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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in a Ramp Crest Carbonate System,
Lower Pecos River Canyon, Texas

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Is it really faulted?

- 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.

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

Kerans (2002)

Lewis Canyon Window

Top Albian 21 HFS (9 mile Seq.) - P/A = -20

Top Albian 20 HFS (Painted Seq.) - P/A = 790

Top Albian 19 HFS (Lewis Seq.) - P/A = 170

Top Albian 18 HFS (Burt Seq.) - P/A = -190

Top Albian 5 Composite Sequence (Fredricksburg) - P/A = -130

Peri tidal inner ramp facies, dolomitic tidal flats and evaporitic facies
Mud-dominated shallow subtidal shelf with chondroodont/radiolitid buildups
Oyster-rich subtidal marls, interior shelf and basin-center
Shallow shelf milliolid-rich and skeletal-peloid-rich facies
High-energy shoal complexes with caprinid rudist buildups
Sequence Stratigraphic Framework

HST

mfs

TST

15 m
Stratigraphic Framework – Previous Work

From Kerans and others (1996, 2002)
Stratigraphic Packages and Tectonic Events

- **Prekinematic (Laramide)**
  - Albian to Santonian
  - Laramide Orogen
  - Devil’s River, Del Rio, Buda
  - Boquillas, Austin Chalk

- **Synkinematic (Ouachita)**
  - Permian-Wolfcampian
  - Ouachitan Orogen

- **Prekinematic (Ouachita)**
  - Woodford-Ellenburger

- **L. Miocene**
  - GOM Extension & Salt Tectonics

- **L. Maas to Paleocene**
  - Laramide Orogen

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

Modified from Ewing, 1995
Tectonic Framework

Paleozoic Ouachita Compression

Modified from Ewing, 1995
Tectonic Framework

Paleozoic Ouachita Compression

L. Cretaceous Laramide Compression

Modified from Ewing, 1995
Tectonic Framework

Paleozoic Ouachita Compression

L. Cretaceous Laramide Compression

Tertiary GOM Extension

Modified from Ewing, 1995
Subsurface Structures (Ellenburger level)

Val Verde Basin

Devil’s River Uplift

Modified from Ewing, 1985
Laramide Reactivation of Paleozoic Structures

Lewis-Harkell-Zixto Fault System
(This study)

Carta Valley Fault System
(Webster, 1980)

Langtry Fault System
(Leonard, 1977)
Secondary Structures of Oblique Compression

Wilcox, Harding and Seely (1973)

Tindall (unpublished)

Woodcock and Schubert (1994)
Fracture Interpretation on Aerial Photo

N57 E

N40 E

N65 E

1,500 m
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
Fault-Related Fracture Halo

FSI = 1-10

1 m
Lateral offset mapping in absence of slip lineations

Offset: 40 m lateral
0.25 m vertical

Albian 20 grainstone
Fault Damage Zone: Variable Facies Response

Offset: 0.15 m vertical
Fault Damage by Facies

- Algal lamin MDP (dol)
- Caprin. debris RS (dol)
- Skeletal GDP (dol)
- Algal lamin MDP (dol)
Fault Damage by Facies

C: caprinid debris RS
B: skeletal GDP
A: algal lam. MDP
N40°E Fault – Fault Gouge

Fault “gouge” confined within transgressive systems tracts (TST)

Offset: 0.75 m vertical
N40°E Fault – Fault Gouge

Offset: 0.75 m vertical
Fracture halos vary in extent:

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

Note: FSI = unit thickness / fracture spacing

Fracture Intensity Zonation

- Background (FSI < 1)
- Fault Halo (FSI = 1 – 10)
- Fault Core (FSI > 10)
Intersecting Fractures and Karst Collapse

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

N35W

N65E

N40E
Intersecting Fractures and Collapse

N39 E  N67 E

15 m

HST

TST

Albian 19
Strata-bound fractures

HST

TST

15 m
Intersecting Fractures and Karst Collapse

Intersecting NE Faults

- NE Faults: 1533
- NE Fractures: 1491

Intersecting ENE Faults

- ENE Faults: 1019
- ENE Fractures: 433

Mapped karst collapse associated with fault zones
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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