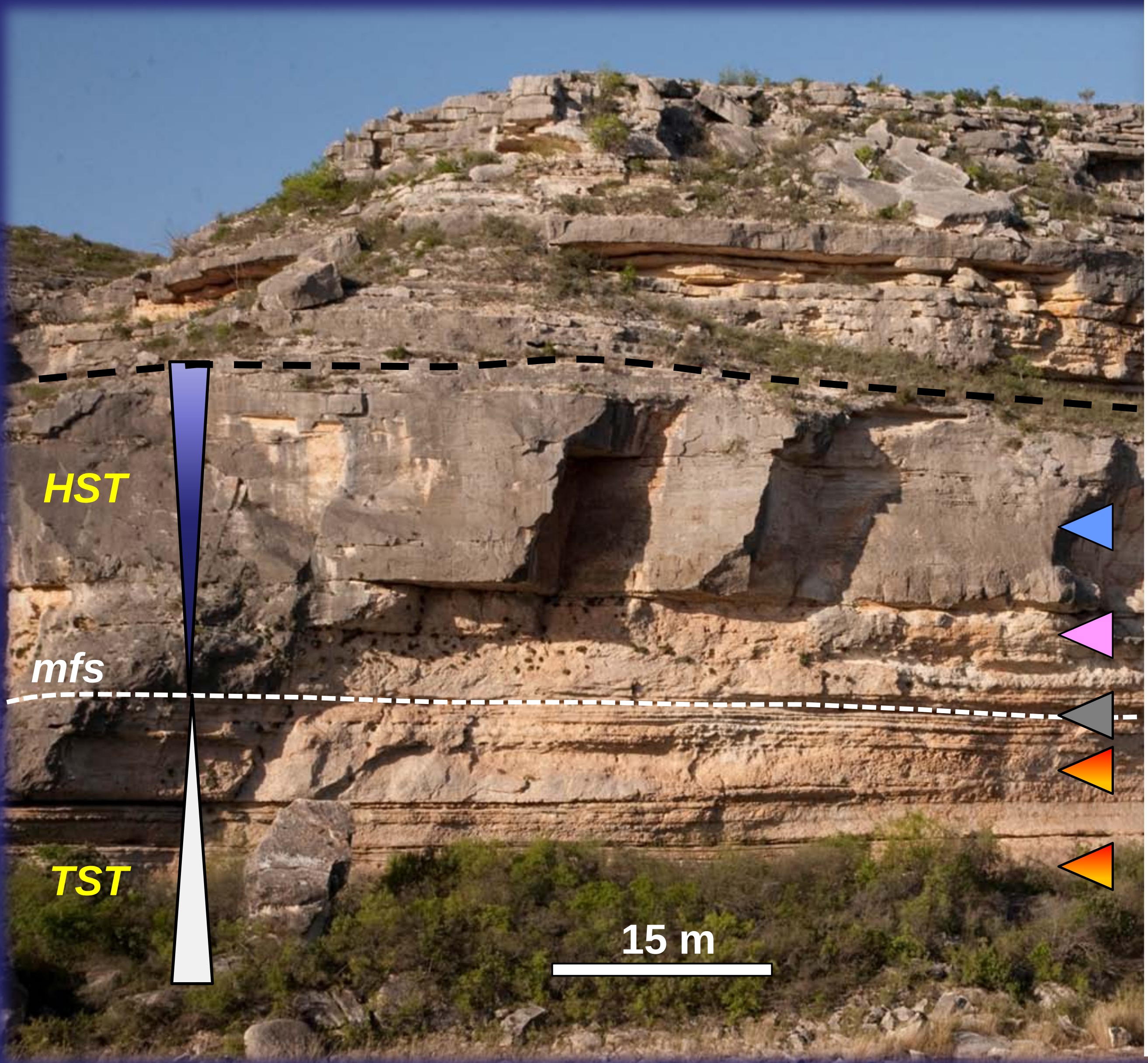


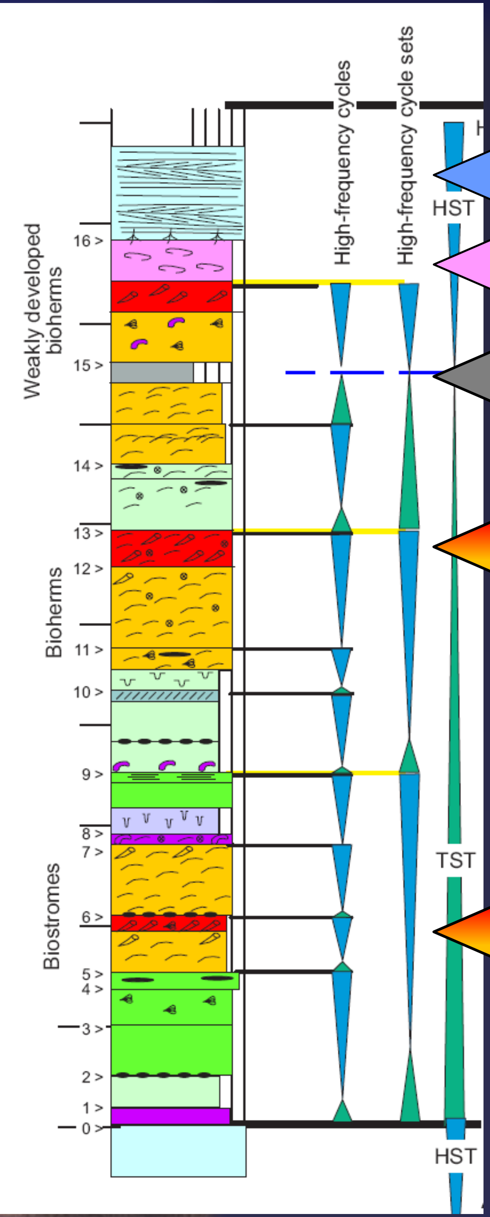
Kerans (2002)

High-Frequency Sequences of the Late Albian

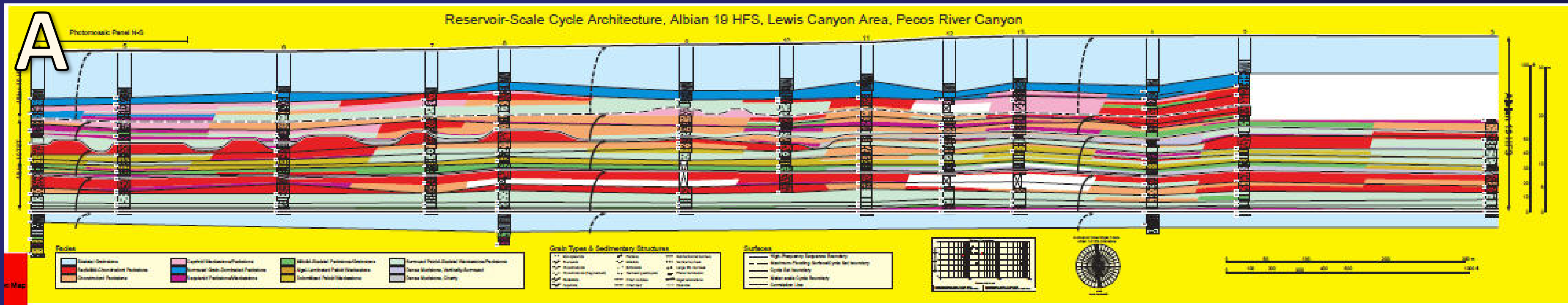


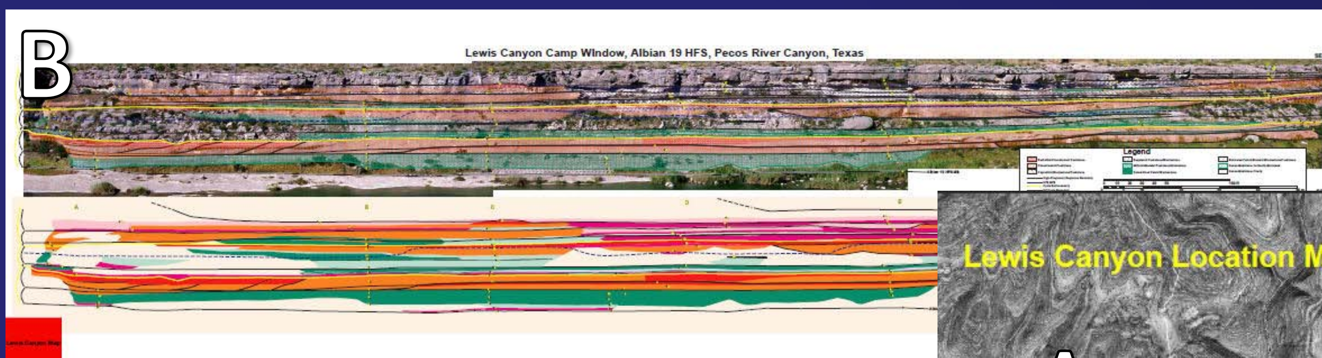
Sequence Stratigraphic Framework

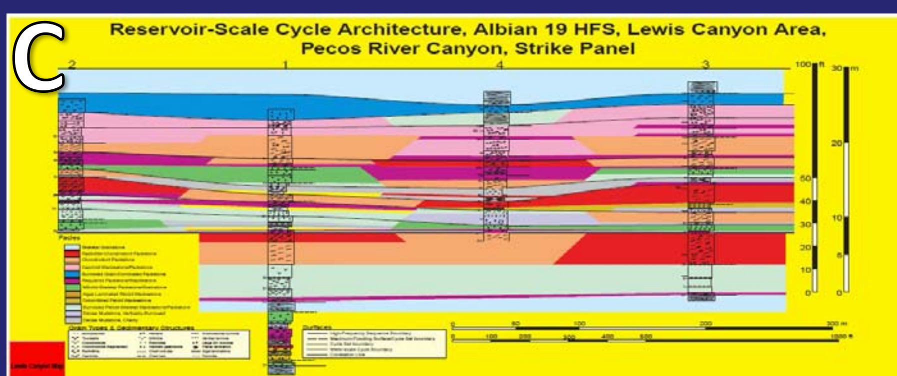


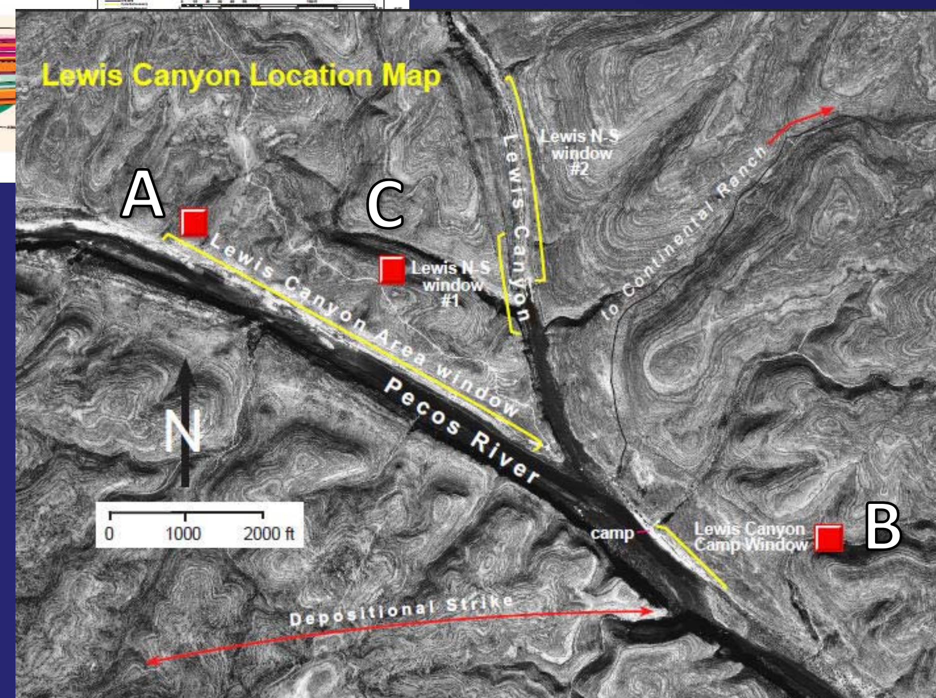


Stratigraphic Framework – Previous Work



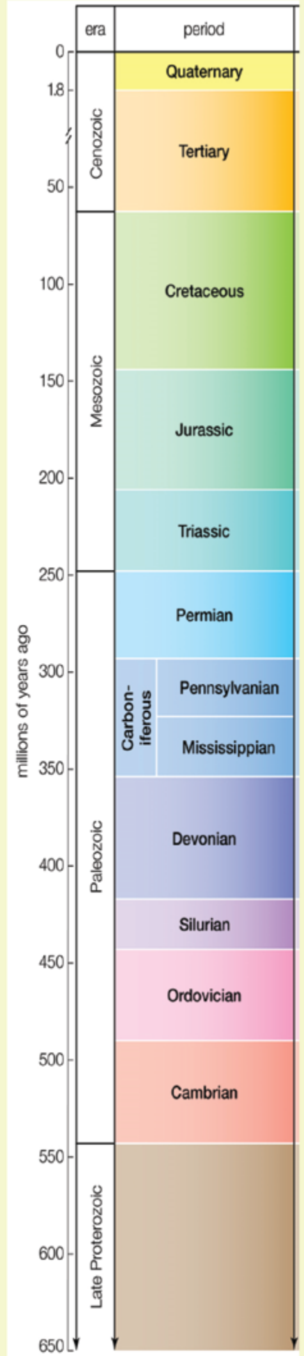






From Kerans and others (1996, 2002)

Stratigraphic Packages and Tectonic Events



L. Miocene
GOM Extension & Salt Tectonics

L. Maas to Paleocene
Laramide Orogen

Prekinematic (Laramide)
Albian to Santonian
Devil's River, Del Rio, Buda
Boquillas, Austin Chalk

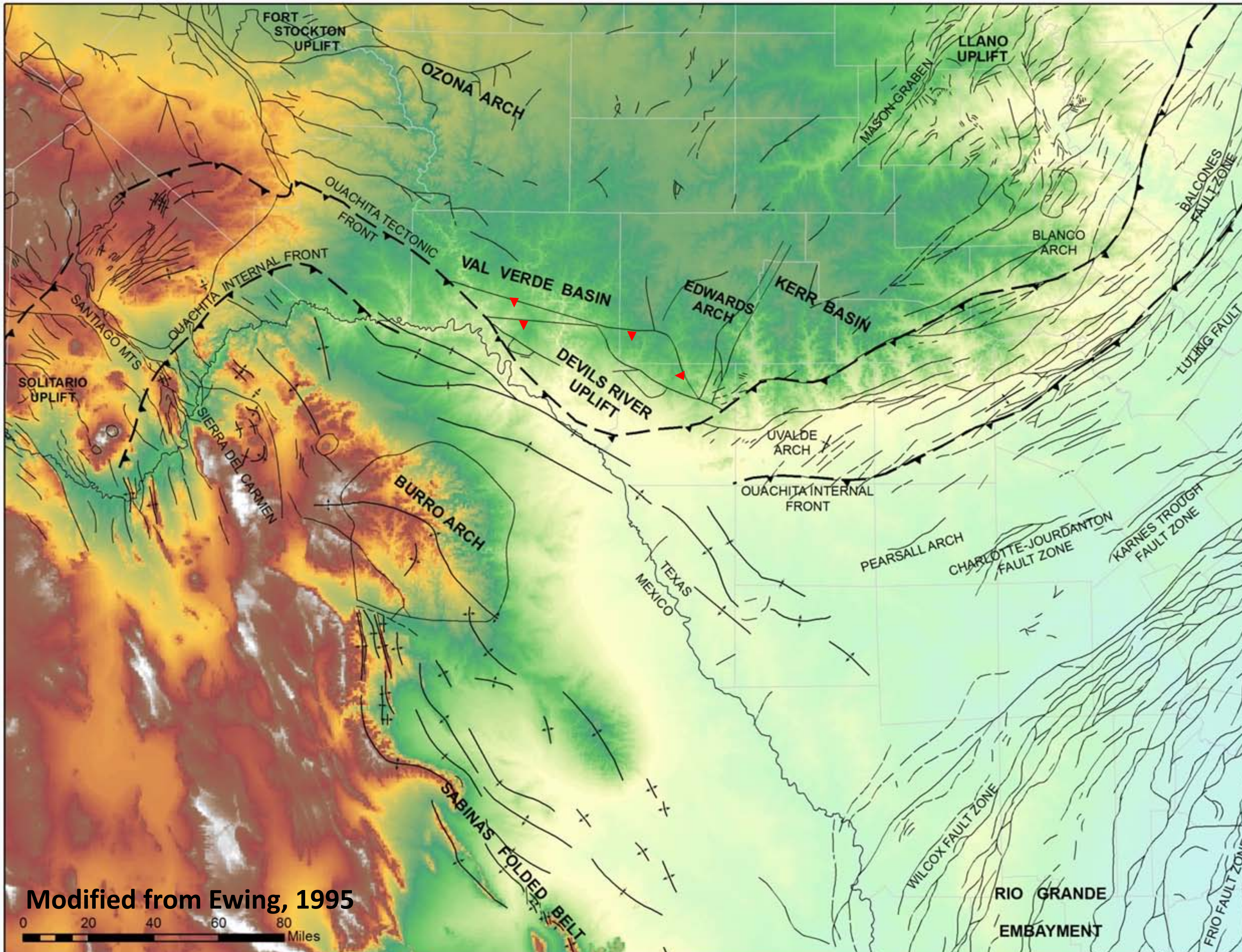
Synkinematic (Ouachita)
Permian-Wolfcampian

L. Miss to E. Permian
Ouachitan Orogen

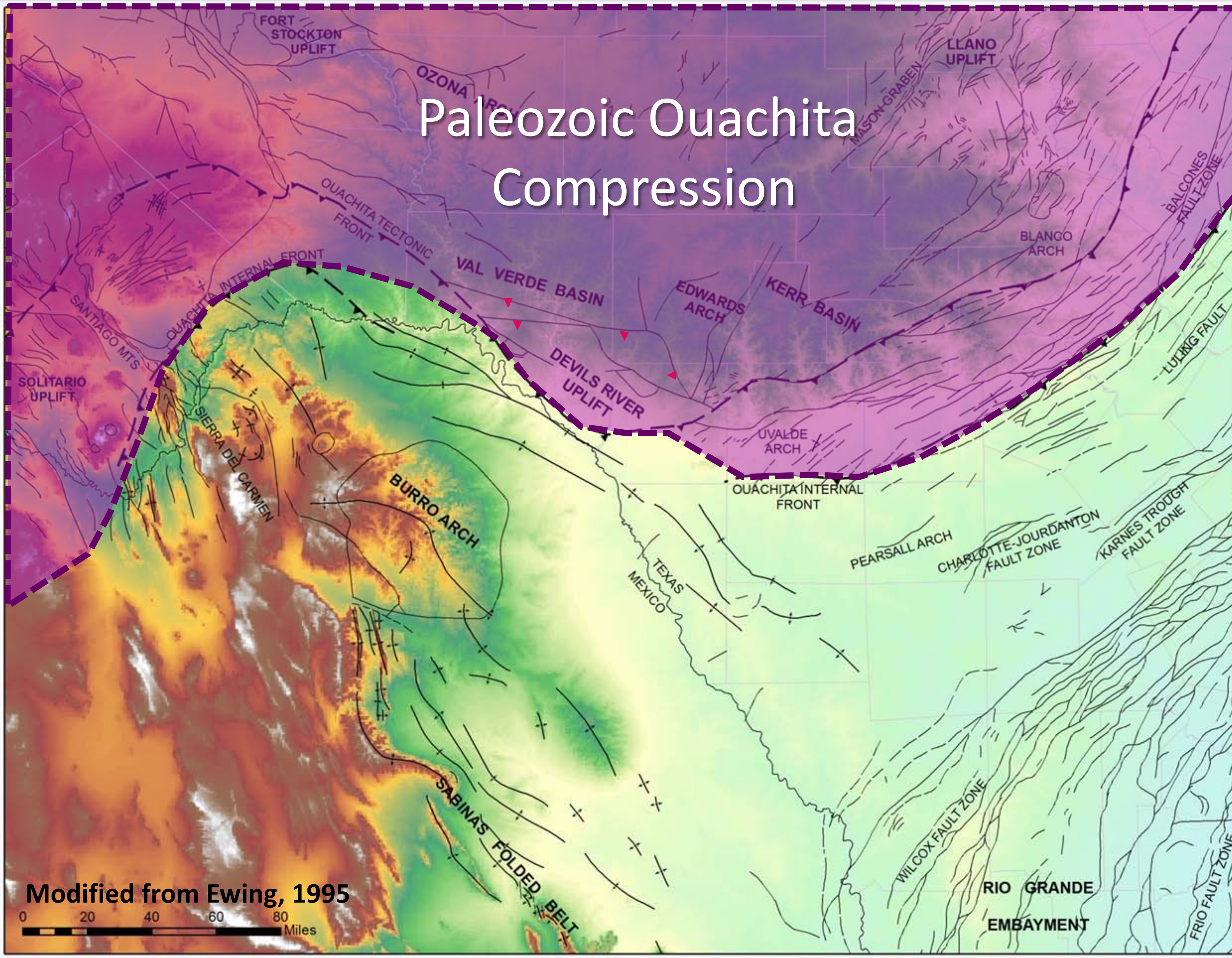
Prekinematic (Ouachita)
Woodford-Ellenburger

1.1 to 0.7 Ga
Rift-transform breakup
and failed rift arms

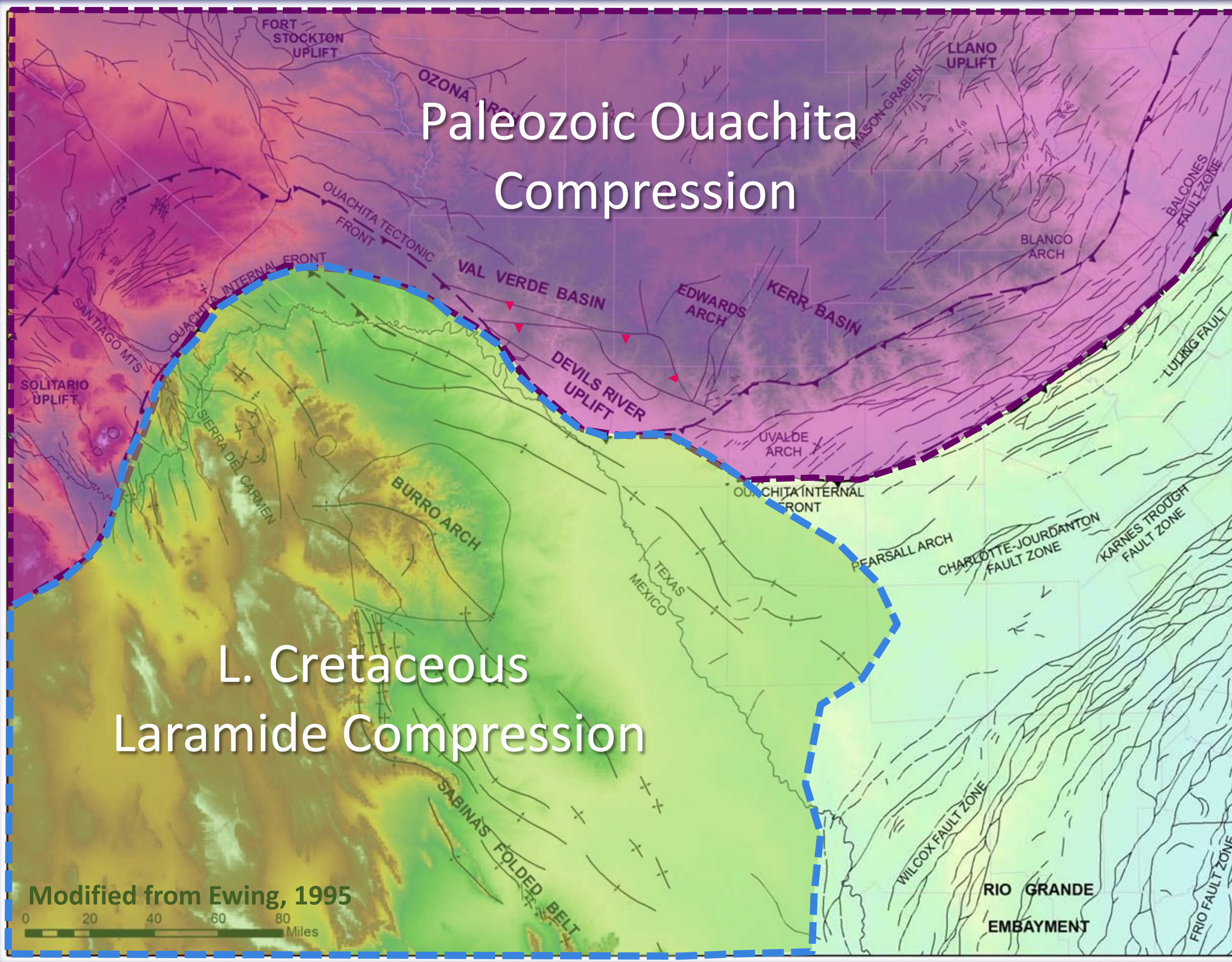
Tectonic Framework



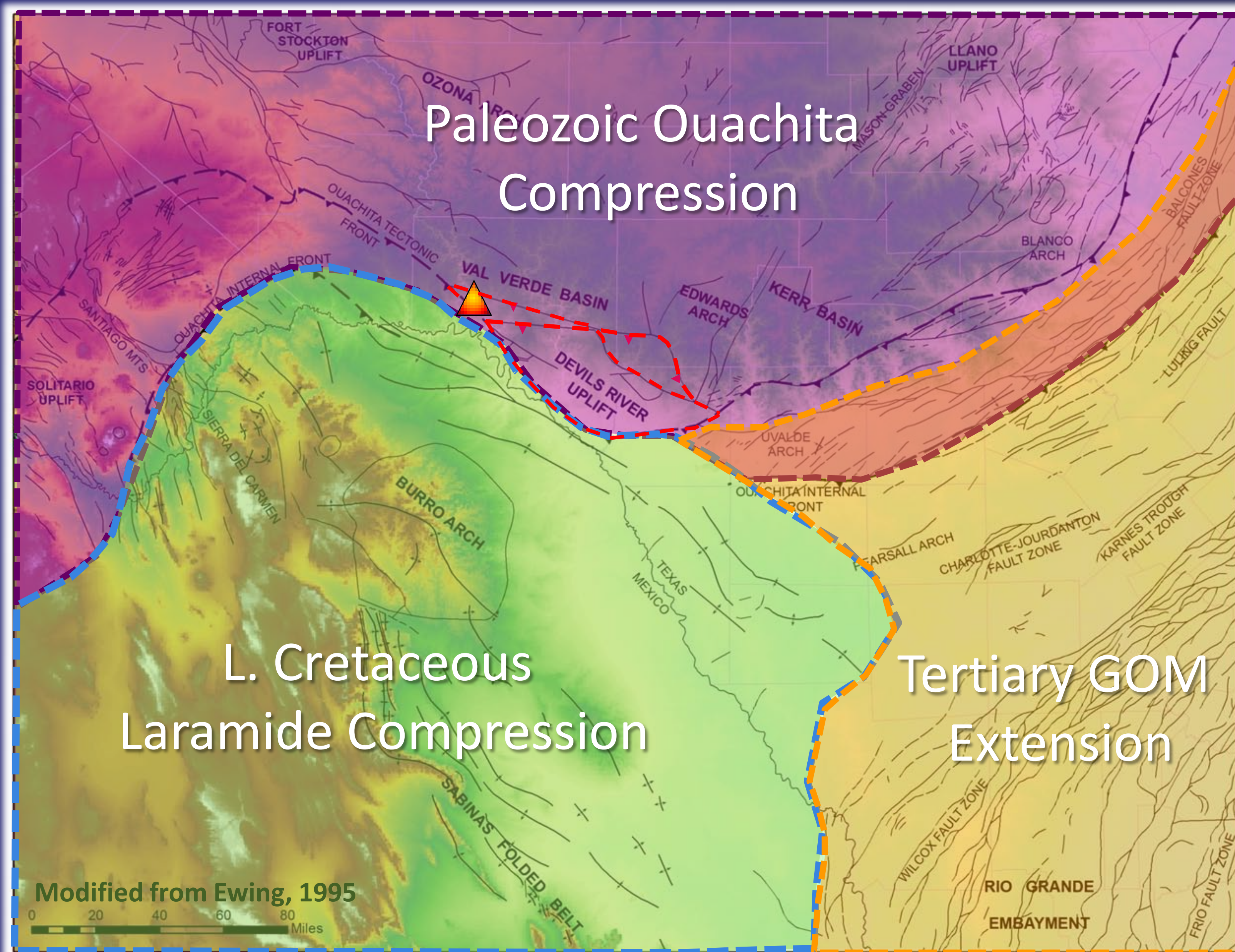
Tectonic Framework



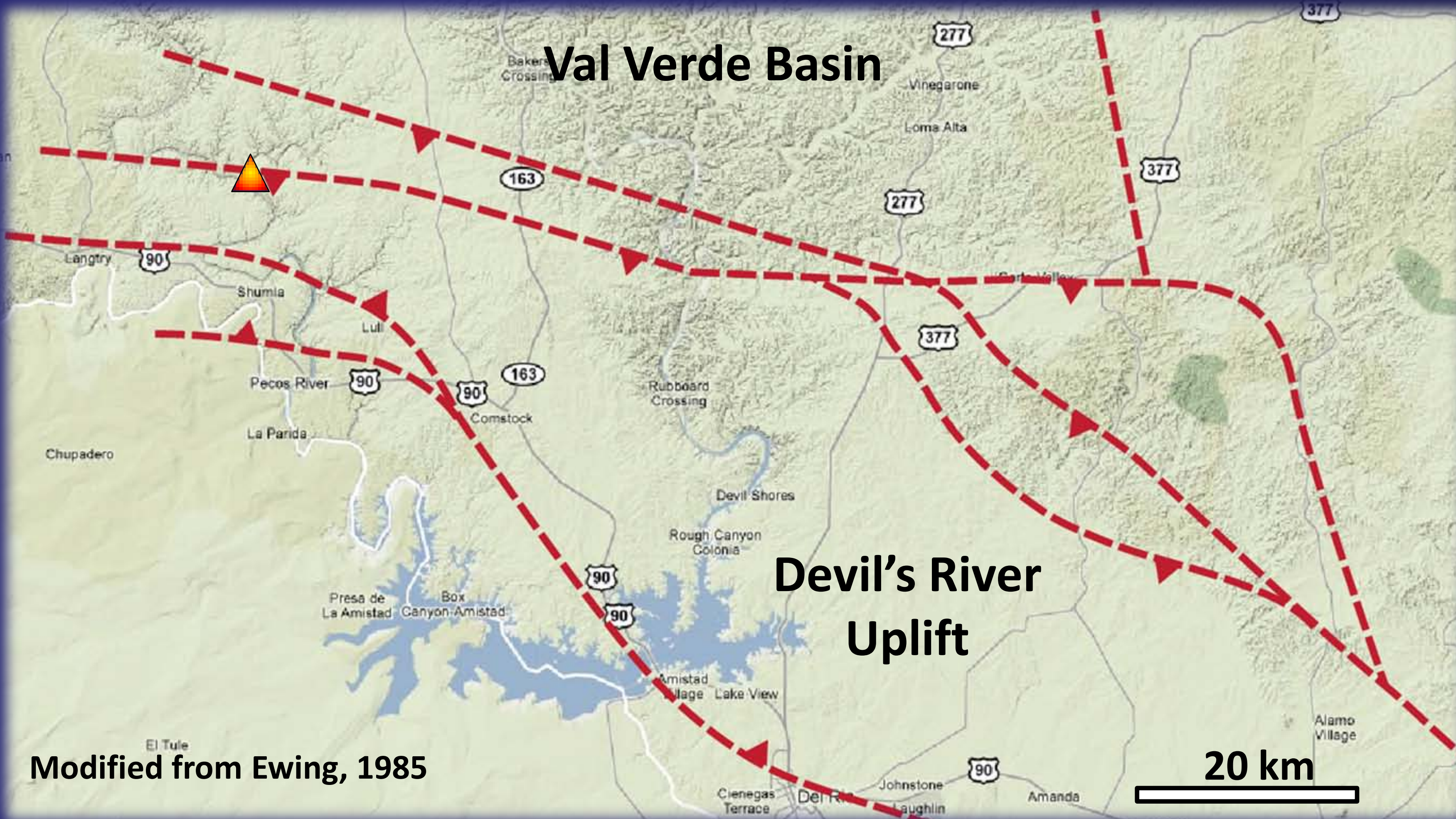
Tectonic Framework



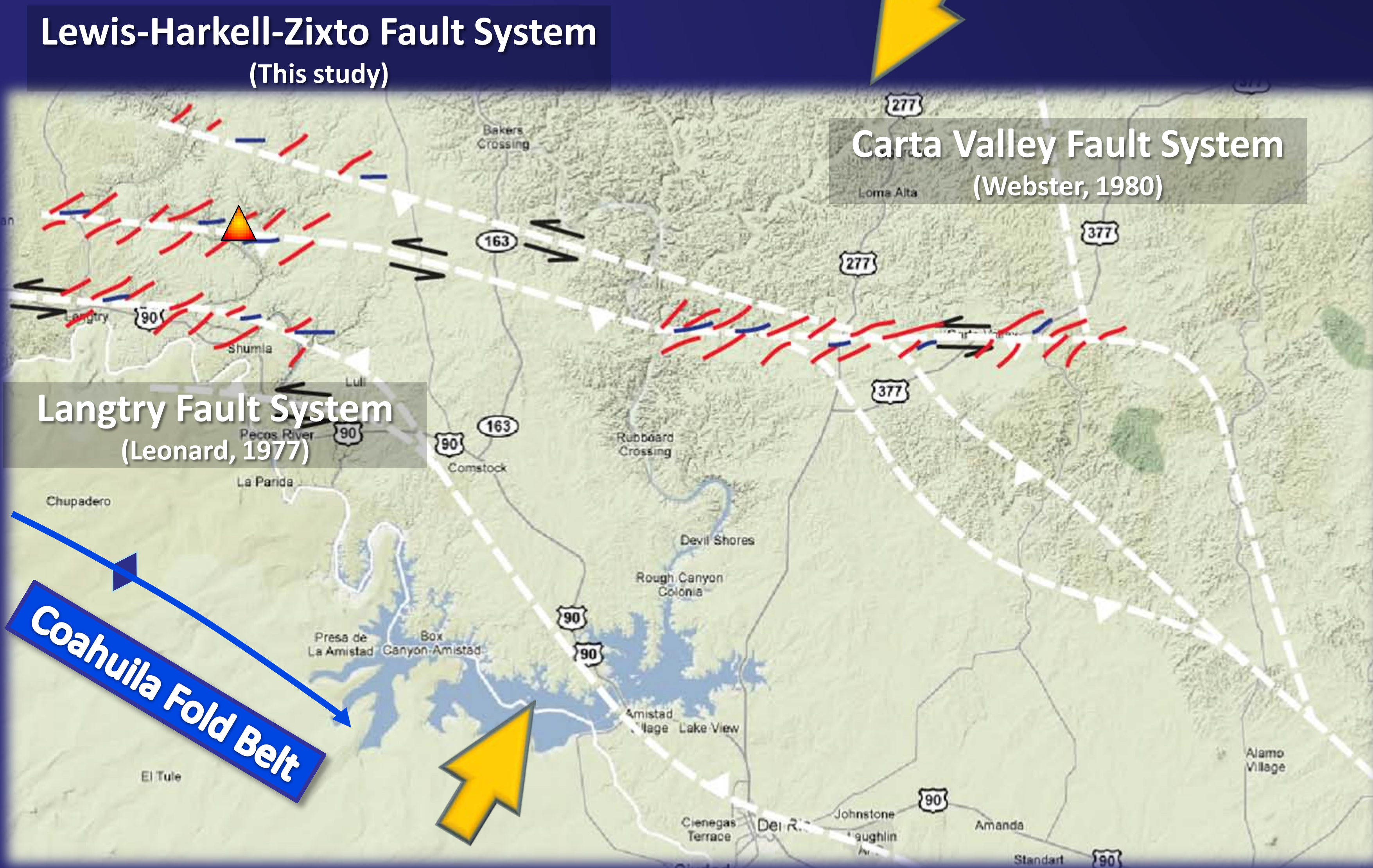
Tectonic Framework



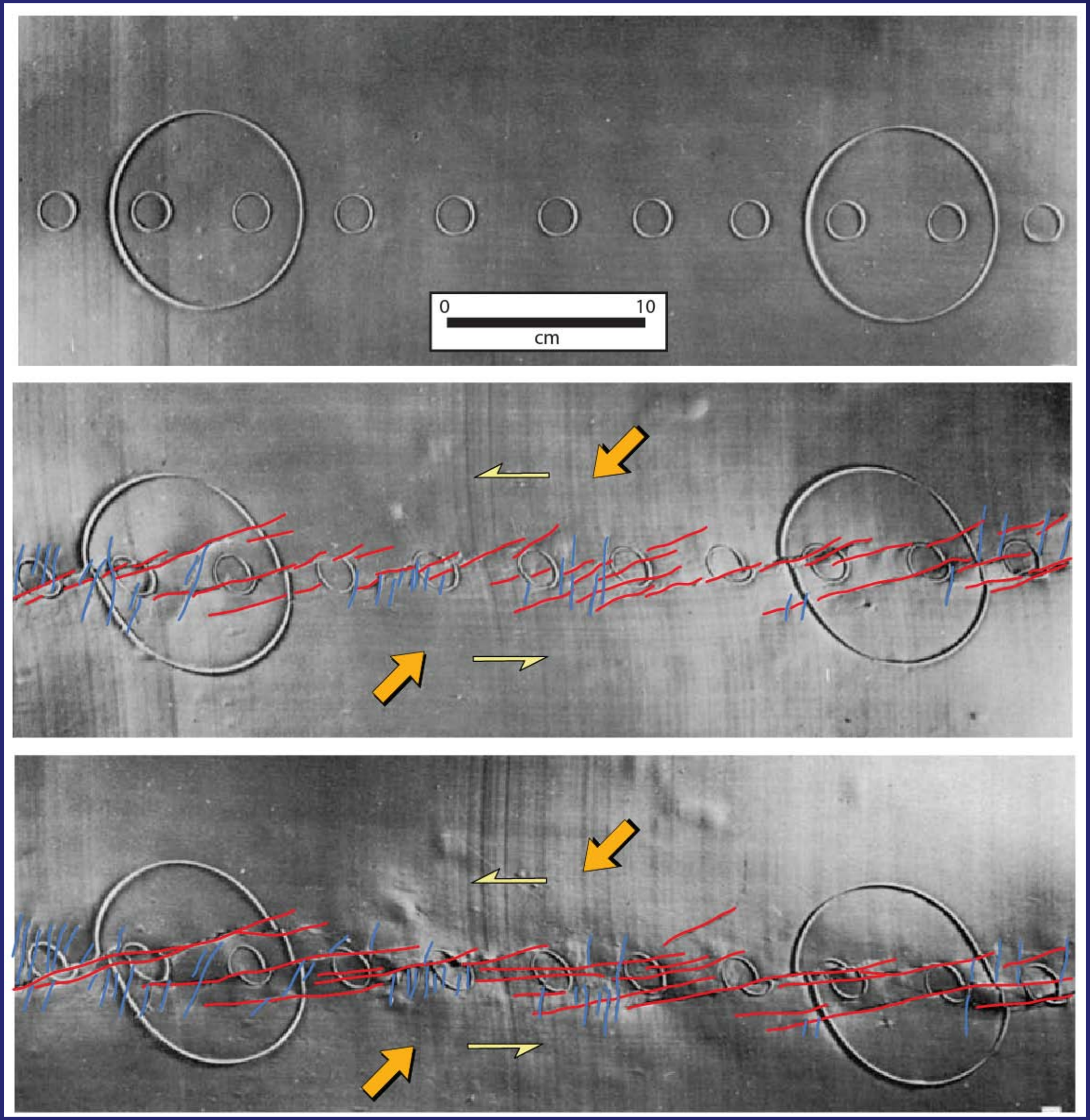
Subsurface Structures (Ellenburger level)



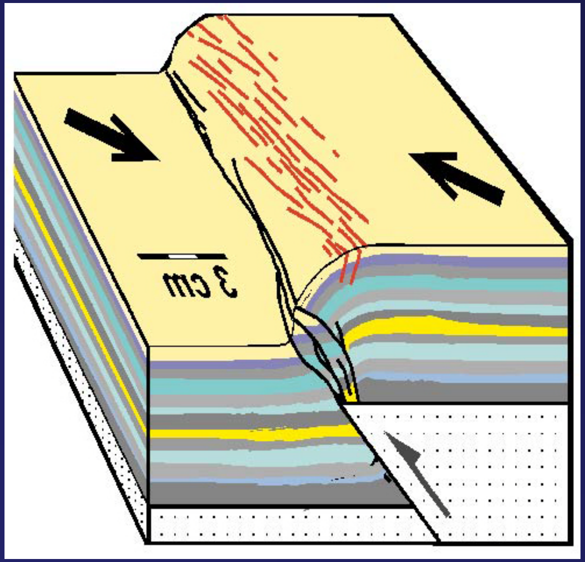
Laramide Reactivation of Paleozoic Structures



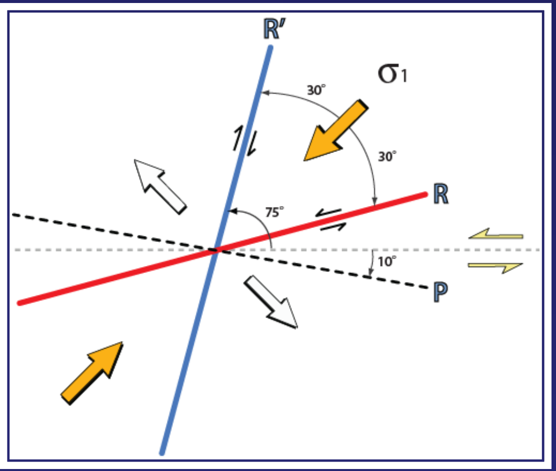
Secondary Structures of Oblique Compression



Wilcox, Harding and Seely (1973)

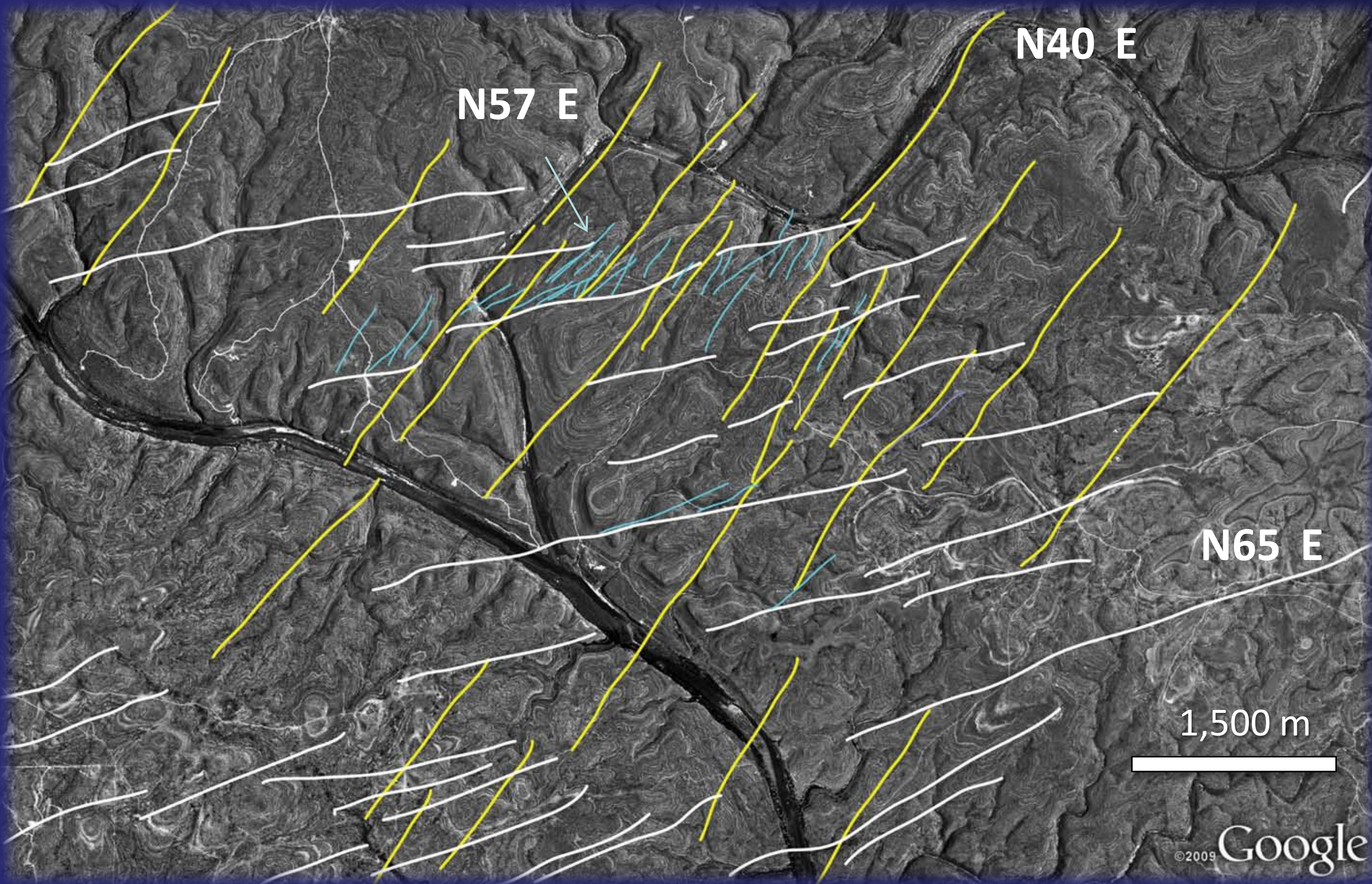


Tindall (unpublished)

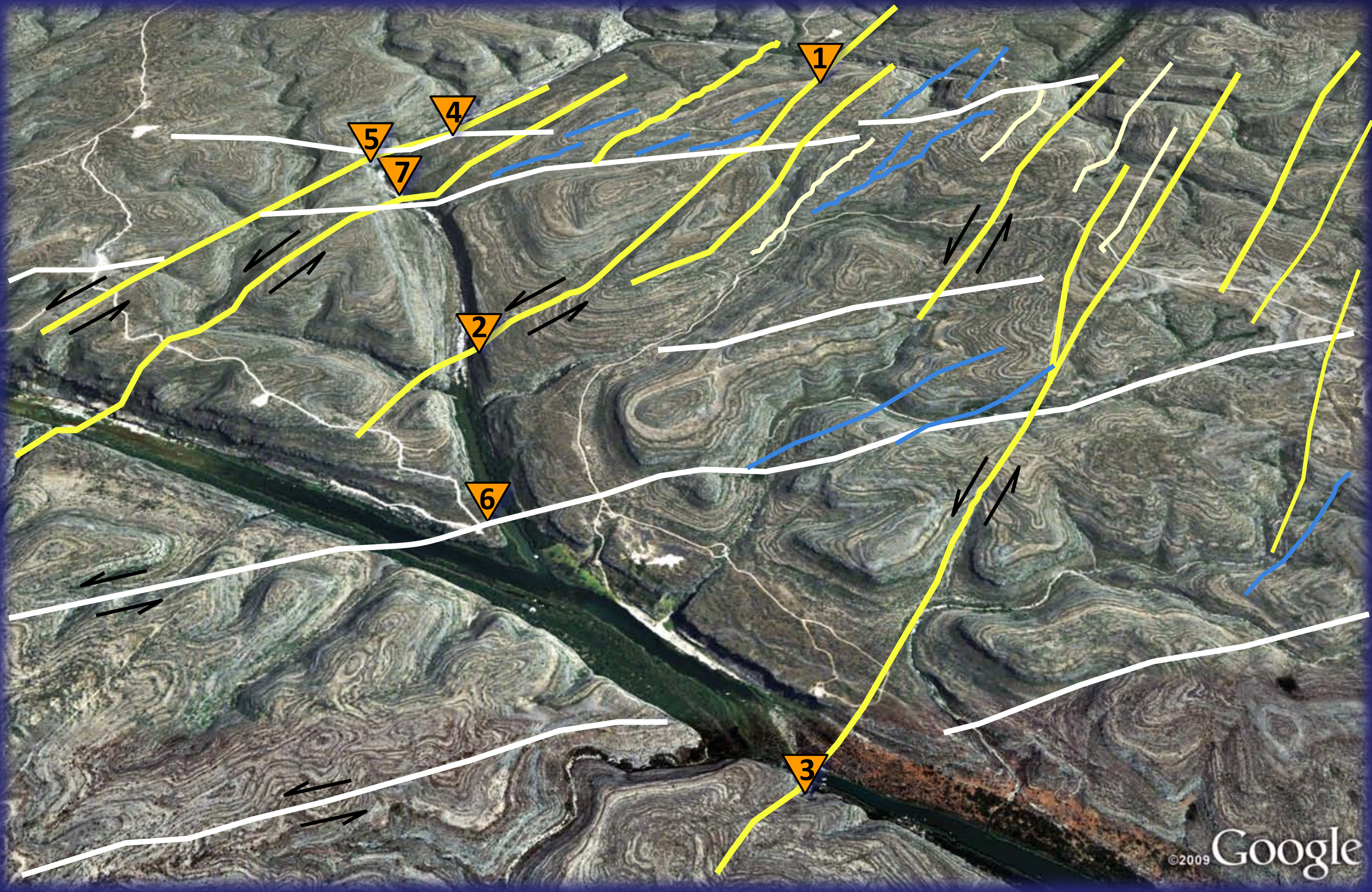


Woodcock and Schubert (1994)

Fracture Interpretation on Aerial Photo

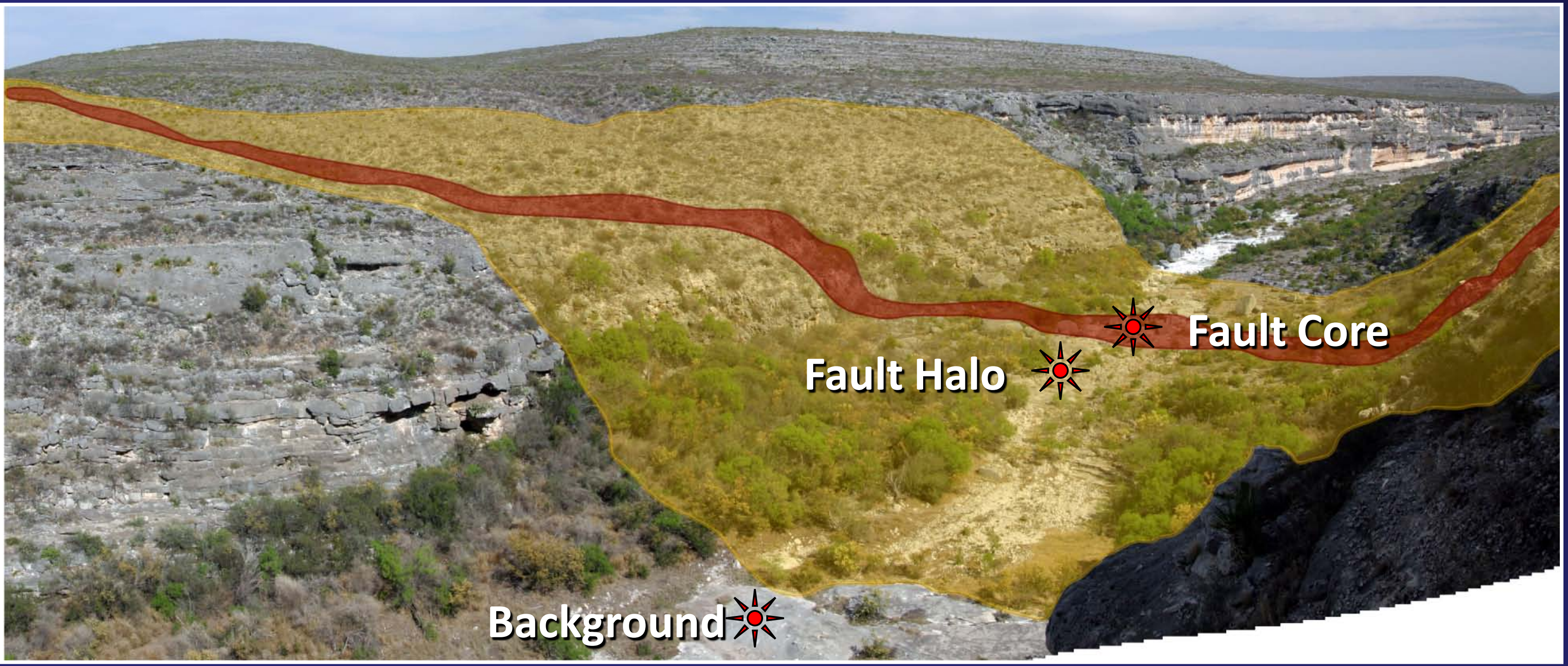


Fault Damage Zones



oblique looking north

Fault Damage Zones in Outcrop



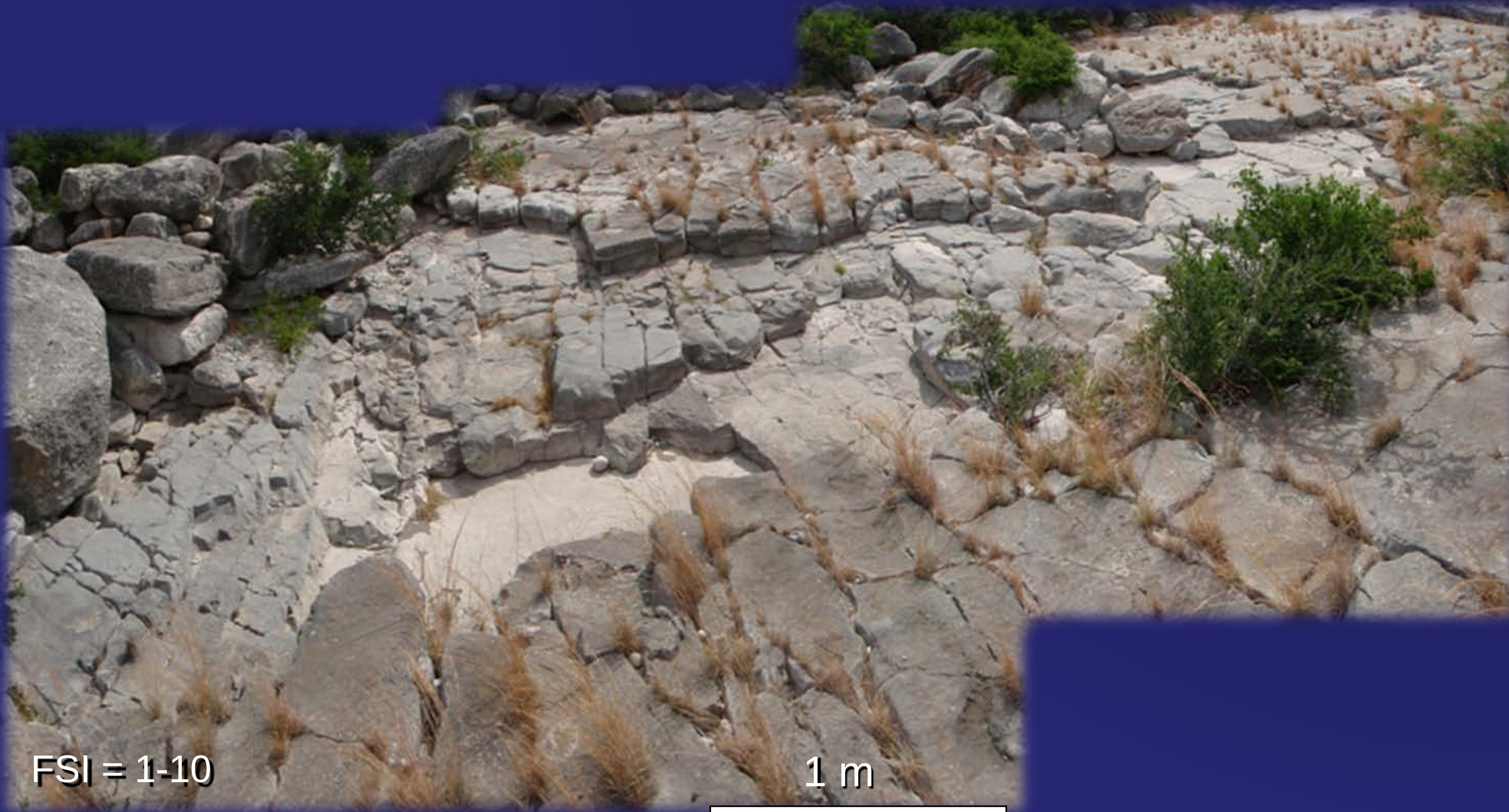
Fracture Intensity Zonation

- Background (FSI <1)
- Fault Halo (FSI = 1 – 10)
- Fault Core (FSI > 10)

Note: FSI = unit thickness / fracture spacing

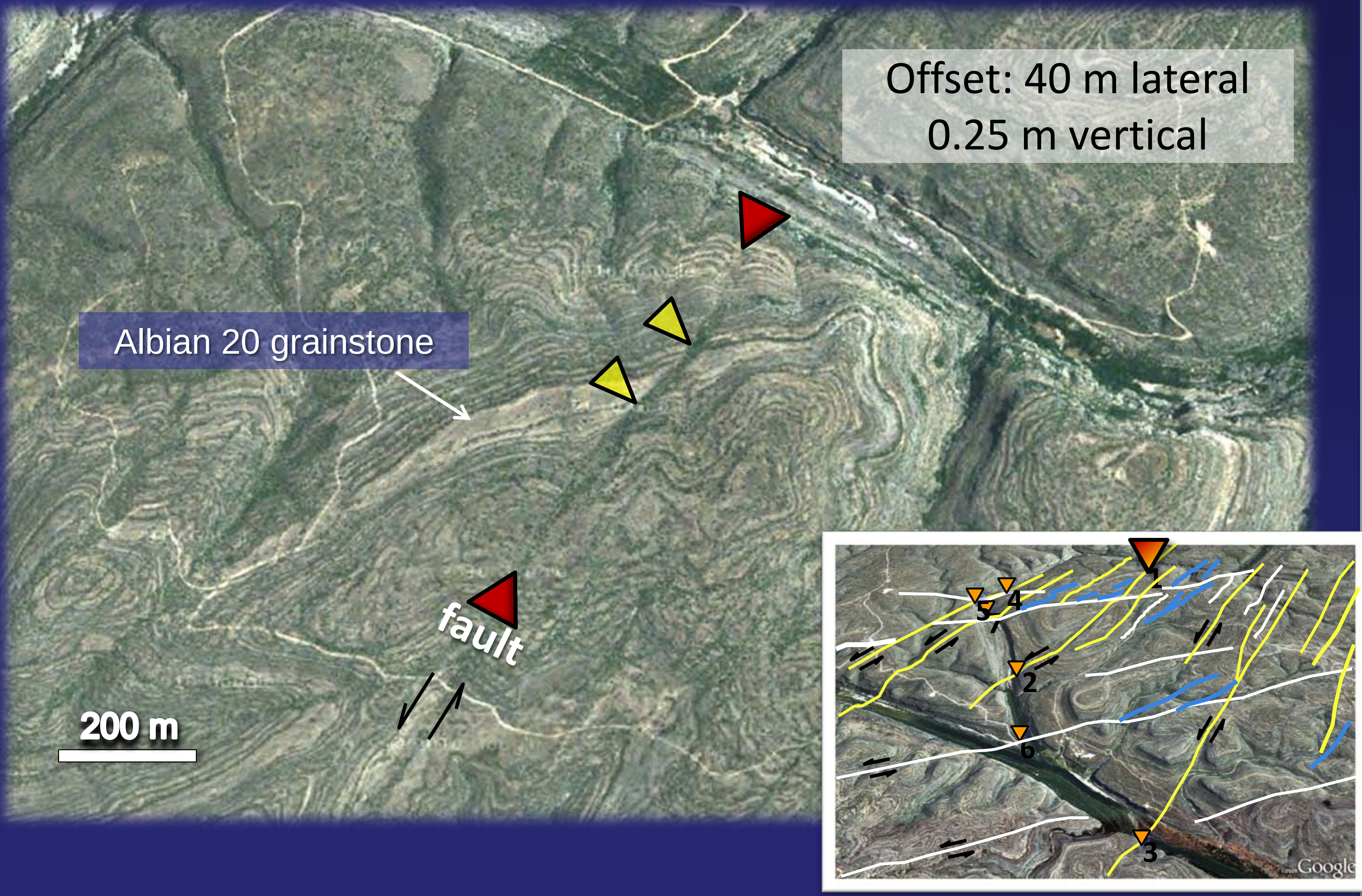
Background Fracture Intensity

Fault-Related Fracture Halo

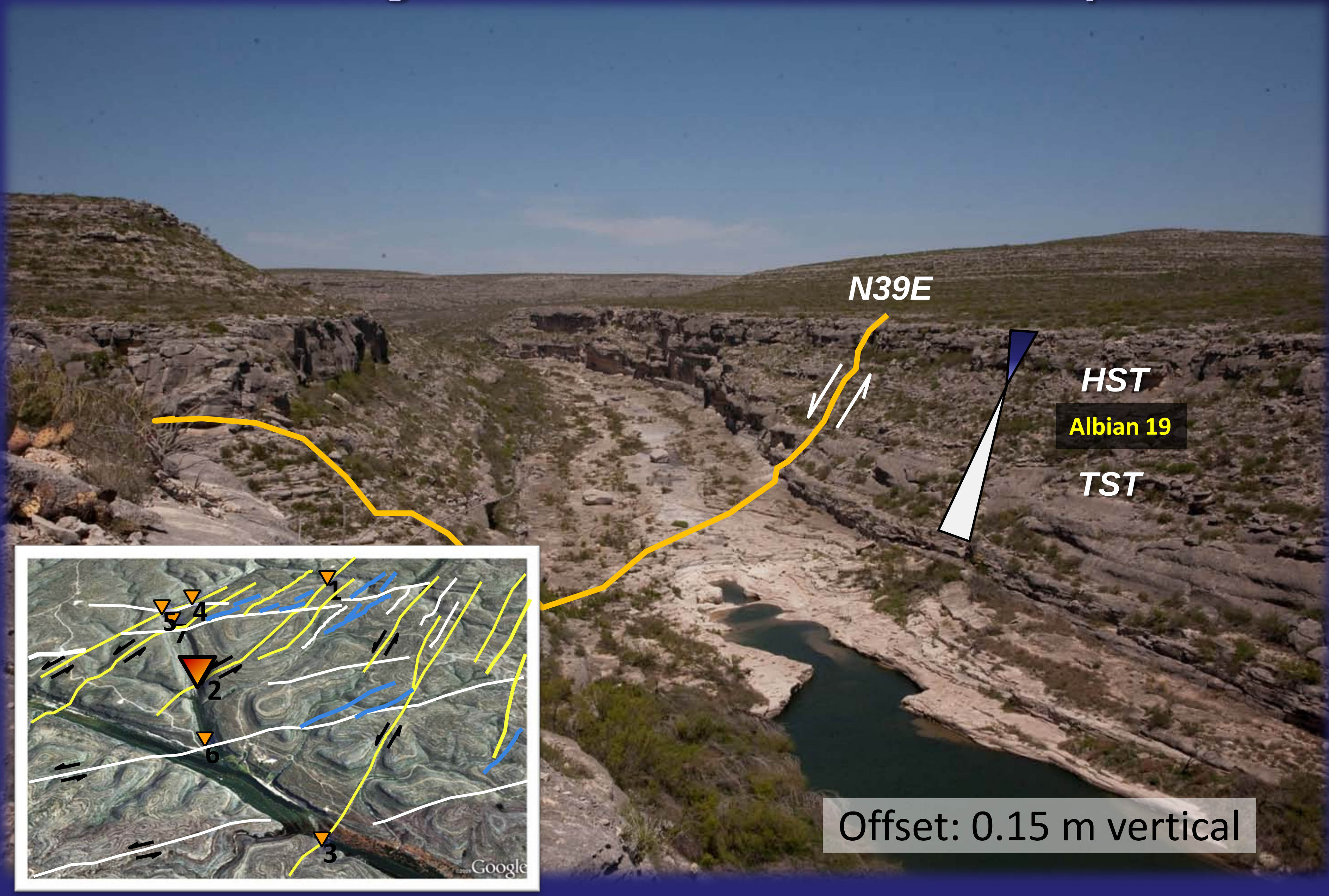


Fault Damage Zone Core

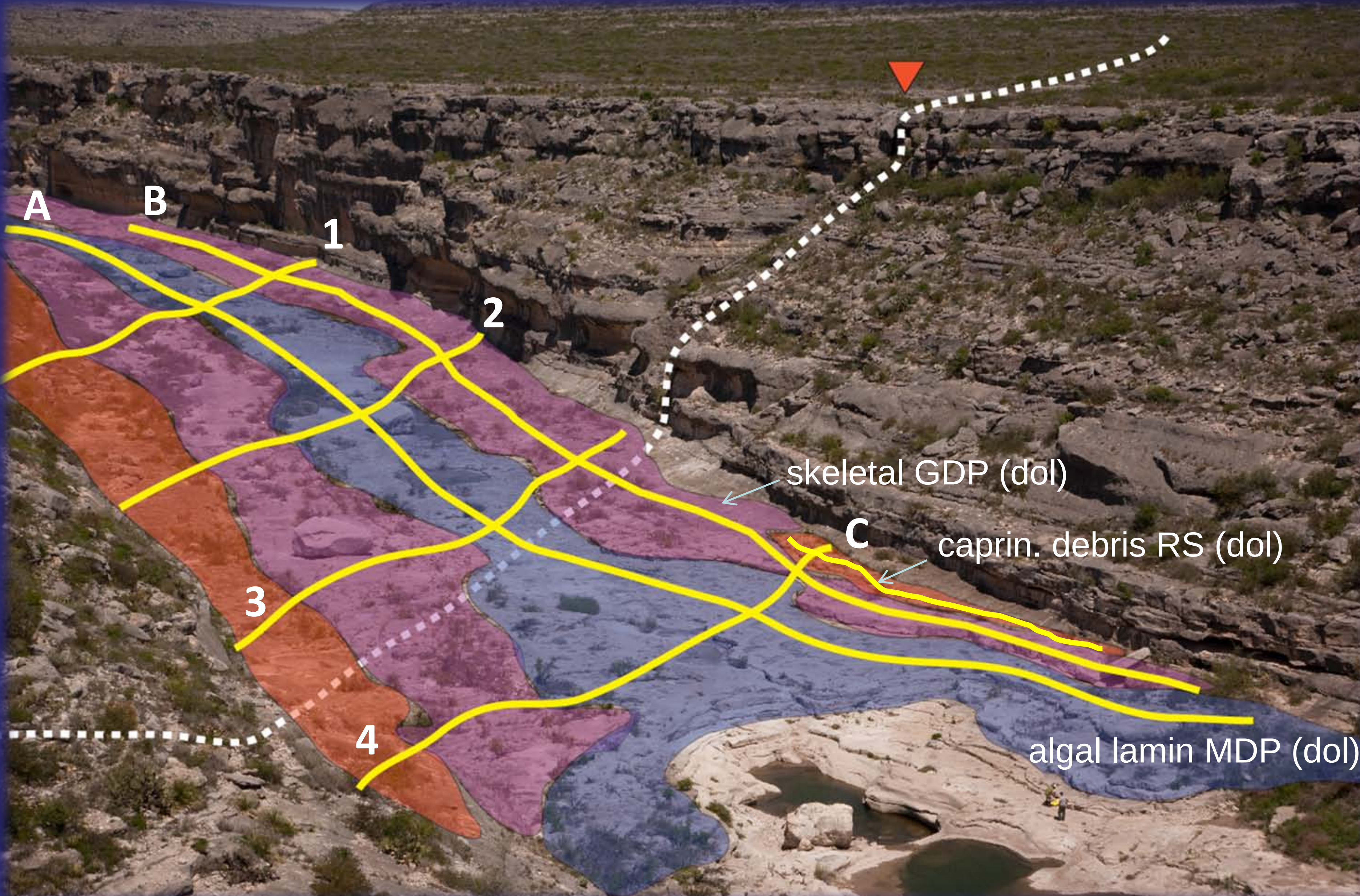
Lateral offset mapping in absence of slip lineations



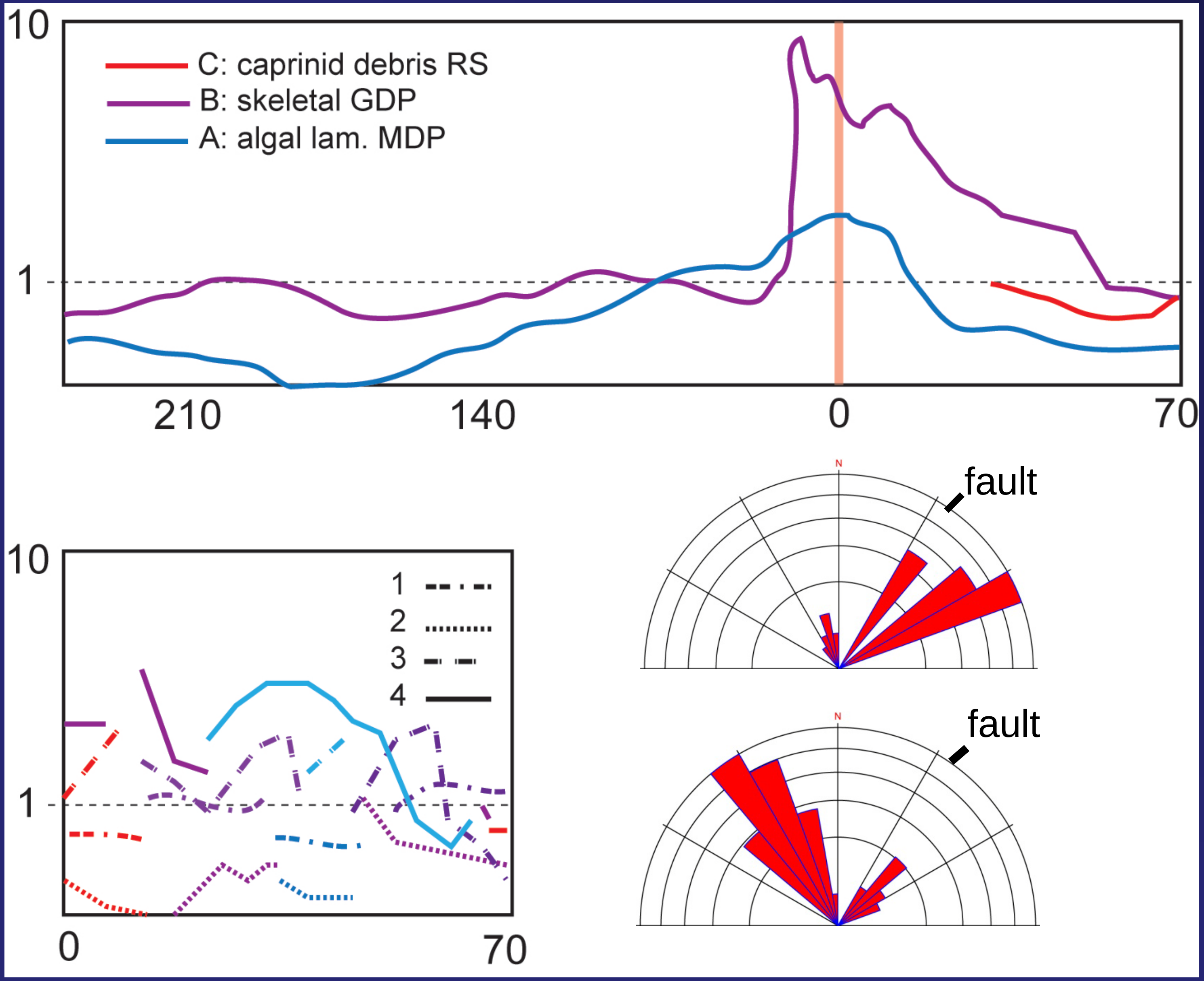
Fault Damage Zone: Variable Facies Response



Fault Damage by Facies



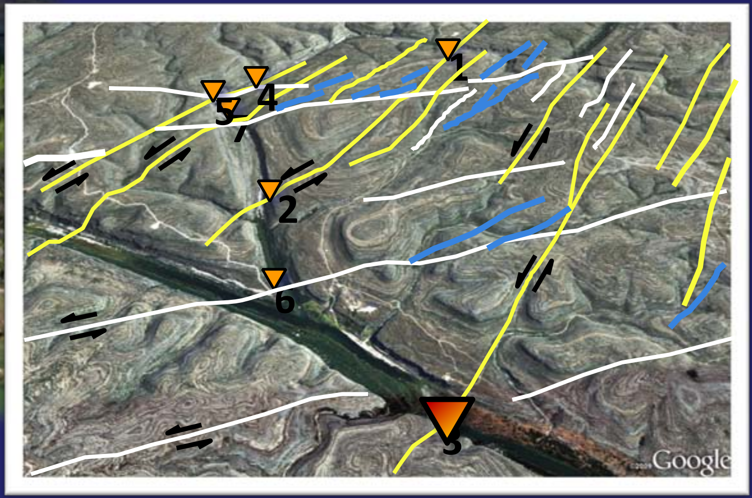
Fault Damage by Facies



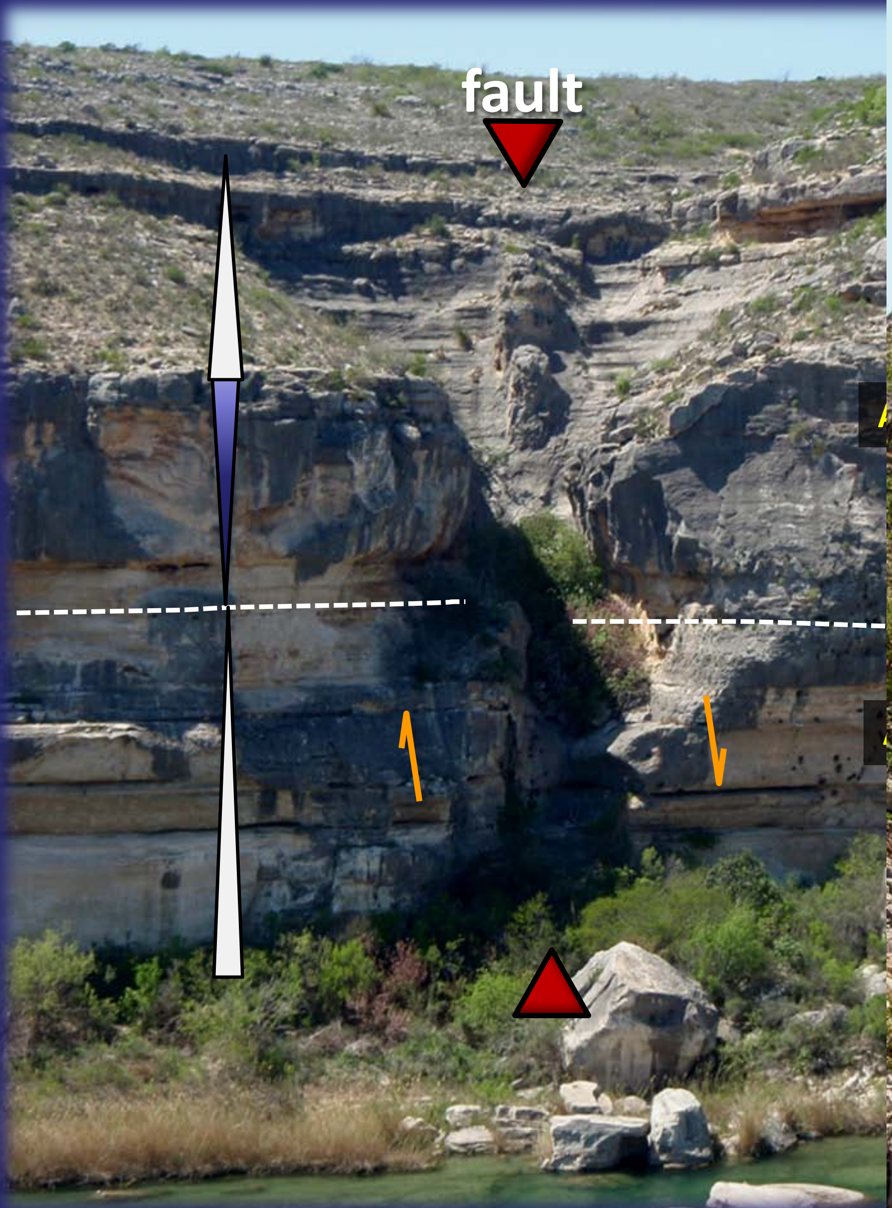
N40°E Fault – Fault Gouge

Offset: 0.75 m vertical

Fault "gouge" confined within transgressive systems tracts (TST)



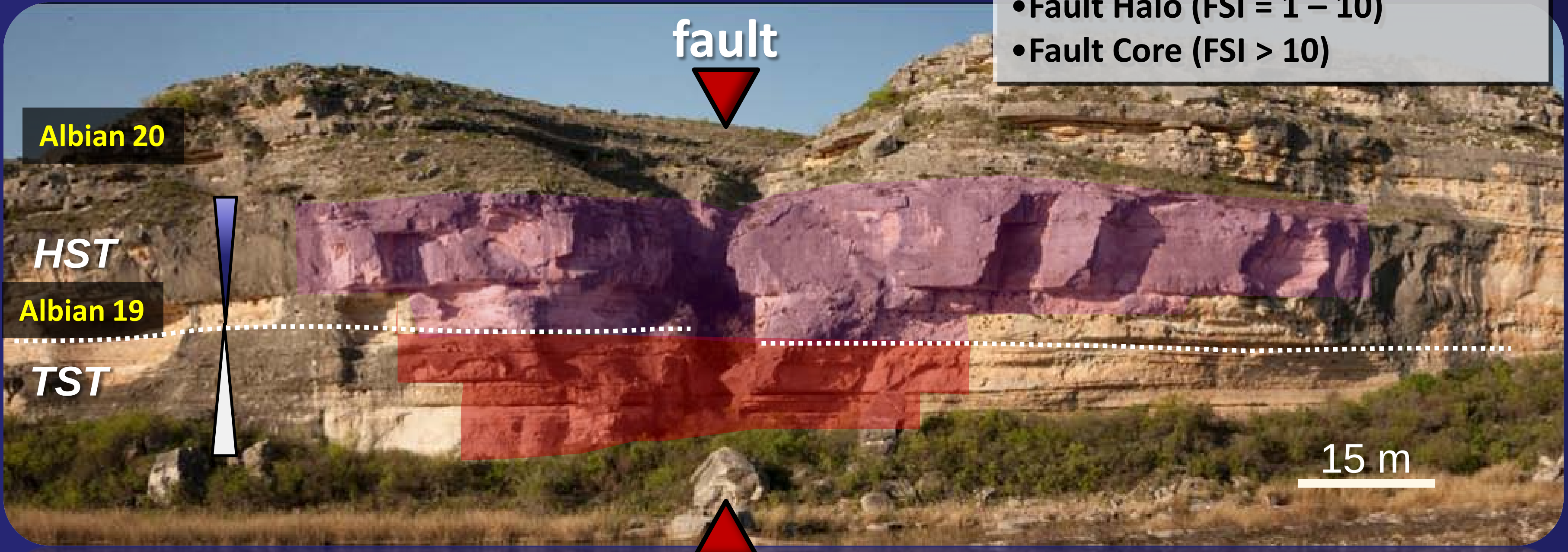
N40°E Fault –



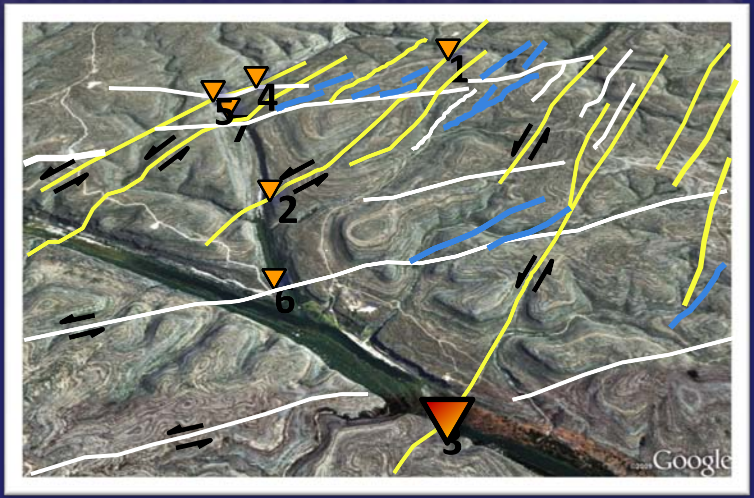
Offset: 0.75 m vertical

Variable Fracture Halo

Fracture Intensity Zonation
- Background (FSI <1)
- Fault Halo (FSI = 1 – 10)
- Fault Core (FSI > 10)



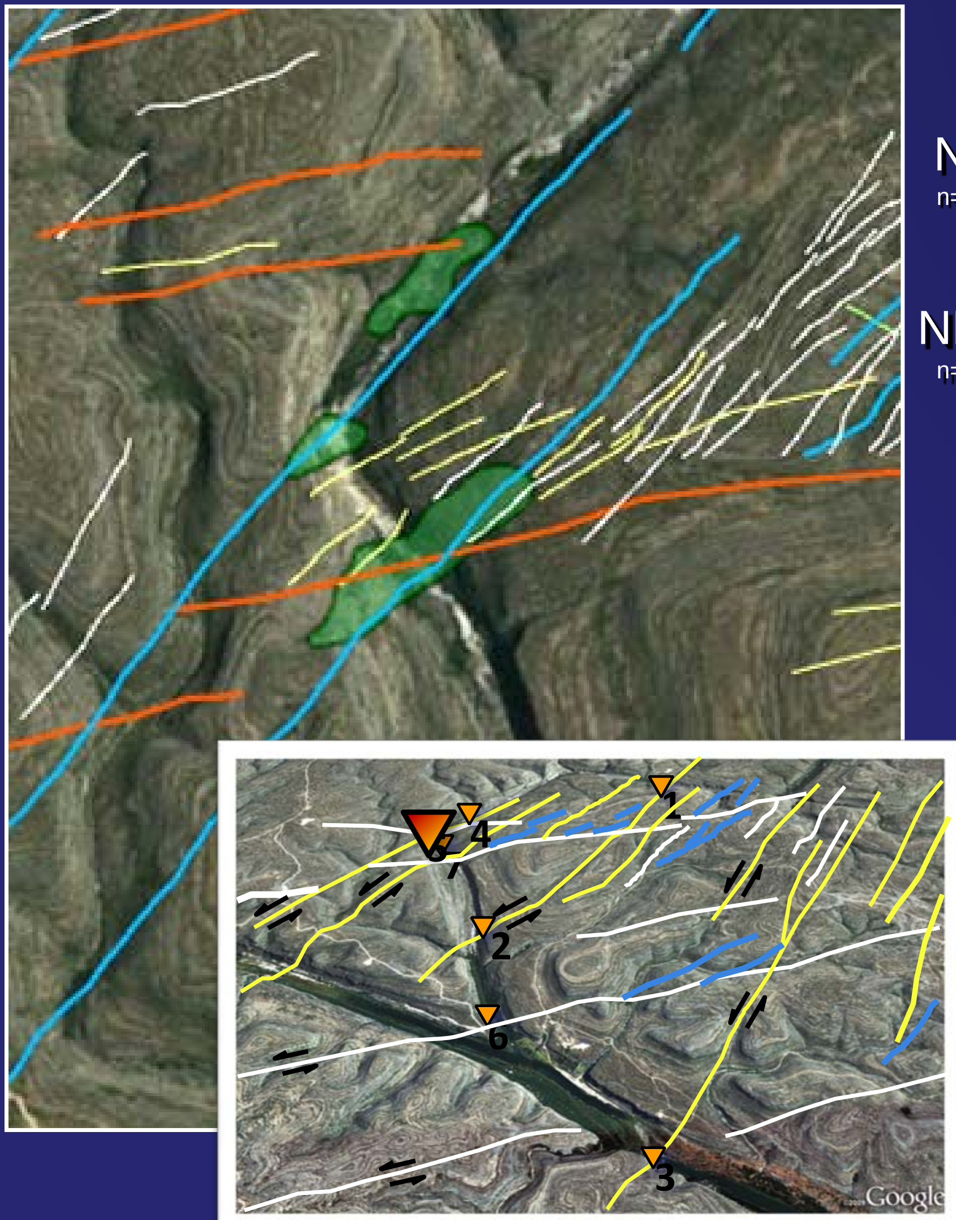
Note: FSI = unit thickness / fracture spacing



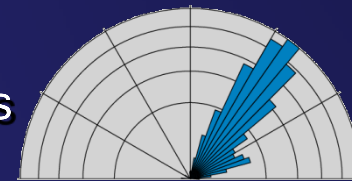
Fracture halos vary in extent:

- **Within TST, limited to +/- 30 m of fault core**
- **Within HST grainstone, limited to +/- 75 m of fault core**

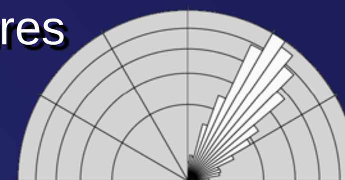
Intersecting Fractures and Karst Collapse



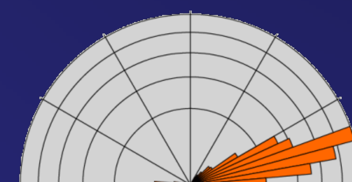
NE Faults
n=1533



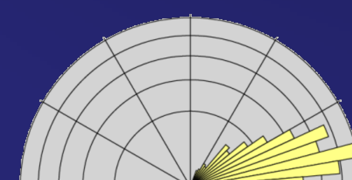
NE Fractures
n=1491



ENE Faults
n=1019

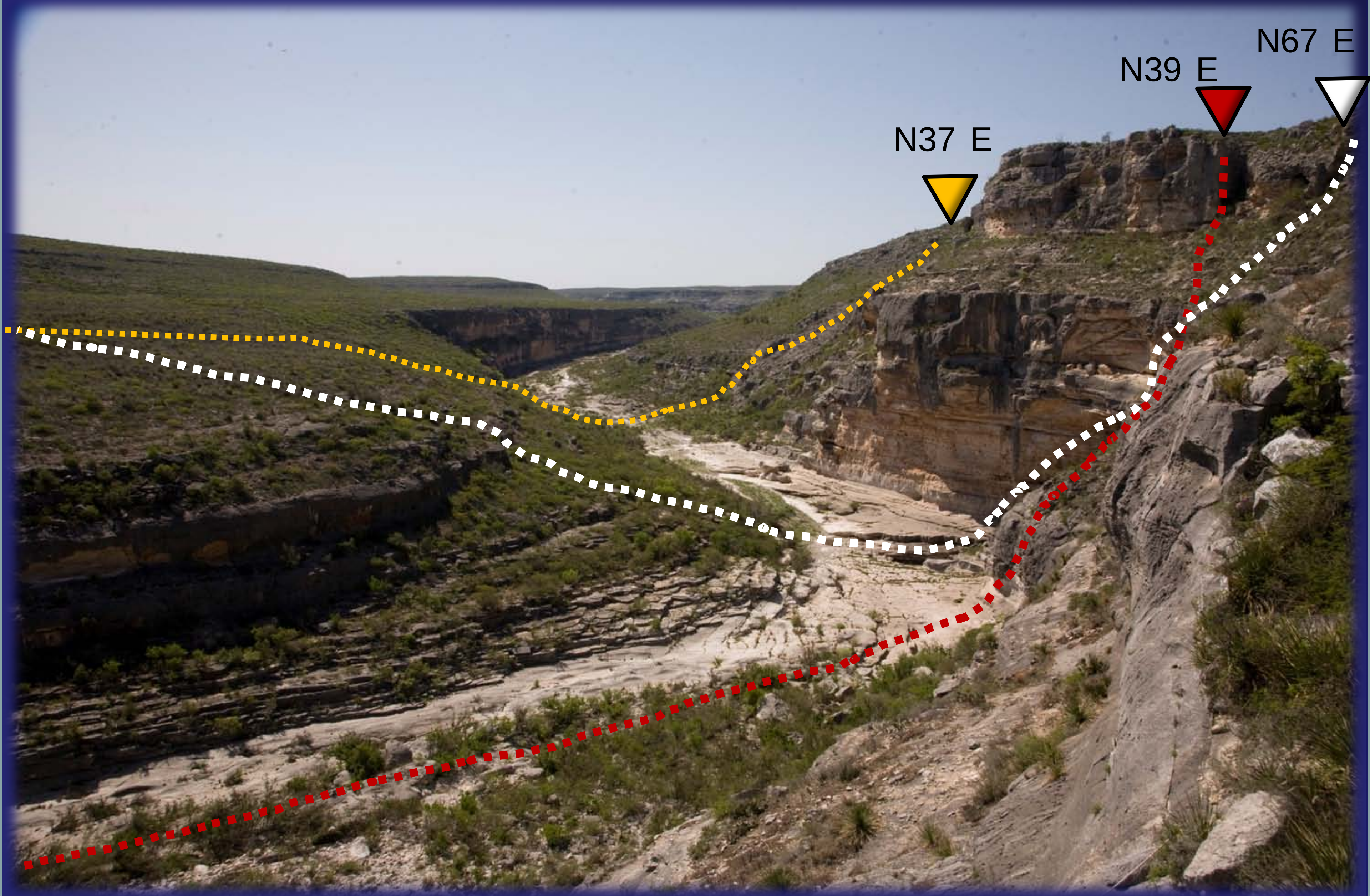


ENE Fractures
n=433

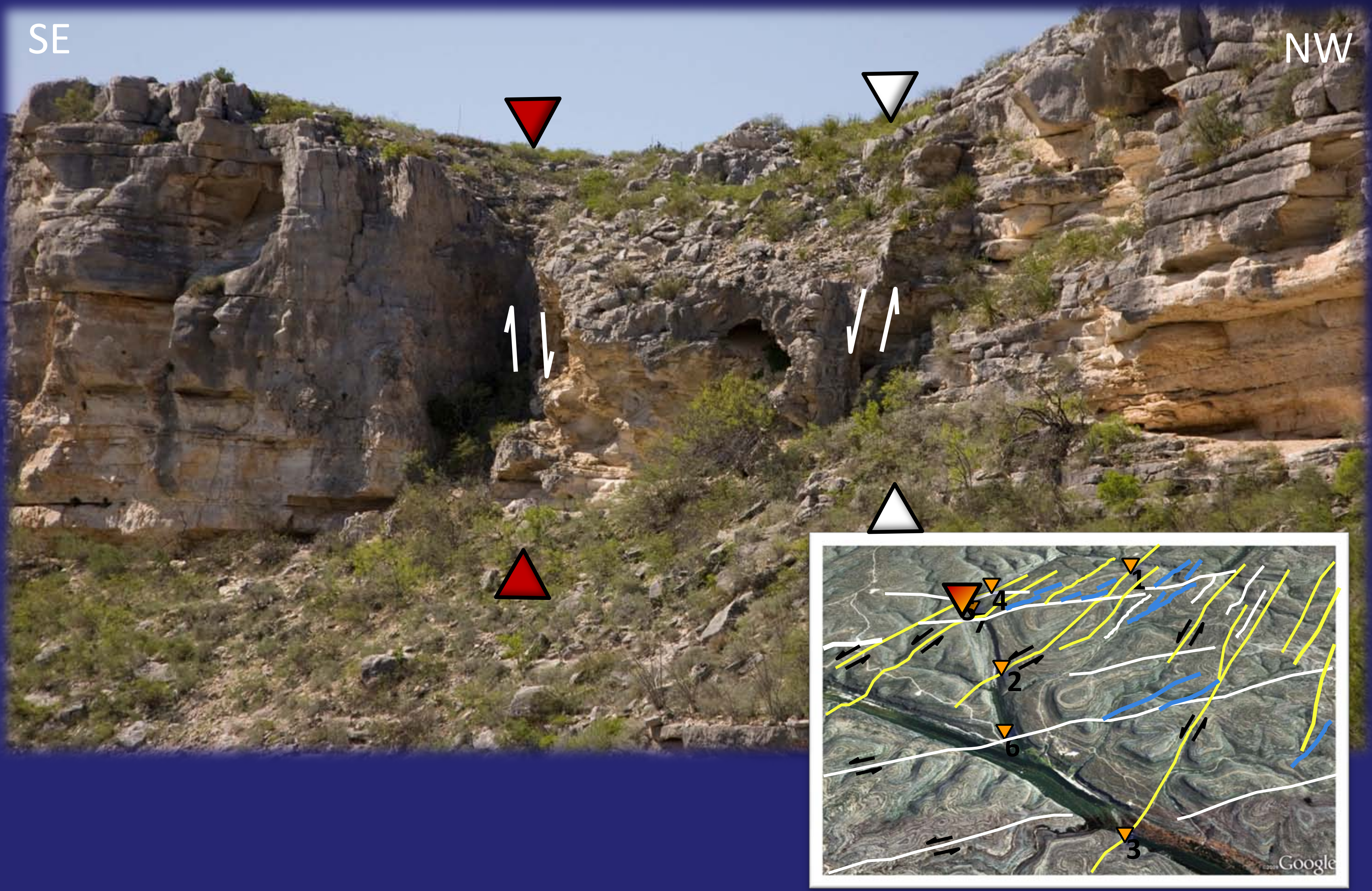


Mapped karst collapse associated with fault zones

Intersecting Fractures and Collapse



Intersection of N39°E and N67°E Faults

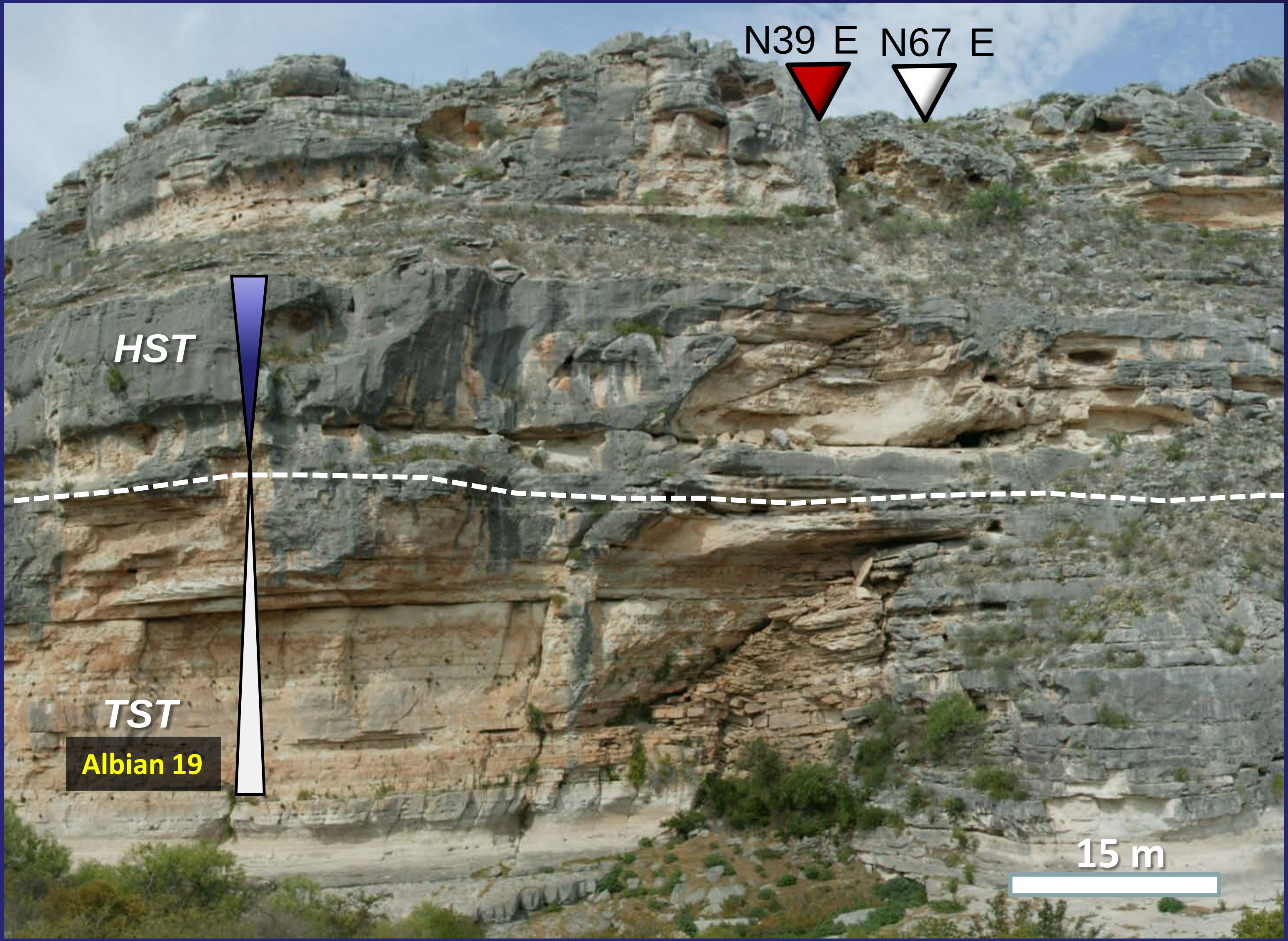


Inside the Fault Zone

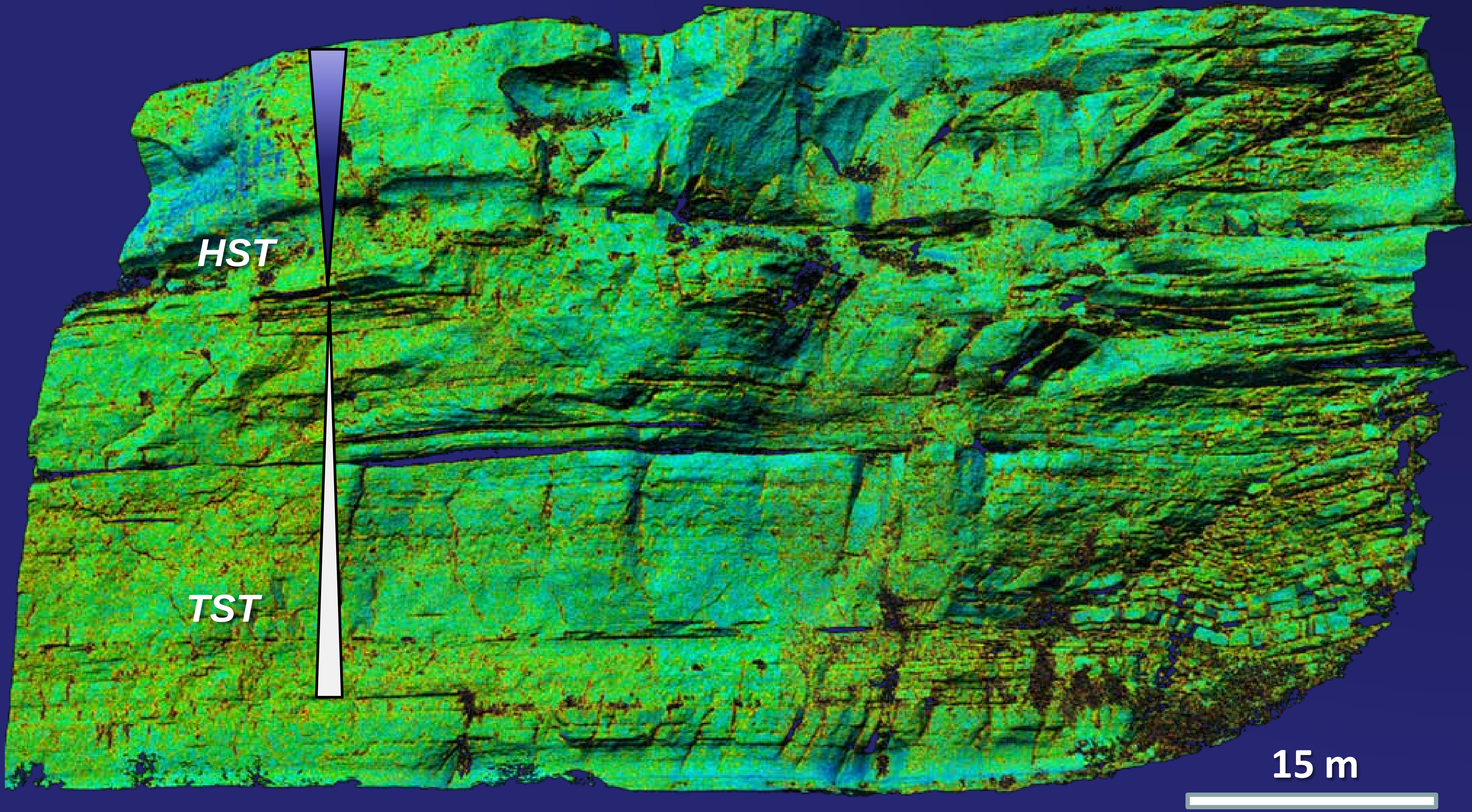
Intersecting Fractures and Collapse

Intersecting Fractures and Collapse

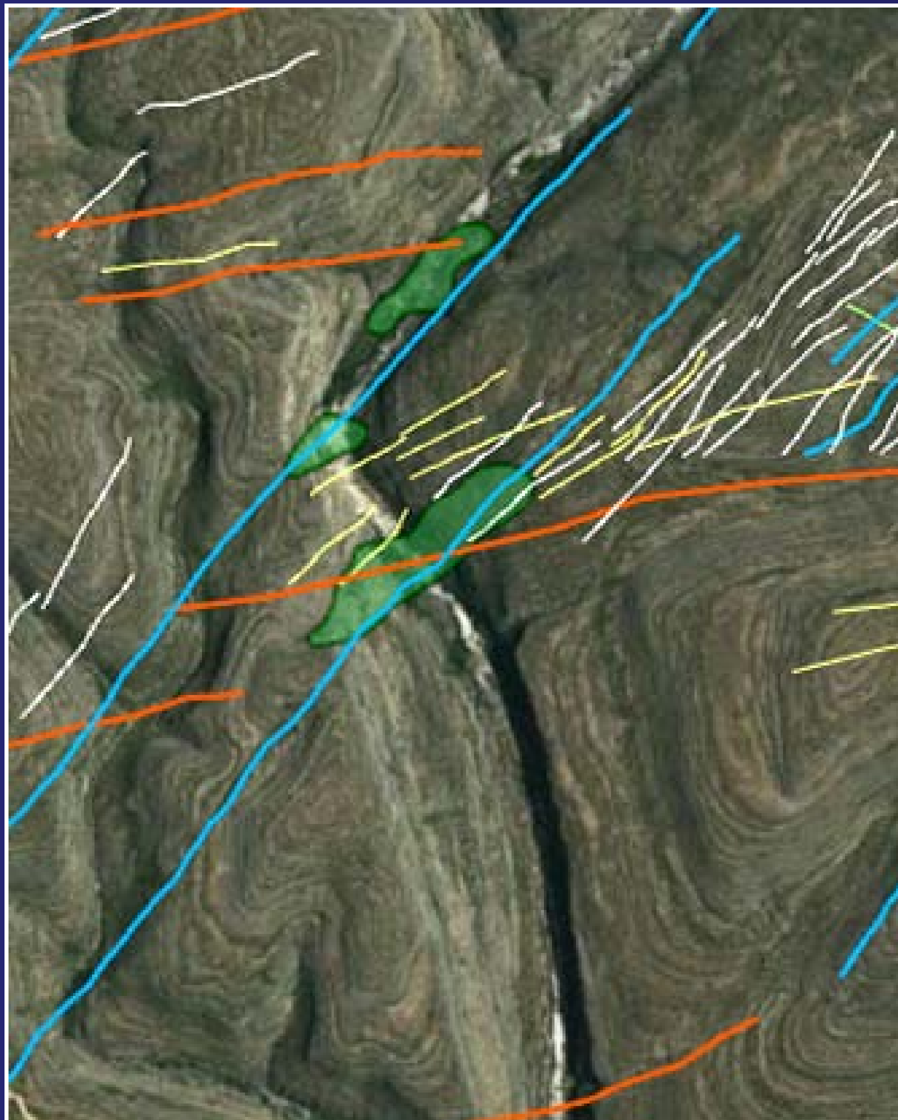
Intersecting Fractures and Collapse



Strata-bound fractures



Intersecting Fractures and Karst Collapse



NE Faults
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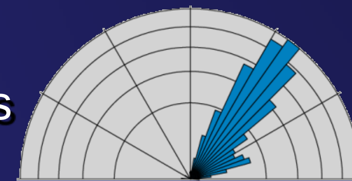

NE Fractures
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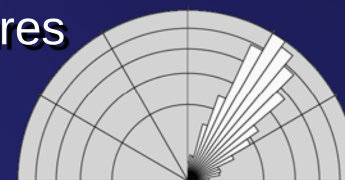
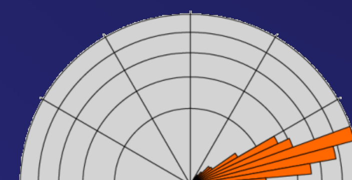
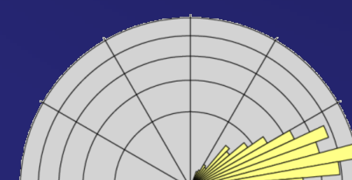


ENE Faults
n=1019



ENE Fractures
n=433



Mapped karst collapse associated with fault zones

Key Points

Appreciate the role of pre-existing structures on later deformation.

Small, oblique-slip faults can create significant, reservoir-scale fracture heterogeneity that remains below most seismic resolution.

The interplay of stratigraphy and structure are important and demonstrate that rocks break differently based on facies, thickness and lithology.

Intersecting fracture zones have a high propensity for post-deformation alteration, i.e., karst dissolution.

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