Pitfalls of Using Entrenched Fracture Relationships: Fracture System within Bedded Carbonates of the Hidden Valley Fault Zone, Canyon Lake Gorge, Comal County, Texas*

Ronald N. McGinnis[1], David A. Ferrill[1], Kevin J. Smart[1], and Alan P. Morris[1]

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[1]Geosciences and Engineering Division, Southwest Research Institute, San Antonio, TX (rmcginnis@swri.org)

Abstract

Characterizing fracture systems involves understanding fracture orientations, spacings, and sizes. Traditionally, observation-based relationships, such as lithology, mechanical stratigraphy, bed thickness, structural position, failure mode, and stress history, have been proposed for predicting fracture spacing as well as the relative abundance of joints versus faults in fractured rocks. Developing a conceptual fracture model from these relationships can be a useful process to help predict deformation in a fractured reservoir or other fractured rock systems of interest. A major pitfall, however, when developing these models, is using assumptions based on general relationships rather than site-specific observational data. In this paper, we examine a mixed carbonate-shale sequence in and adjacent to a seismic-scale normal fault where the fracture system does not follow several (or most) established fracture relationships. Specifically, we find that (i) there is no clear relationship between frequency of joints and proximity to the main fault trace, (ii) there is no detectable relationship between fracture spacing and bed thickness, and (iii) joint/fault ratios are far smaller than values typically reported for deformed rocks. However, we did find that (i) the frequency of small-displacement faults is strongly and positively correlated with proximity to the main fault trace, (ii) fracture networks change pattern and failure mode (extension versus shear fracture) from pavement to pavement in vertically adjacent beds, and (iii) faults are more abundant than joints in many areas within the fracture network. We conclude that a different set of fracture network rules apply in rocks where shear failure dominates.

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Geosciences and Engineering Division

Southwest Research Institute ®

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The late William C. Ward for providing the stratigraphic framework..

Background

Natural fractures influence production in shale and tight reservoirs

Mechanical stratigraphy and *in situ* stress strongly influence natural as well as induced fracturing

Improved understanding of these factors will lead to better well planning and stimulation design

Background

Conceptual fracture models based on general relationships can be a useful predictive tool for fractured reservoirs…

…as long as assumptions are based on site-specific observational data rather than general relationships.

Entrenched fracture relationships work…except where they don't.

Natural Fractures

Two primary types of natural fractures

- "Tensile", "Mode 1", "Extension", "Joints"
  - These have no sense of shear displacement across them
- Faults, "shear", or "Mode 2" fractures
  - These have shear displacement across them

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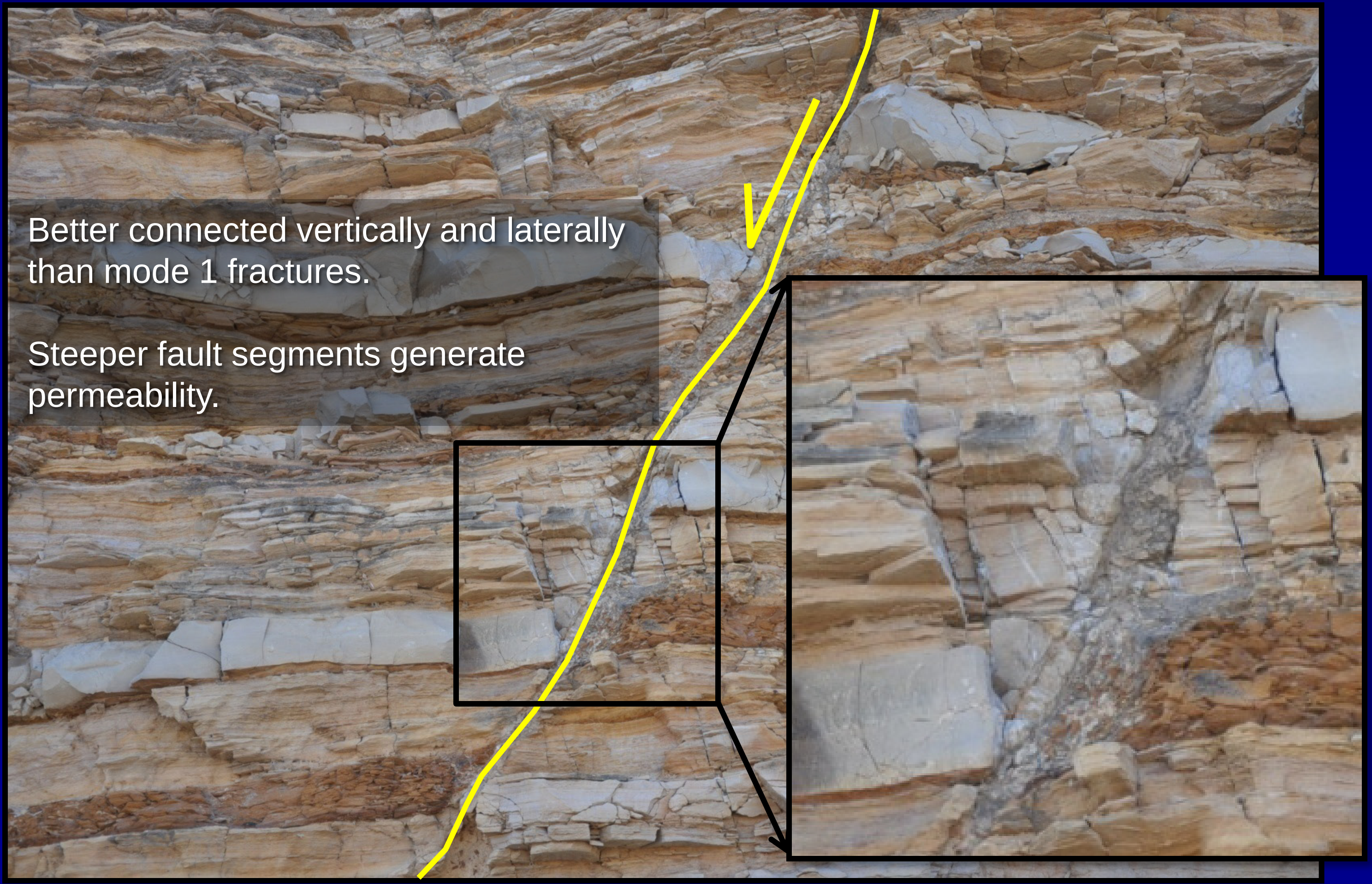


Fracture Relationships

Relationship 1:

There is a positive correlation between joint spacing and bed thickness

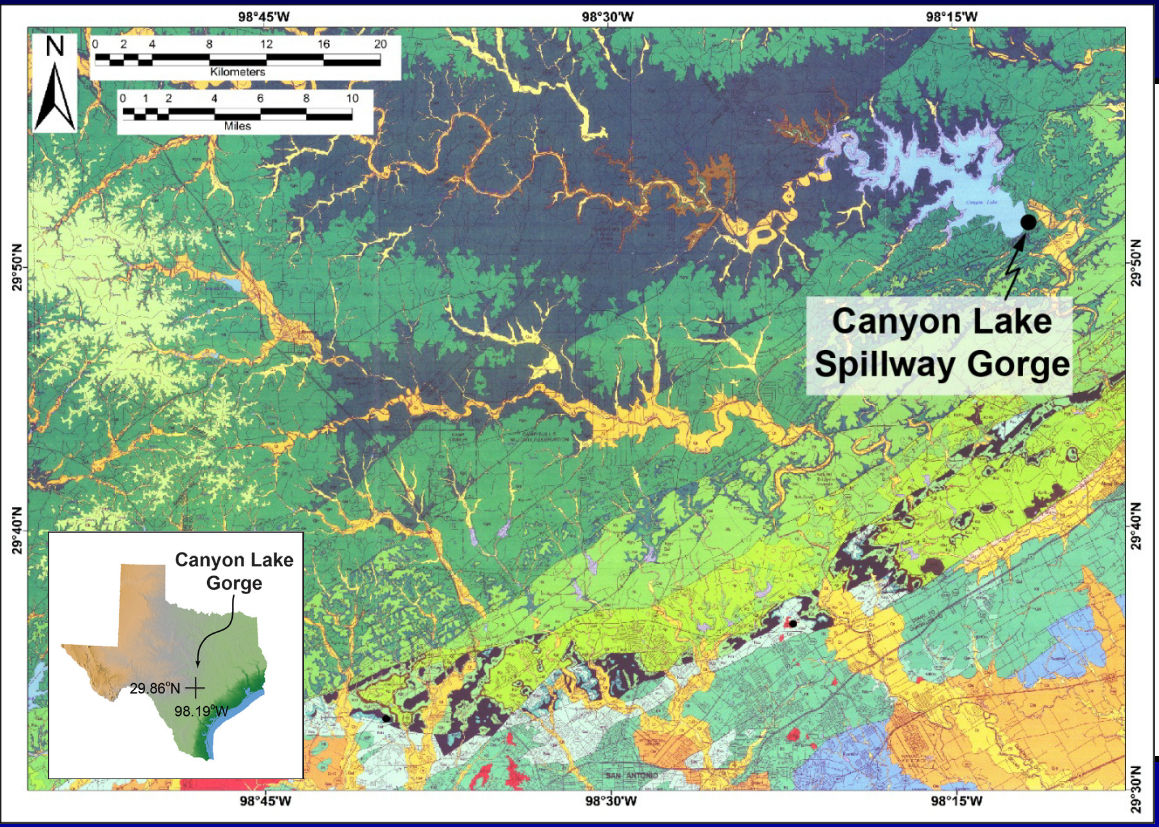
Relationship 2:

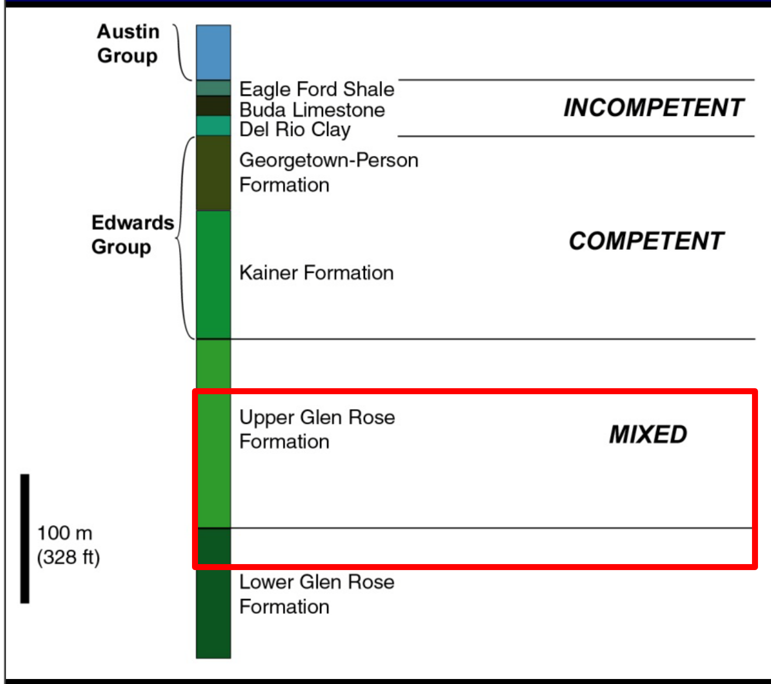
For a given system, joints are much more abundant than shear fractures or faults

Relationship 3:

Joint intensity increases in a fault damage zone with proximity to the fault core

Canyon Lake Spillway Gorge





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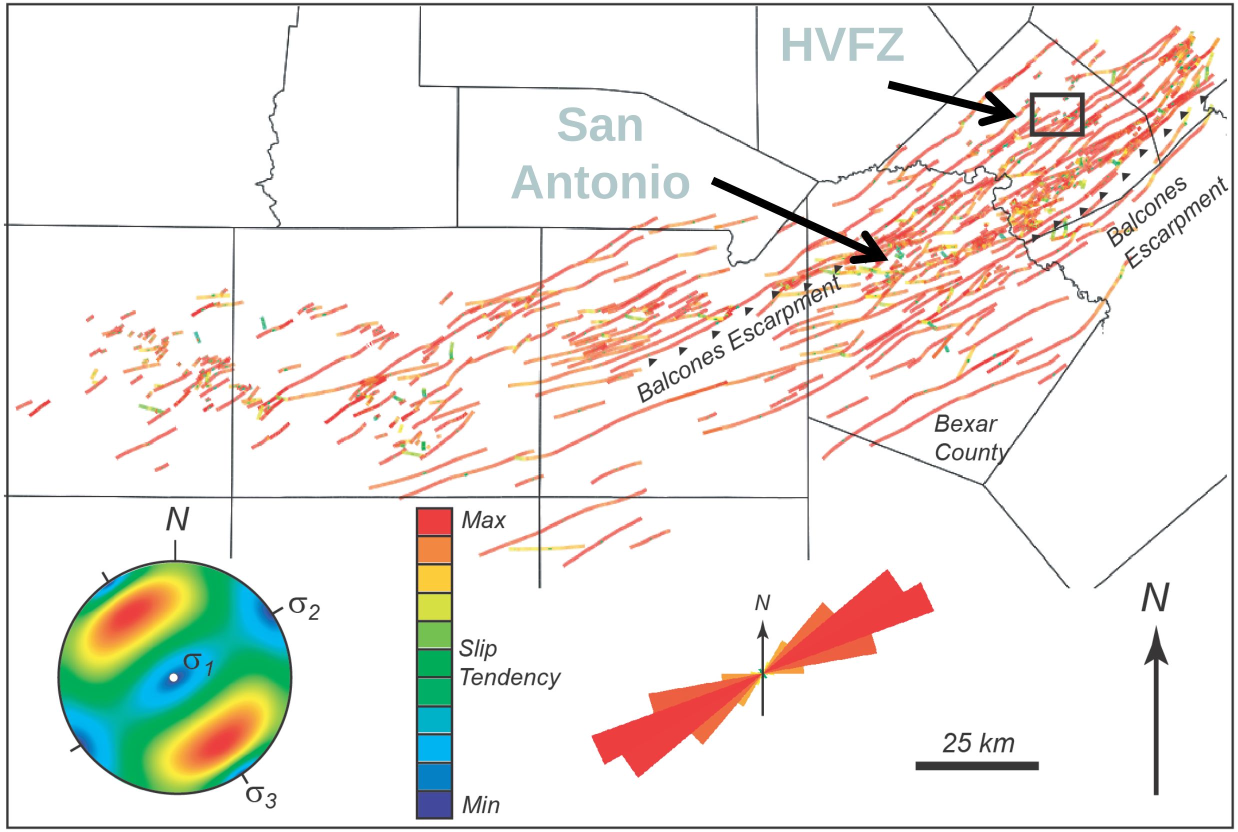
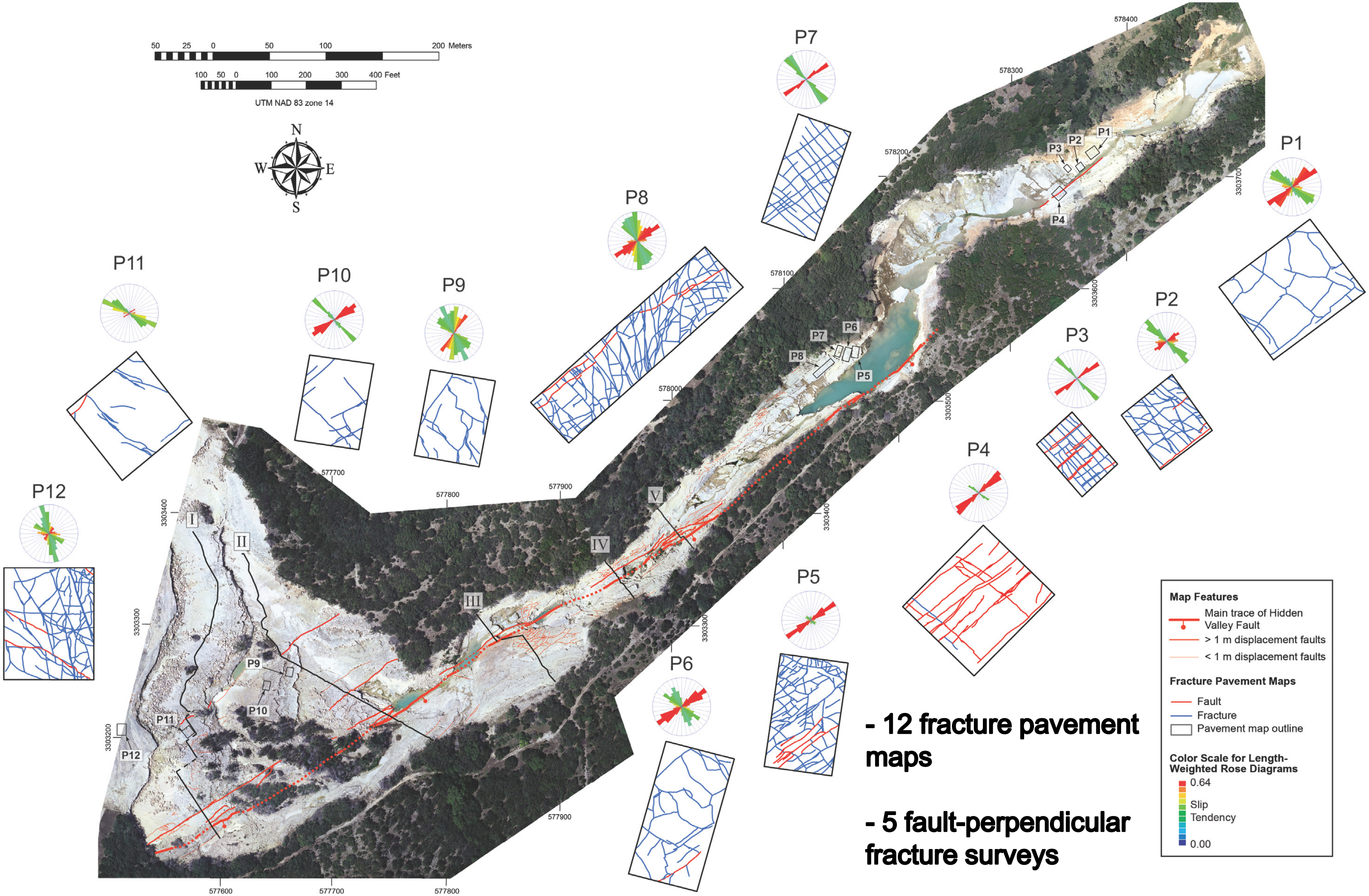
Balcones Fault System



Map of the Balcones fault system in the San Antonio area with fault traces colored according to their slip tendencies. Slip tendency analysis was performed using 3DStress™ v. 1.3.3 (see Ferrill et al., 2004) based on mapped faults of Collins and Hovorka (1997).

Hidden Valley Fault Zone

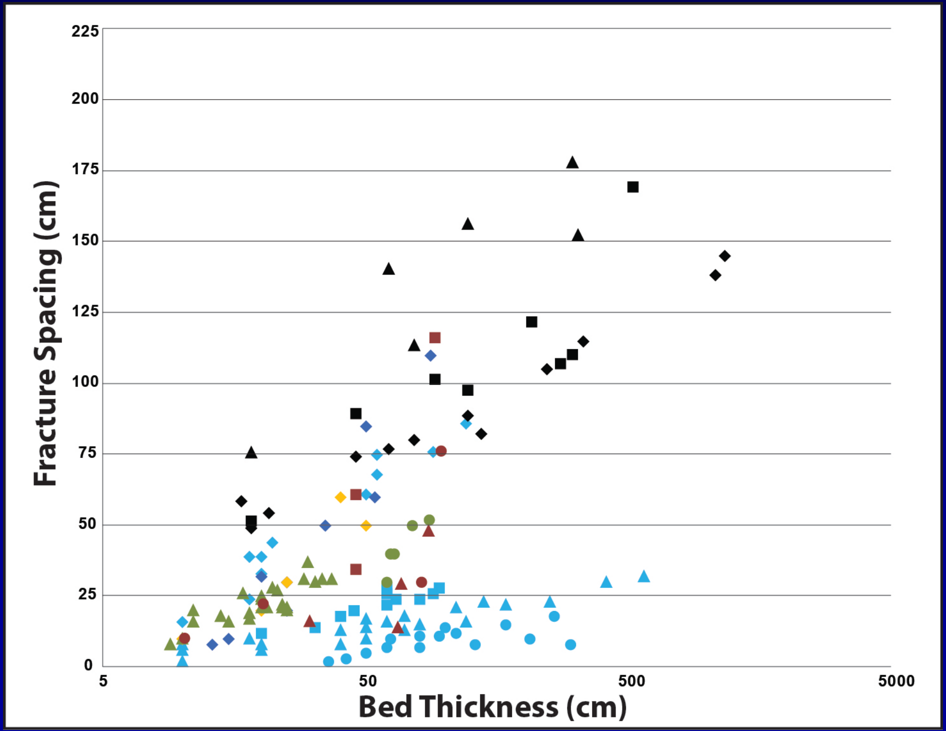


- 12 fracture pavement maps

- 5 fault-perpendicular fracture surveys

Fault and Joint Geometries

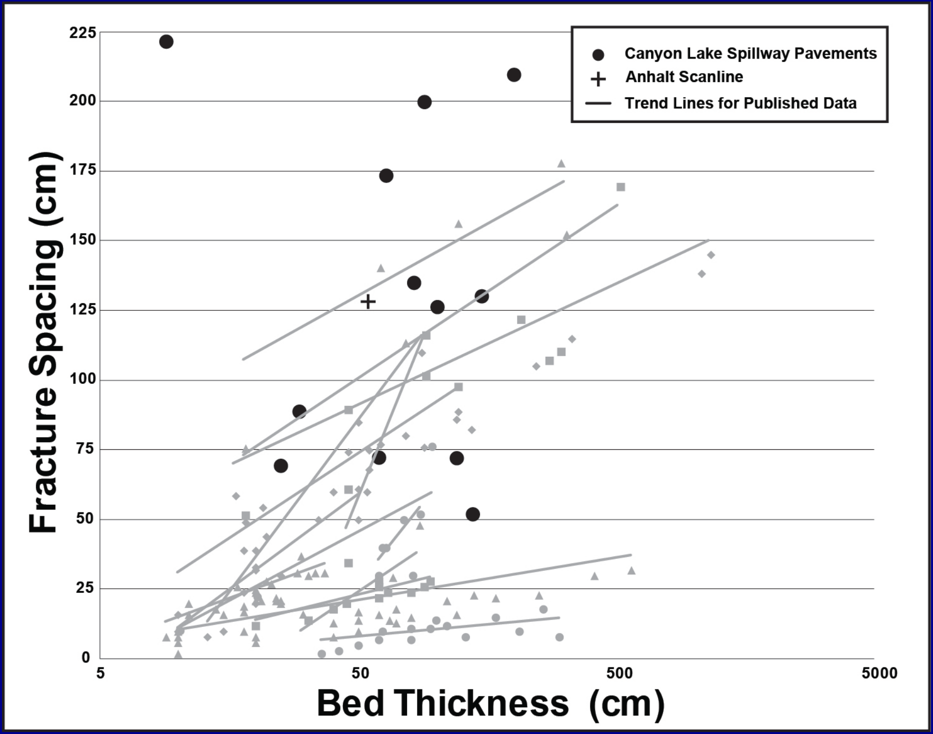
Relationship 1: Bed thickness vs Facture Spacing



Published data for a range of carbonate rocks (Price, 1966; McQuillan, 1973; Ladeira and Price, 1981; Narr and Suppe, 1991; Huang and Angelier, 1989; Corbett et al., 1987)

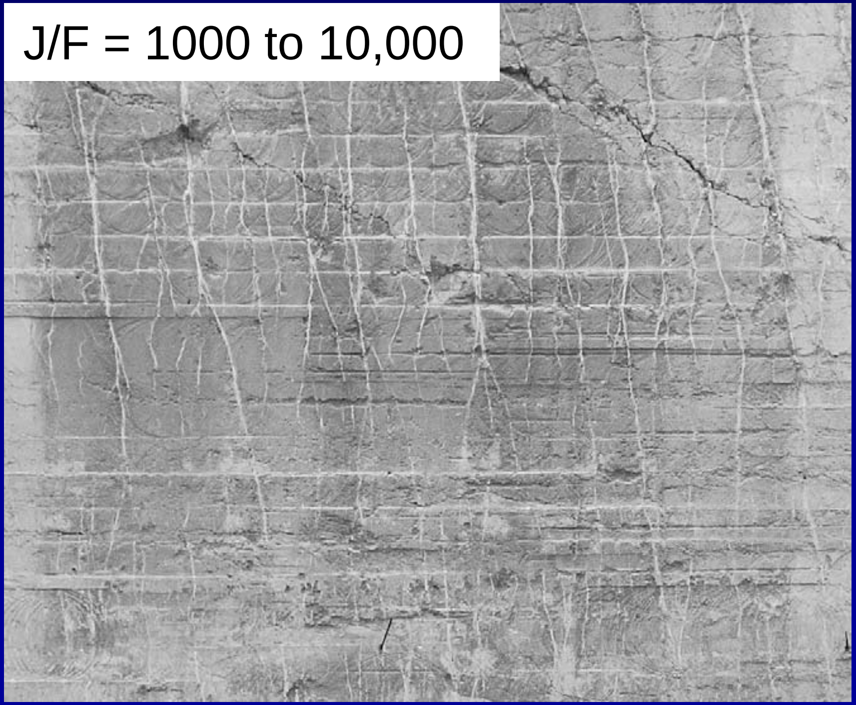
Published spacing/thickness ratios generally fall between 0.1 and 3

Fracture data from the Hidden Valley Fault zone don't seem to follow this relationship.



Relationship 2: Joint to Fault Ratio (J/F)

- J/F ratio is a way to generalize a fracture system
- The relationship can vary significantly depending on structural position, stress conditions, and mechanical stratigraphy
- Reported J/F ratios from layered carbonate rocks range from 1000 to 100,000 or $10^3 – 10^5$ (Caputo, 2010)
- J/F ratios from the Hidden Valley fault zone…



Quaternary marine bioclastic calcarenites from Salento, Southern Italy (Caputo, 2010).

Relationship 2: J/F Ratio

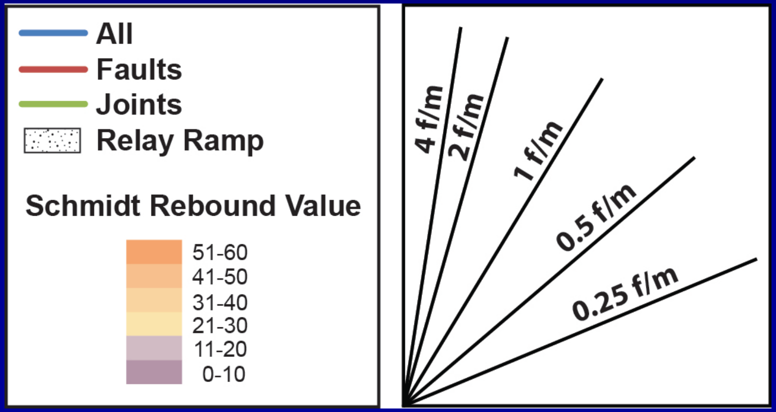
PROFILES (Hidden Valley Fault Zone)

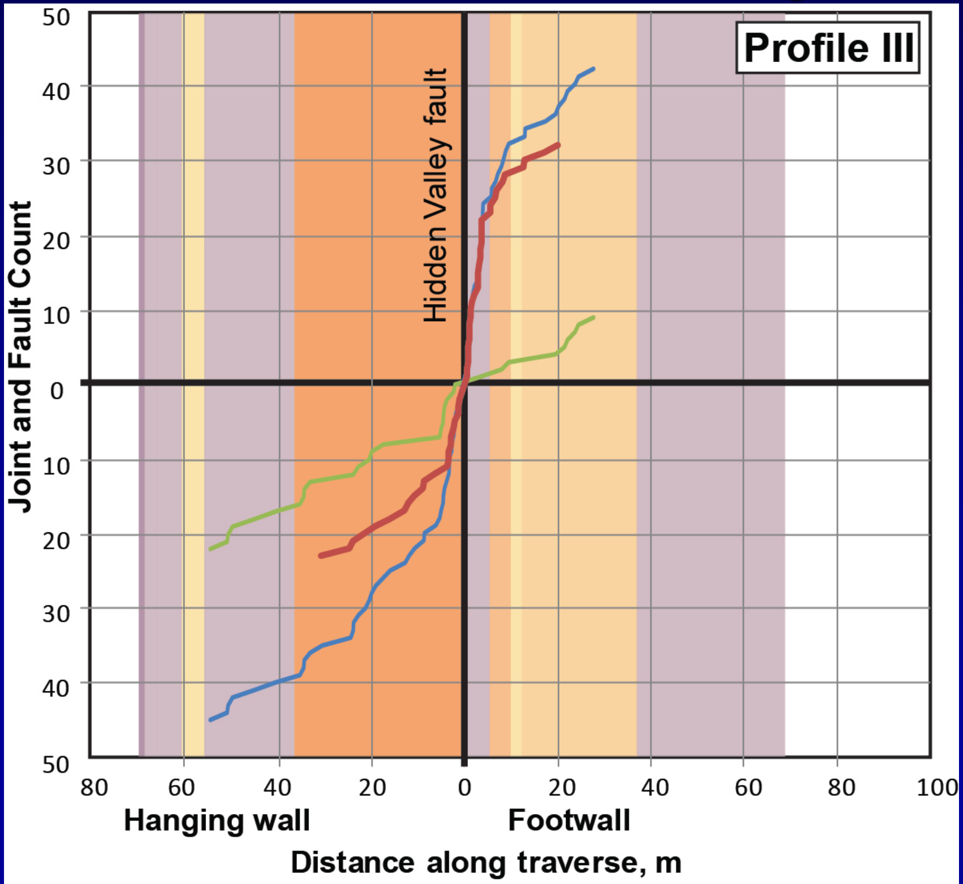
- All five fault-perpendicular profiles have J/F ratios <<10
- The “background” dataset has a J/F ratio <10
- These results are in sharp contrast to typical range of 1000 to 100,000 described by Caputo (2010)

Profile	J/F Ratio		
	Overall	Near HVF	Away HVF
I	1.38	1.80	0.70
II	0.49	0.45	0.60
III	0.03	0.00	0.04
IV	0.57	0.24	1.08
V	0.26	0.12	10.00
Highway 46 (Anhalt, TX)	8.17		

Relationship 3:
Damage Zone and Fracture Intensity

Relationship 3: Joint intensity increases with proximity to fault core





Hidden Valley fault data do not seem to obey Relationship 3:

- Joint intensity remains ~ constant across fault core, but…
- Fault frequency increases with proximity to fault core

Observations

- There is no clear relationship between joint spacing and bed thickness
- J/F ratios are orders of magnitude lower than published data sets
- Joint frequency does not increase with proximity to the main fault, although…
  - Small-displacement-fault frequency does increase with proximity to the main Hidden Valley fault core

Interpretation

The majority of deformation occurred at maximum burial (~1.5 km) associated with the onset of Balcones fault zone faulting

Within the HVFZ, relatively high differential stresses led to failure in shear rather than tensile mode

The presence of shear fractures suppressed the need for tensile failure during unloading

Proportionality between fracture spacing and bed thickness may not apply where saturation has not been reached (e.g., undeformed rocks) or where shear fractures dominate (high differential stress and mechanically layered rocks)

Conclusions

Entrenched fracture relationships can and do work, except where they don't…

where shear failure is the dominant failure mechanism, observations from the Hidden Valley fault zone may apply.

Where shear fractures (faults) are abundant, joint (tensile, mode 1, extension fracture) systems may be underdeveloped.

Observations of lithology, mechanical stratigraphy, bed thickness, structural position, failure mode, and stress history, rather than assuming general fracture relationships, will always prove useful and may reduce the uncertainty in fracture models.

Presenter's notes: Frac programs may be producing shear fractures instead of tensile.