

Natural Fractures in Shale Hydrocarbon Reservoirs*

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Abstract

Using examples from shale reservoirs worldwide, I demonstrate the diversity of shale-hosted fracture systems and present evidence for how and why various fractures systems form. Core and outcrop observations, strength tests on shale and on fractures in core, and geomechanical models allow prediction of fracture patterns and attributes that can be taken into account in well placement and hydraulic fracture treatment design. Both open and sealed fractures can interact with and modify hydraulic fracture size and shape. Open fractures can enhance reservoir permeability but may conduct treatment fluids great distances, in some instances possibly aseismically. We have addressed the challenge of incomplete sampling of subsurface fractures through comprehensive fracture data collection in cores and image logs and careful selection of outcrops, coupled with an understanding of how fractures and their attributes scale. We also use tested mechanistic models of how fractures grow in tight sandstones and carbonates to interpret fractures in shale. In order to predict fracture patterns and attributes, it is helpful to understand their mechanism of formation and timing in the context of the burial and tectonic histories of the basin in which they are forming. A key variable is the depth of burial, and thereby the temperature, pore-fluid pressure and effective stress at the time of fracture development. For the most part, the origin of fractures cannot be determined from their orientation or commonly-measured attributes, such as width, height and length. The mineral fill in sealed fractures does provide an opportunity, however, and we use fluid-inclusion studies of fracture cements tied to burial history to unravel their origin. Interaction with hydraulic fracture treatments may serve to increase the effectiveness of the hydraulic fracture network, or could work against it. Factors governing the interaction include natural fracture intensity, orientation with respect to reservoir stress directions, and the strength of the fracture plane relative to intact host rock. We tested the effect of calcite-sealed fractures in Barnett Shale on tensile strength of shale with a bending test. Samples containing natural fractures have half the tensile strength of those without and always break along the natural fracture plane. Yet in other examples the weakness is in the cement itself, partly because of retained fracture porosity. Natural fractures in shales likely grew by slow, chemically assisted (subcritical) propagation, and we use a subcritical propagation criterion to model the growing fractures. The subcritical crack index is a mechanical rock property that controls fracture spacing and an input parameter for the models. We measured the subcritical crack index for several shales. The index is generally high for Barnett Shale, in excess of 100, although it does show variability with facies. By contrast, subcritical indices in the New Albany Shale are much lower, and also show considerable variability. Barnett Shale subcritical indices suggest high clustering, whereas New Albany Shale subcritical indices

suggest fractures are likely to be more evenly spaced, with spacing related to mechanical layer thickness. We are investigating the variability in subcritical index in shale and how it might tie to other rock properties.

References Cited

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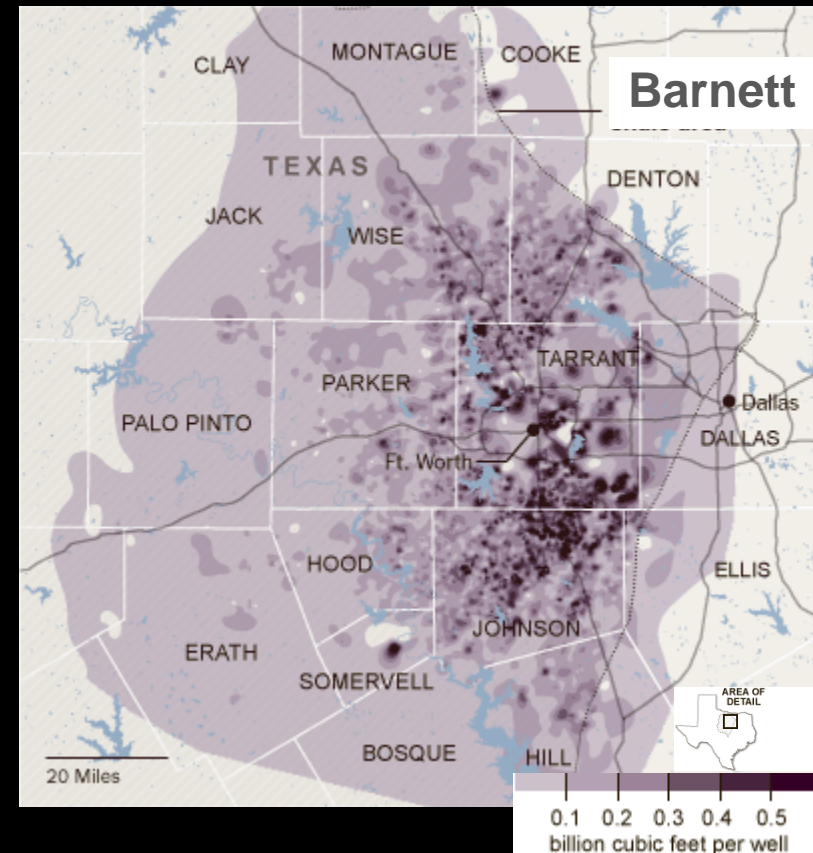
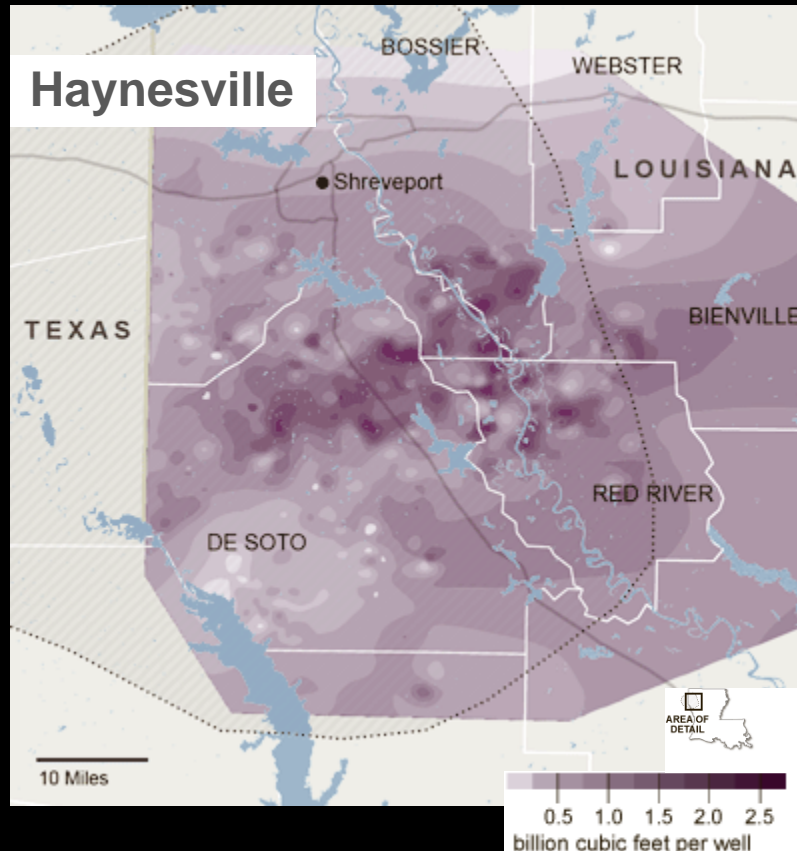
Steve Laubach, Jon Olson, Randy Marrett,
Jon Holder, Peter Eichhubl, András Fall, Esti Ukar,
Luke Fidler, Laura Pommer

FRAC FRACTURE RESEARCH &
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"Dedicated to conquering the challenges of fractured and unconventional reservoirs by 2020"

Why Worry About Fractures?

Production Variability



NY Times, June 26, 2011

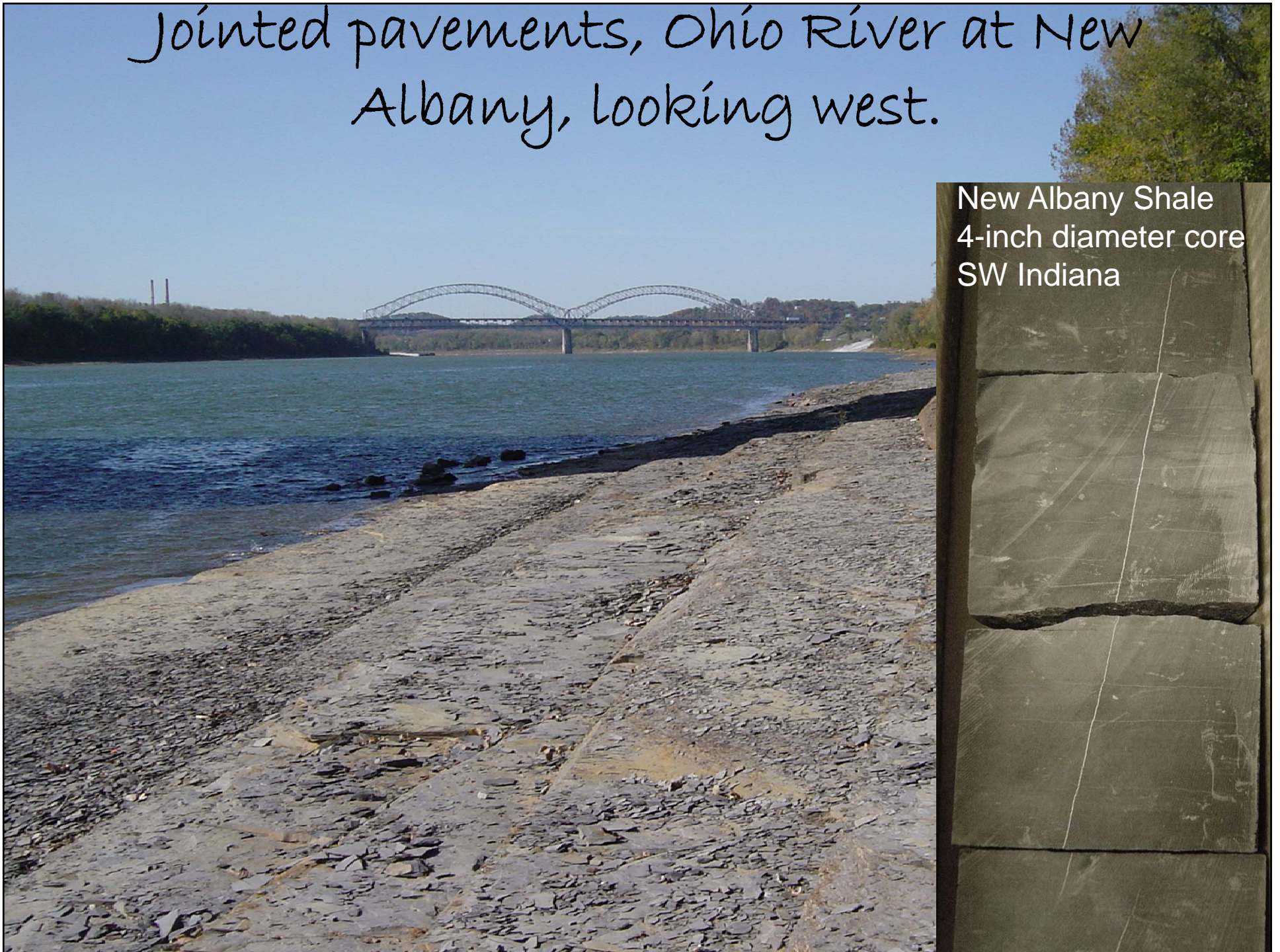
*“...shale formations have **small spots of very productive & profitable wells**, surrounded by **large areas where wells produce far less gas...**”*

Classic symptom of fractures

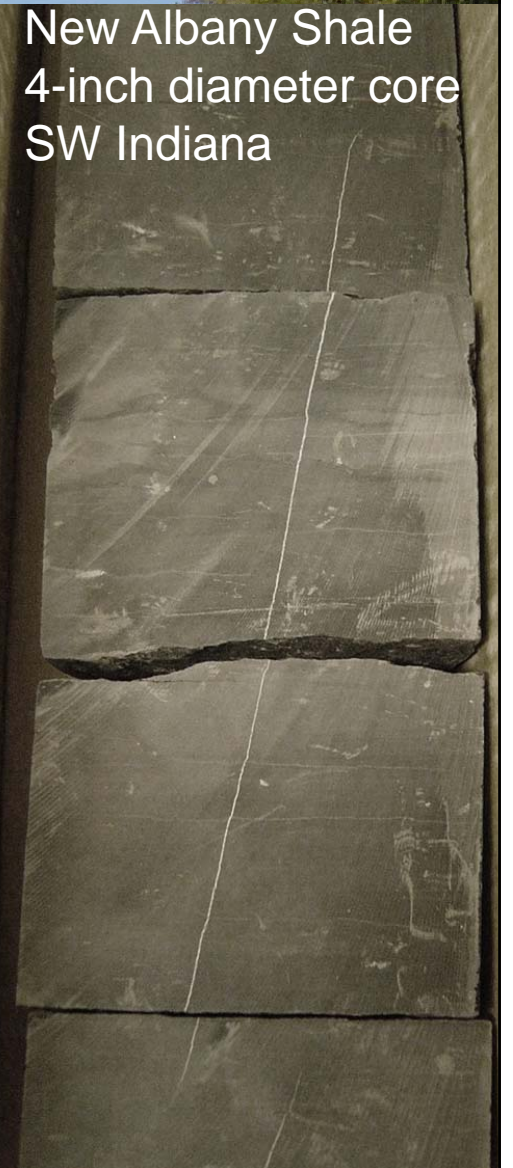
Basic Questions

- Are natural fractures present?
 - How abundant are they?
 - Are there different fracture types?
 - What is their intensity?
 - How large are they; are they connected?
- Do they affect production?
 - Do they interact with hydraulic fracture treatments?
 - Do they enhance permeability?
- Can we predict them?

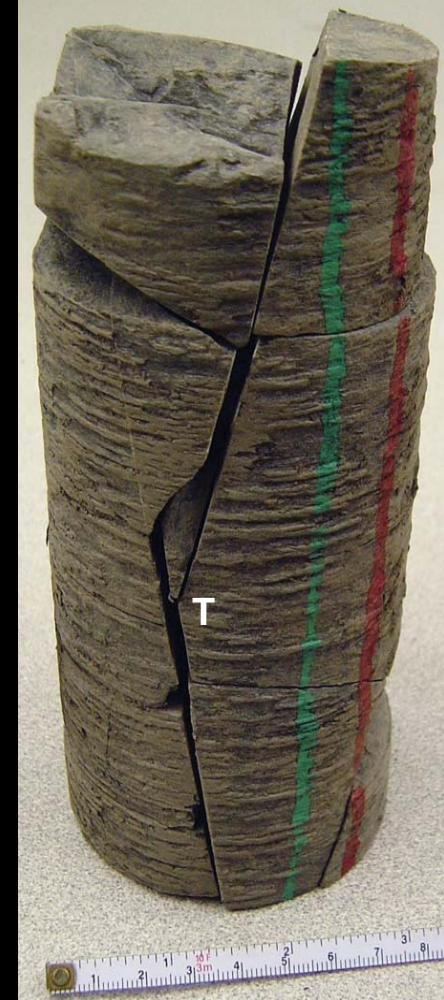
Jointed pavements, Ohio River at New Albany, looking west.



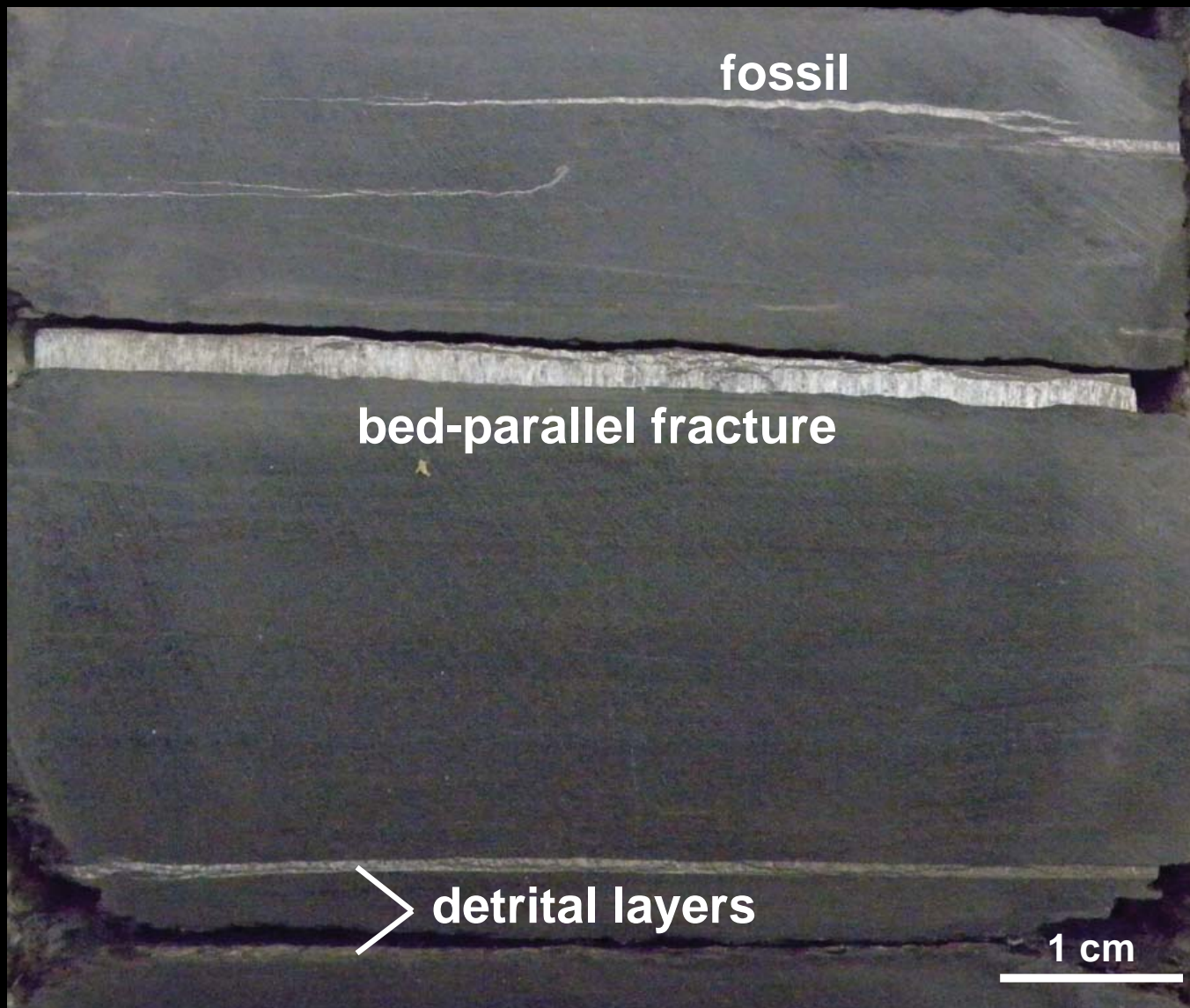
New Albany Shale
4-inch diameter core
SW Indiana



Subvertical Fractures



Bedding-Parallel Fractures

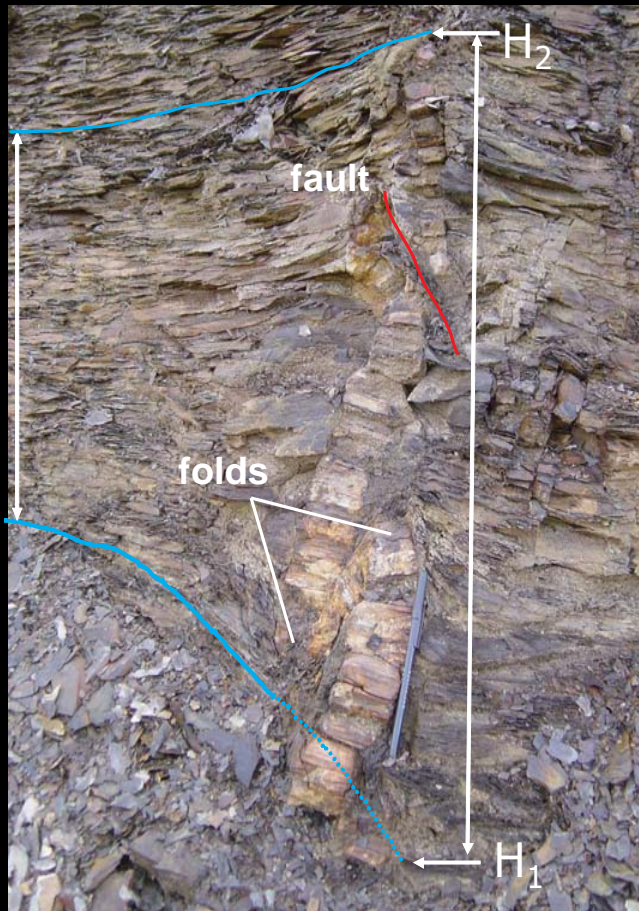


Bedding-Parallel Fractures



Examples from Smithwick Shale, San Saba Co.
Houston Oil and Minerals, Neal, R.V. #A-1-1
2 5/8-inch diameter core

Compacted Fractures and Concretion-Related Fractures



New Albany



Barnett,
Delaware Basin



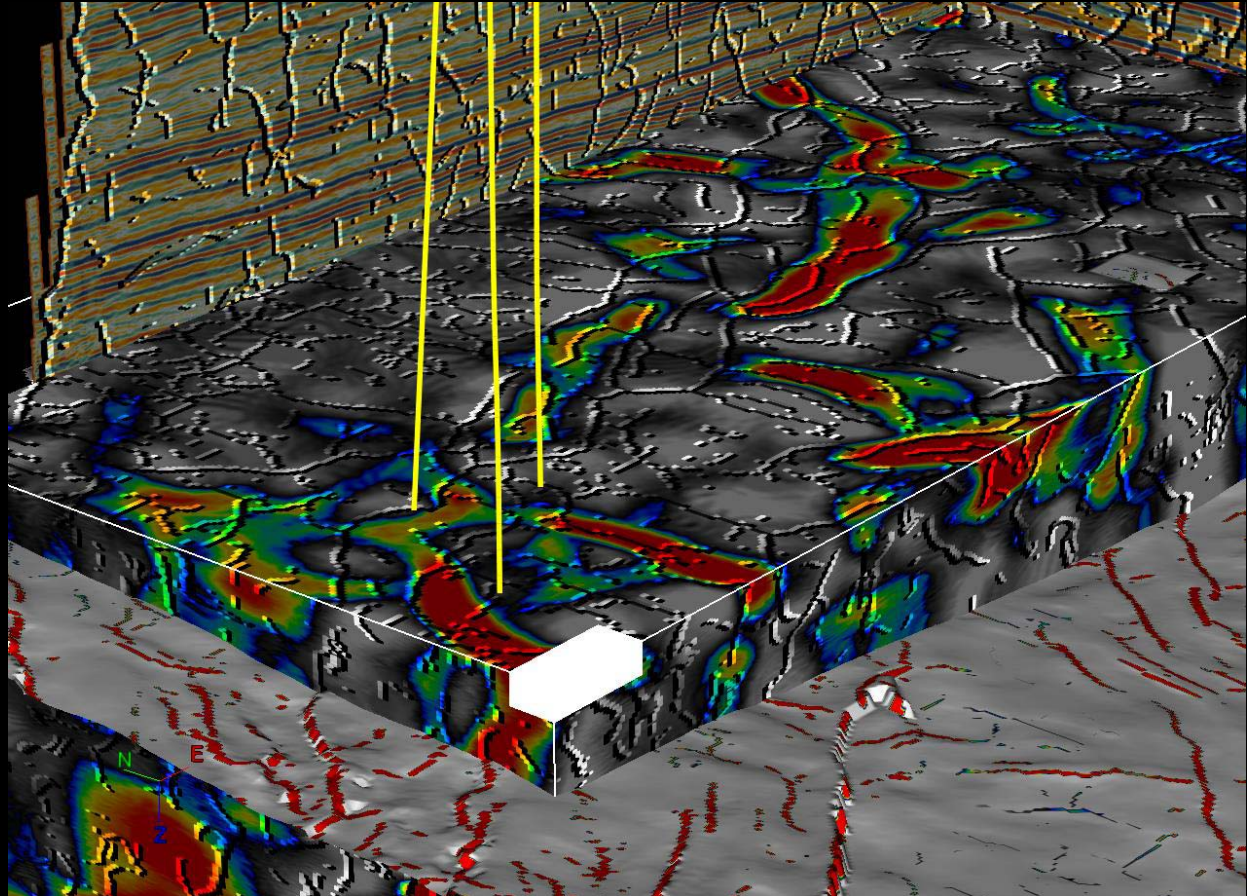
Marcellus



Faults



Niobrara



South Texas seismic volume

Roth et al., 2013 Sweetspot Mapping in the Eagle Ford with Multi-Volume Seismic Analysis, RMAG 3D Symposium

Quantification of Fracture Populations

- Abundance (semi-quantitative)
 - Degree to which fractures present
 - Used where sample does not permit intensity measure
- Intensity, frequency (quantitative)
 - Number of fractures per unit length, area or volume
 - Requires extensive sample relative to fracture size

Sampling Fractures in Vertical Wells

Well A:

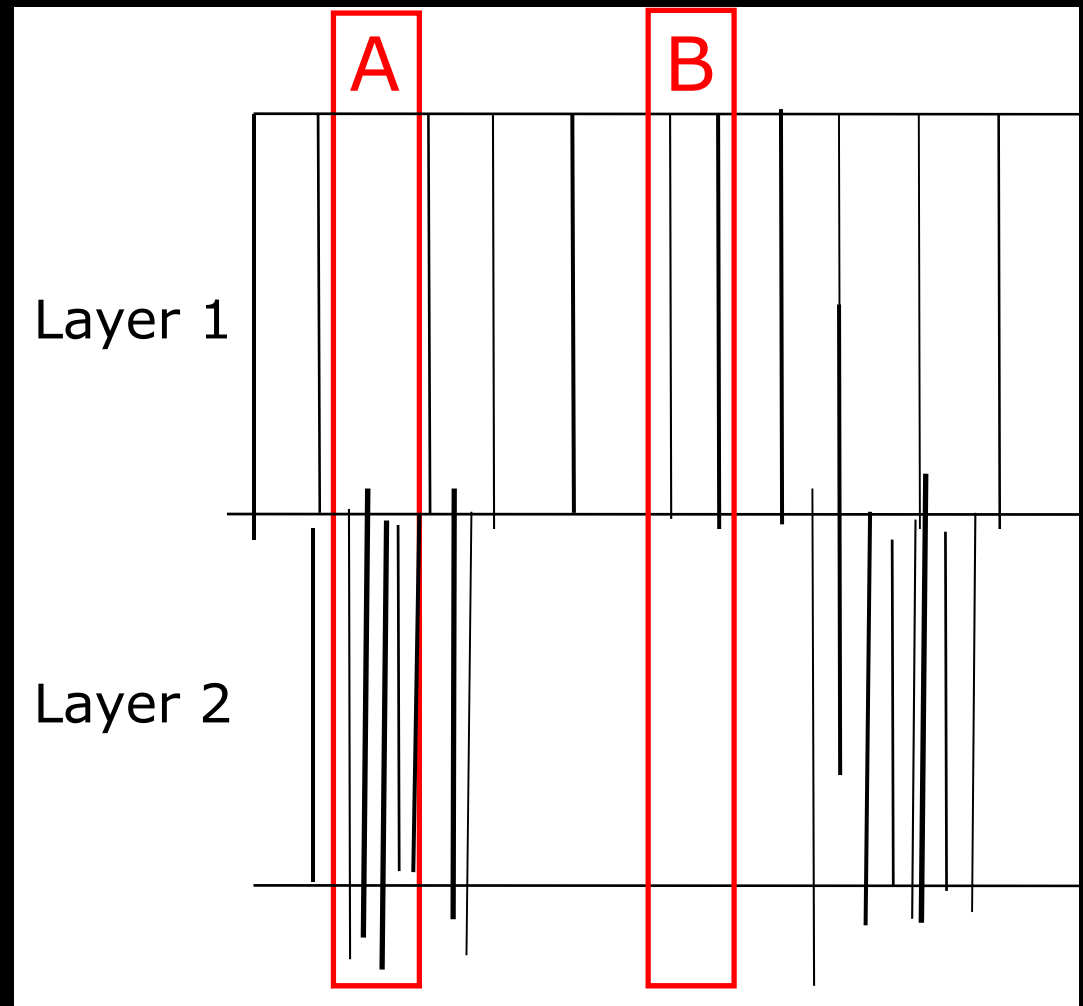
No fractures in layer 1

Many fractures in layer 2

Well B:

A few fractures in layer 1

No fractures in layer 2



Quantifying Fracture Abundance

- Count number of fractures per 100 ft of vertical core (include all fractures $\geq 30 \mu\text{m}$ wide)
- Apply descriptor to ranges of abundance
 - Many: >10 per 100 ft
 - Several: 5-10 per 100 ft
 - Few: < 5 per 100 ft
- 18 shale formations examined
- Additional data from literature



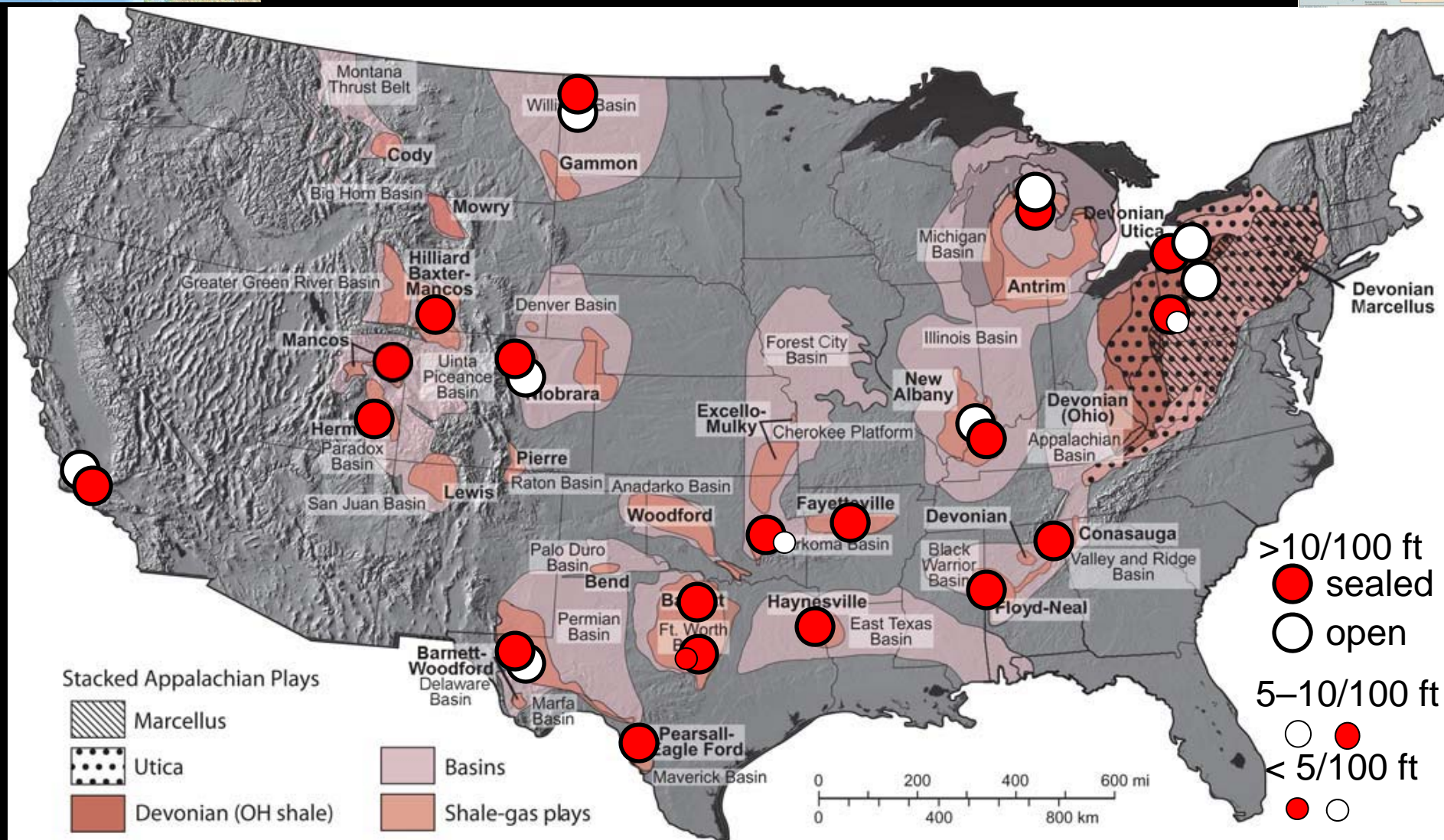
Horn River Basin

Subvertical Fractures

In all cores studied



Neuquen Basin



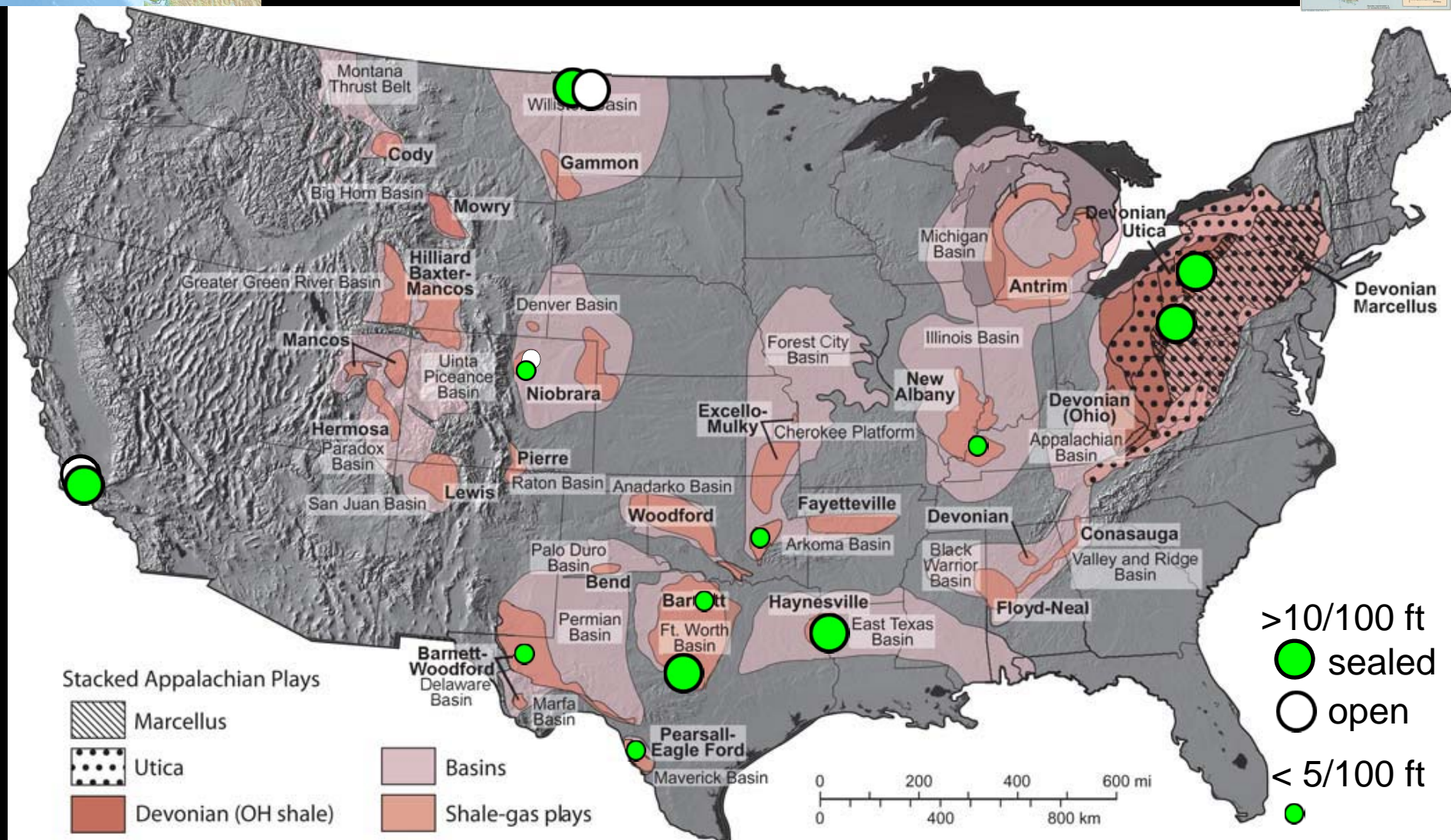


Horn River Basin

Bedding-Parallel Fractures



Neuquen Basin



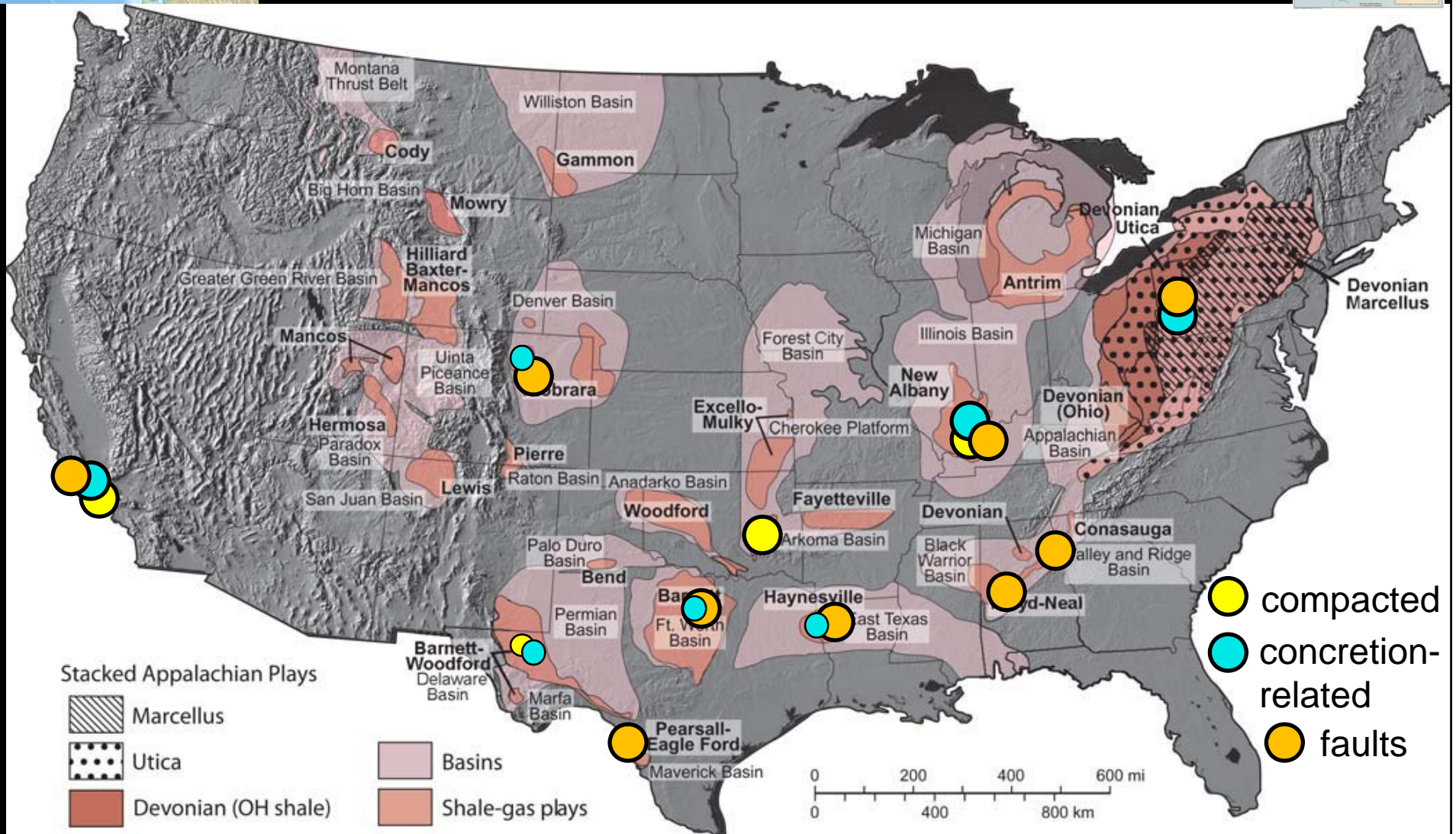


Horn River Basin

Compacted Fractures, Concretion-Related Fractures & Faults



Neuquen Basin



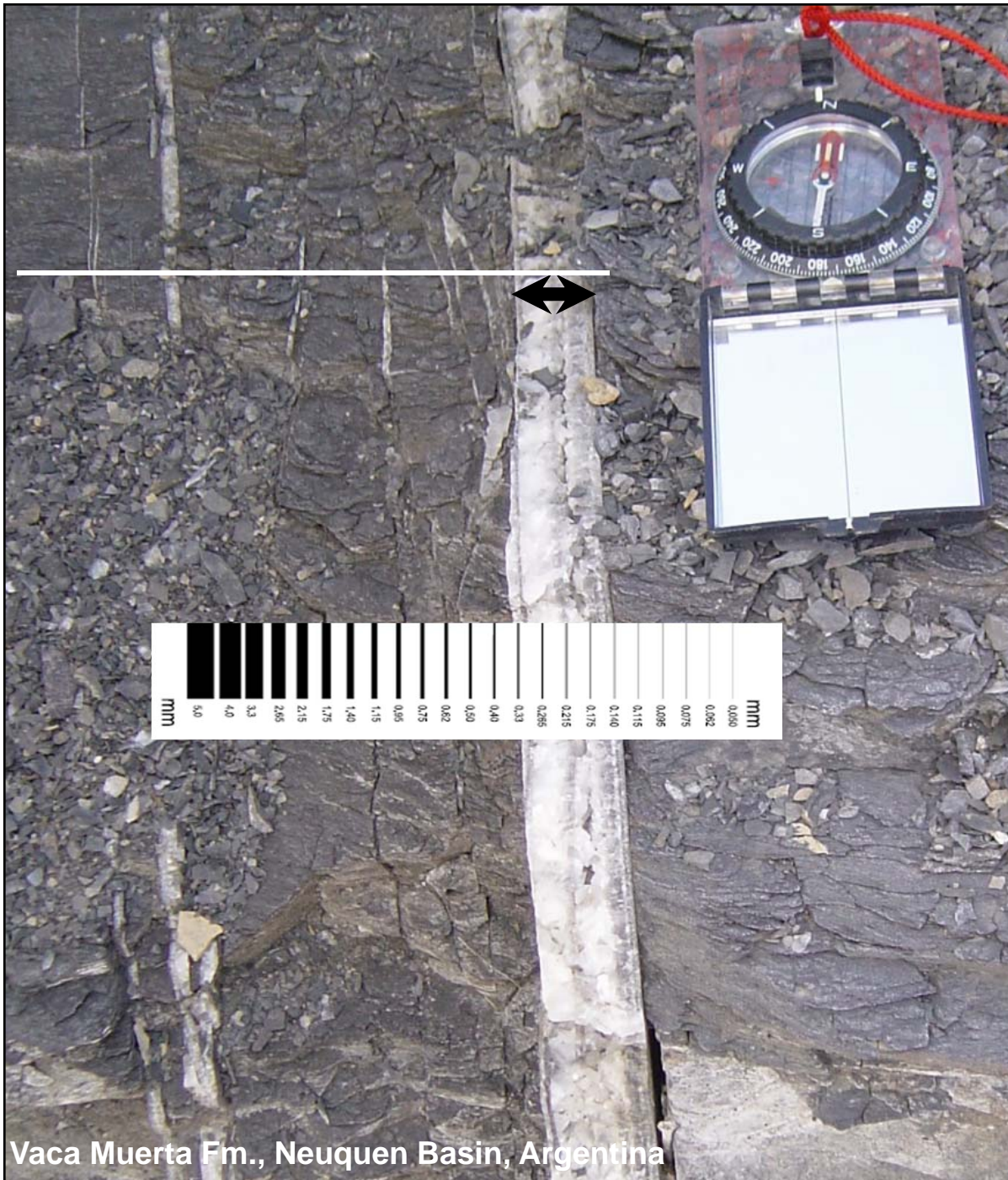
Quantification of Fracture Populations

- How can we measure frequency?
- Intensity challenging to quantify
 - Fractures may be clustered
 - Sampling limitation in subsurface
 - Intensity must be considered relative to fracture size

Fracture Kinematic Aperture

Includes cement
and opening

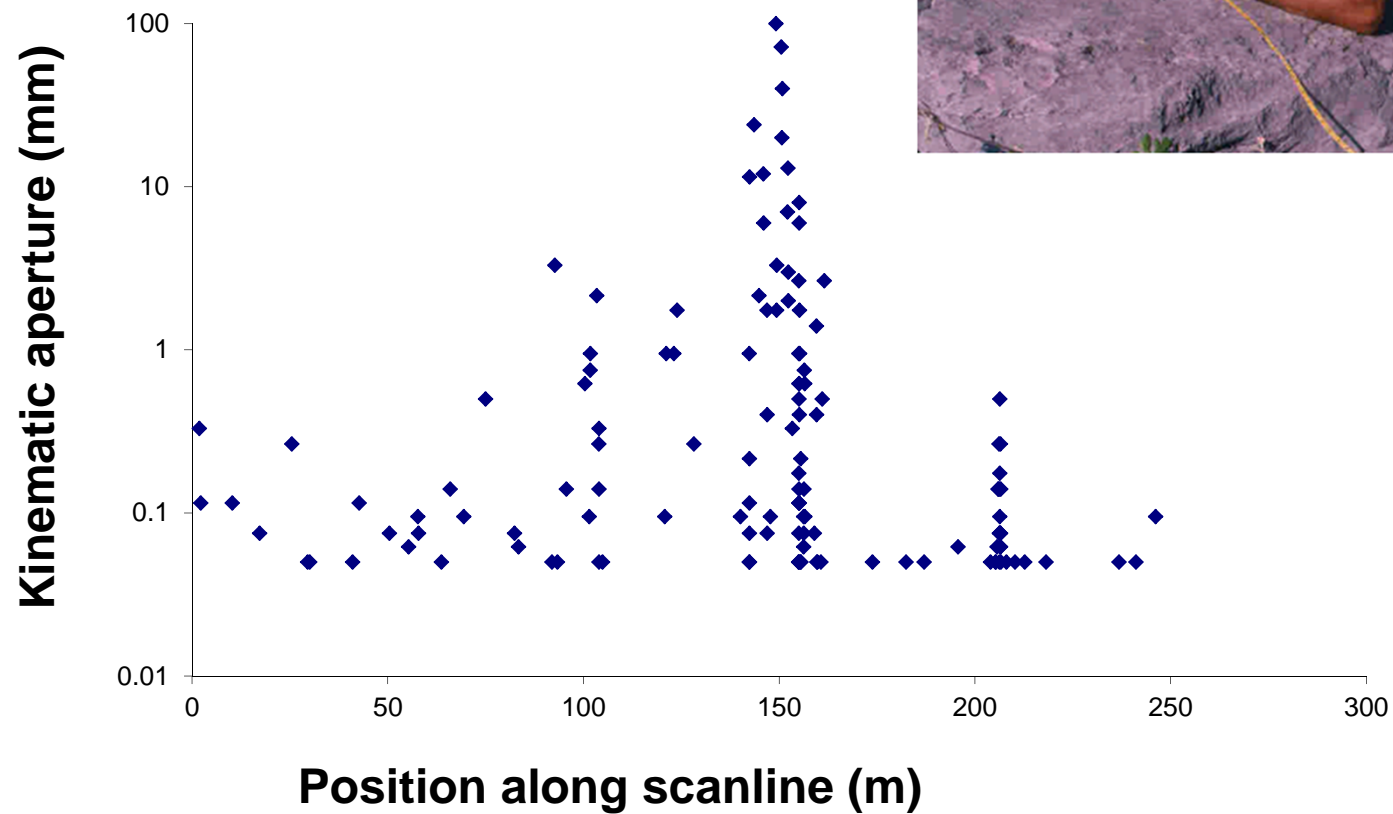
Measured
orthogonal to
fracture walls



Vaca Muerta Fm., Neuquen Basin, Argentina

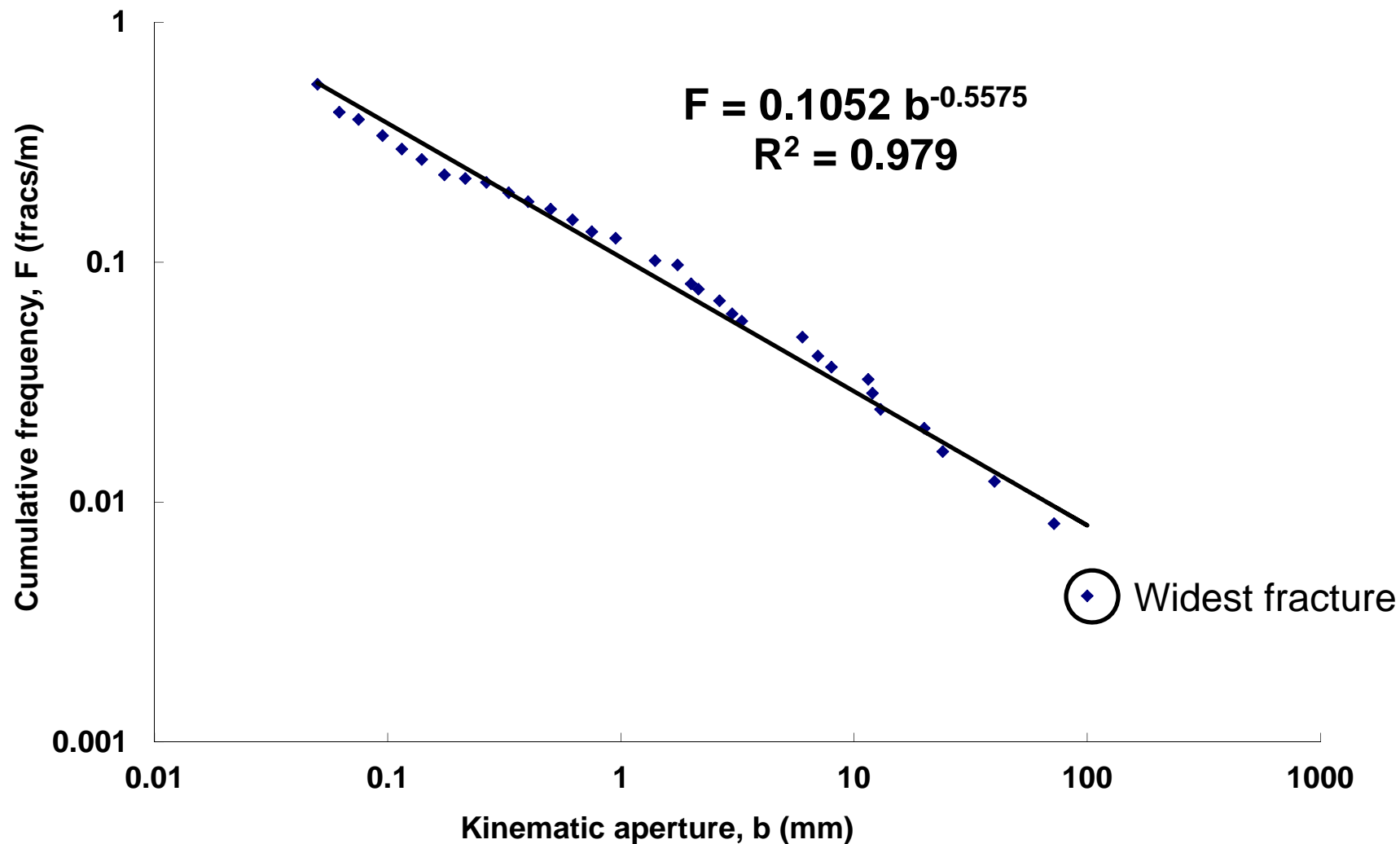
Fracture Frequency

Austin Chalk, Grove Creek, Waxahachie, TX

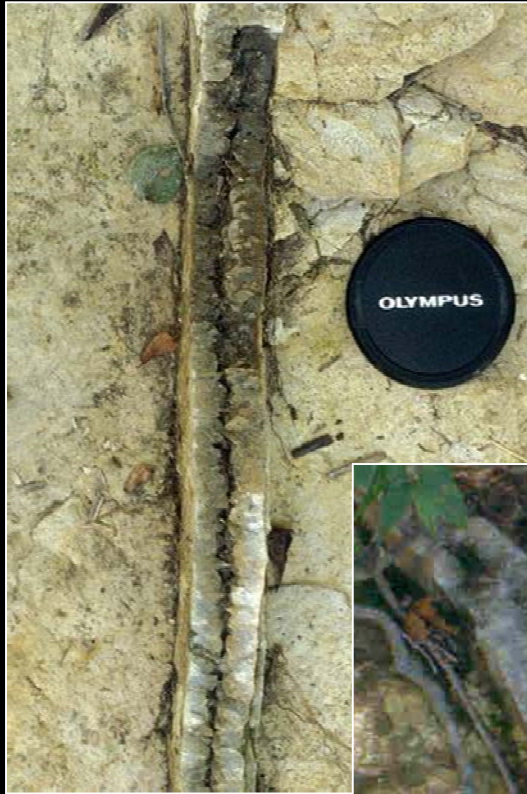


Aperture-Size Distribution

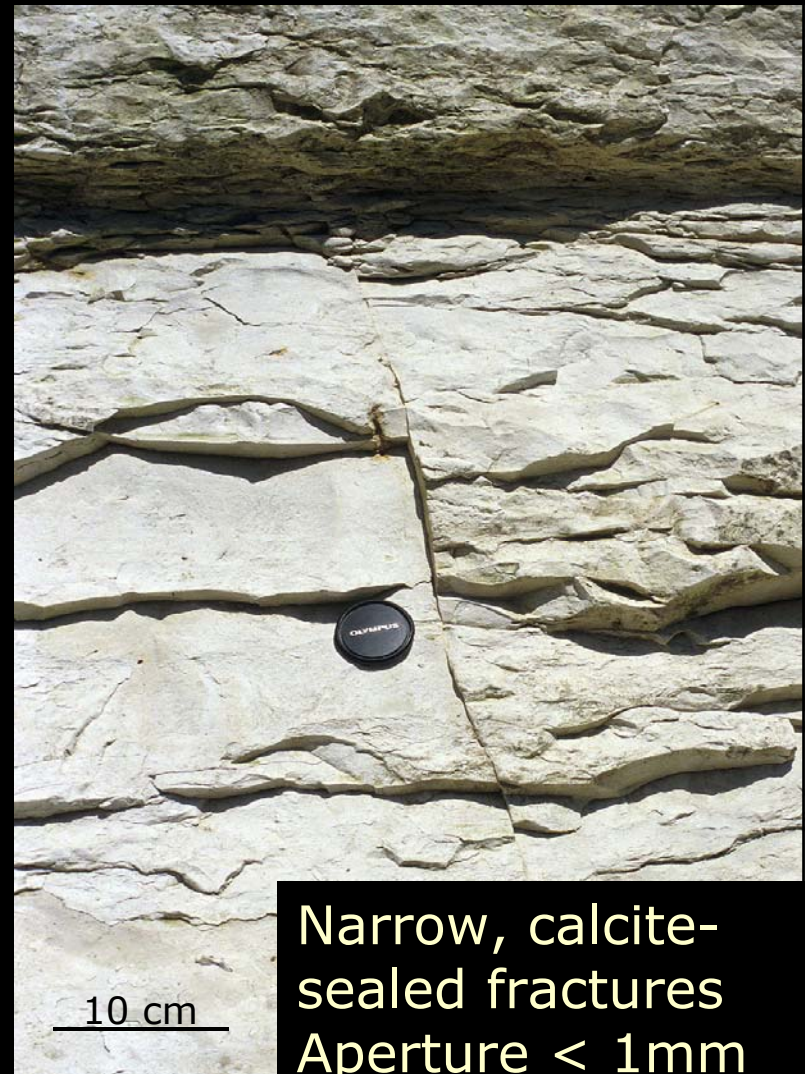
Austin Chalk, Grove Creek



Which Fractures Are Open?

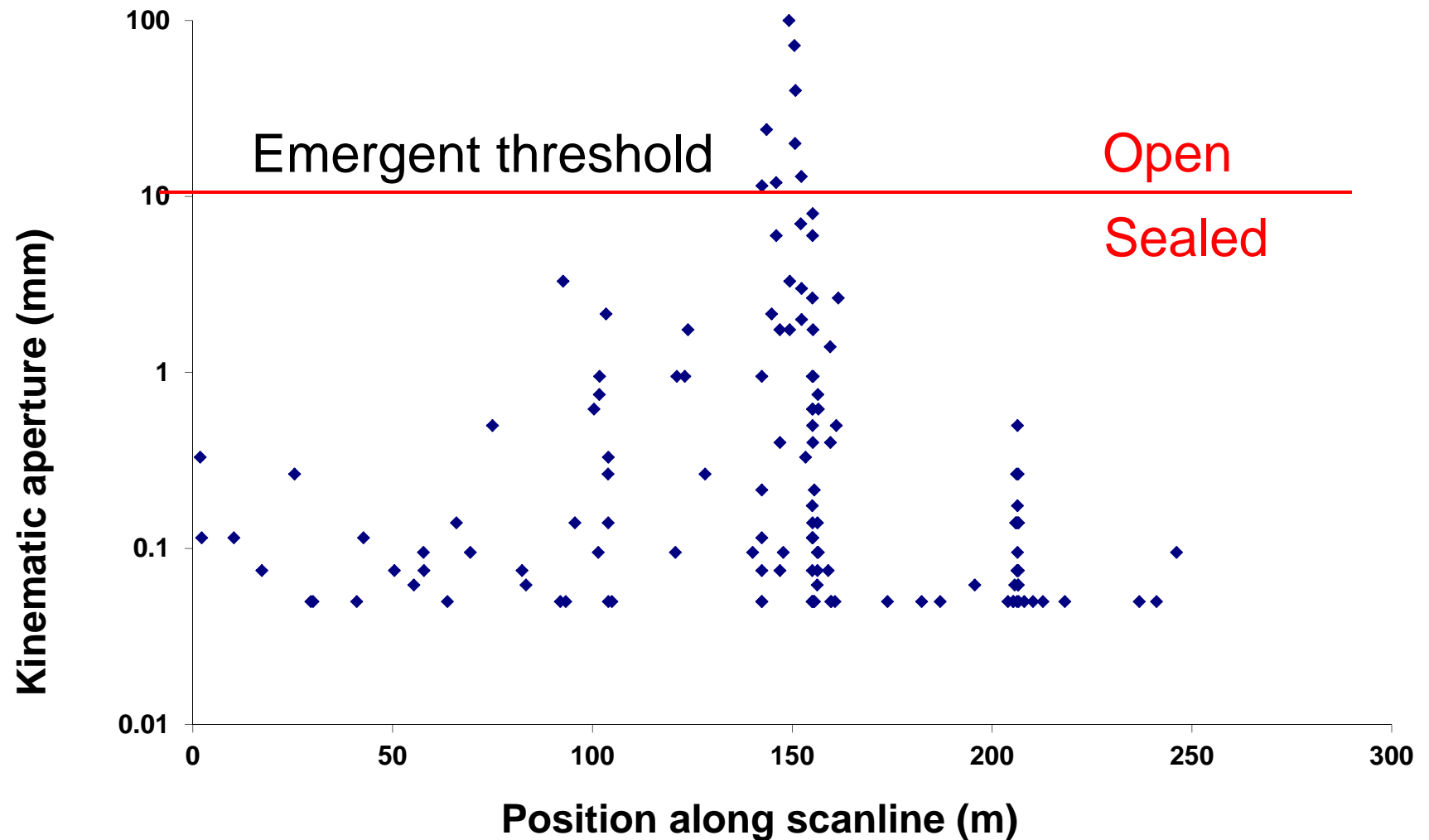


Wide,
partly open
fractures

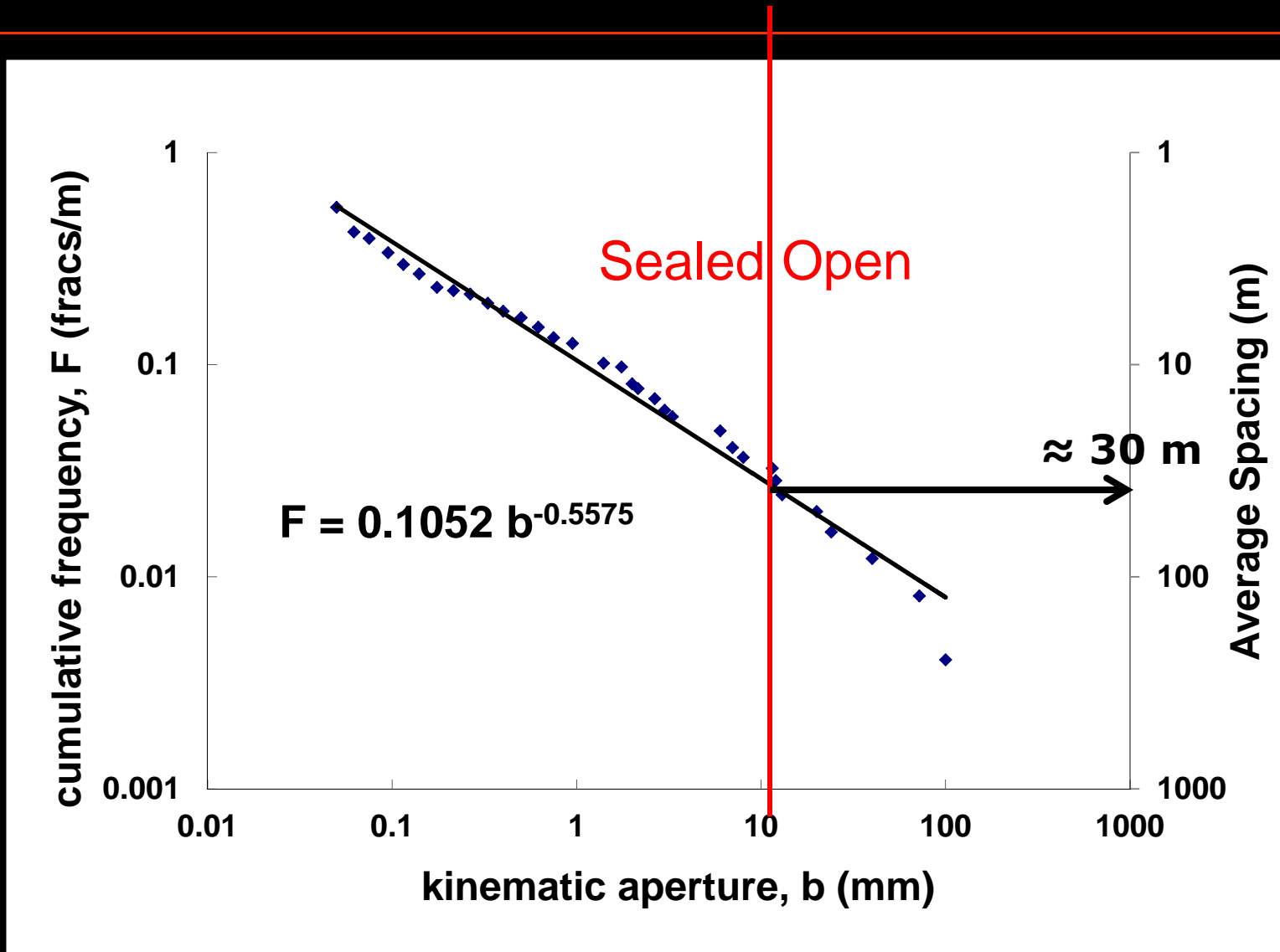


Narrow, calcite-
sealed fractures
Aperture $< 1\text{mm}$

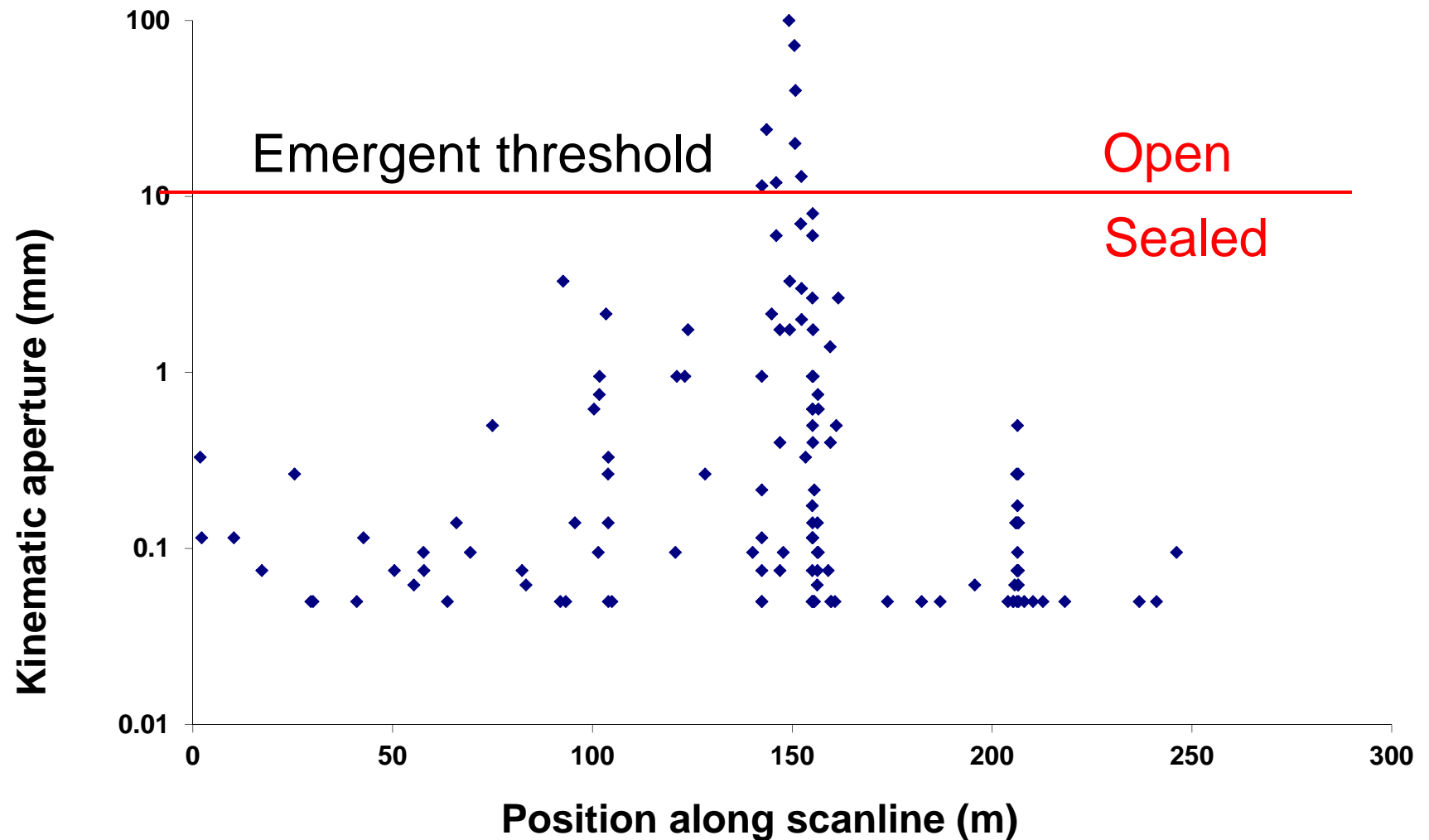
Which Fractures are Open?



Which Fractures are Open?



Which Fractures are Open?



Fracture Sealing Patterns in Shales



Wide, partly
open fractures

Calcite cement

Woodford Fm.

2 cm

New Albany
Shale

5 cm

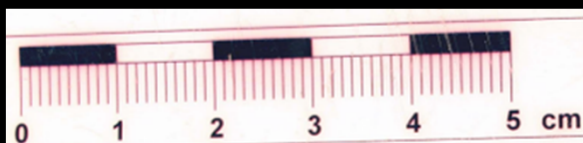
Calcite-
sealed
fractures
<1 mm
wide

Smithwick Fm.

5 cm

Marcellus Fm.

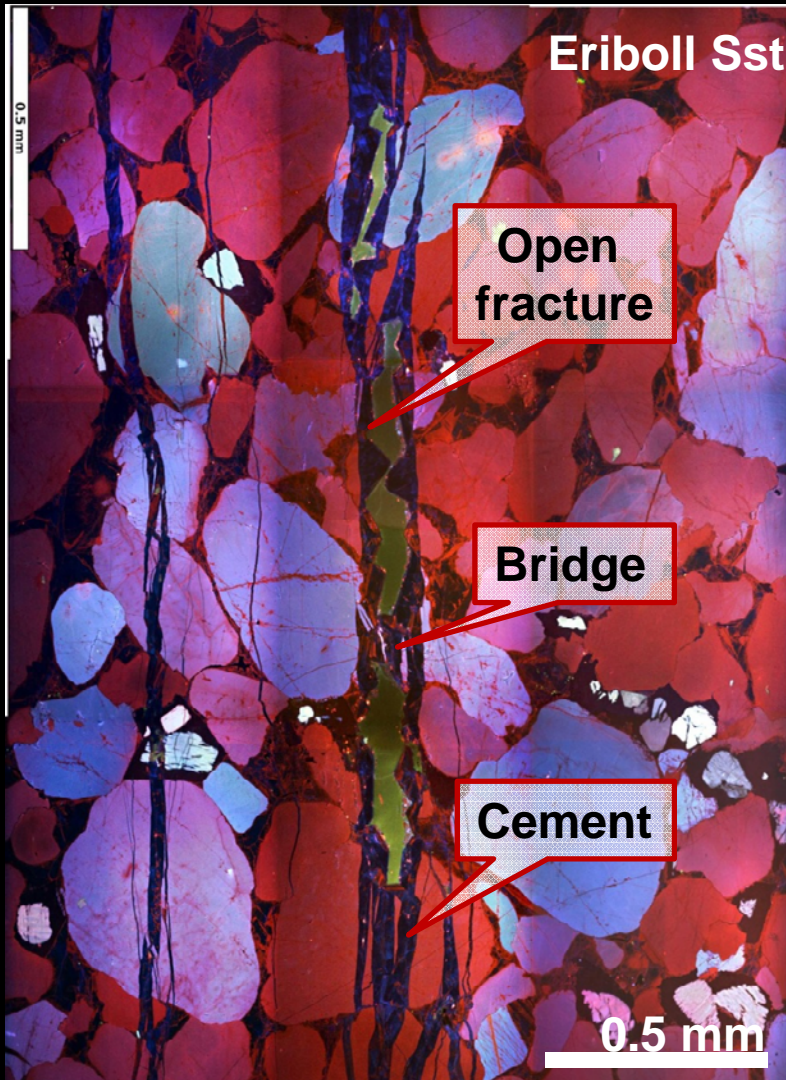
5 cm



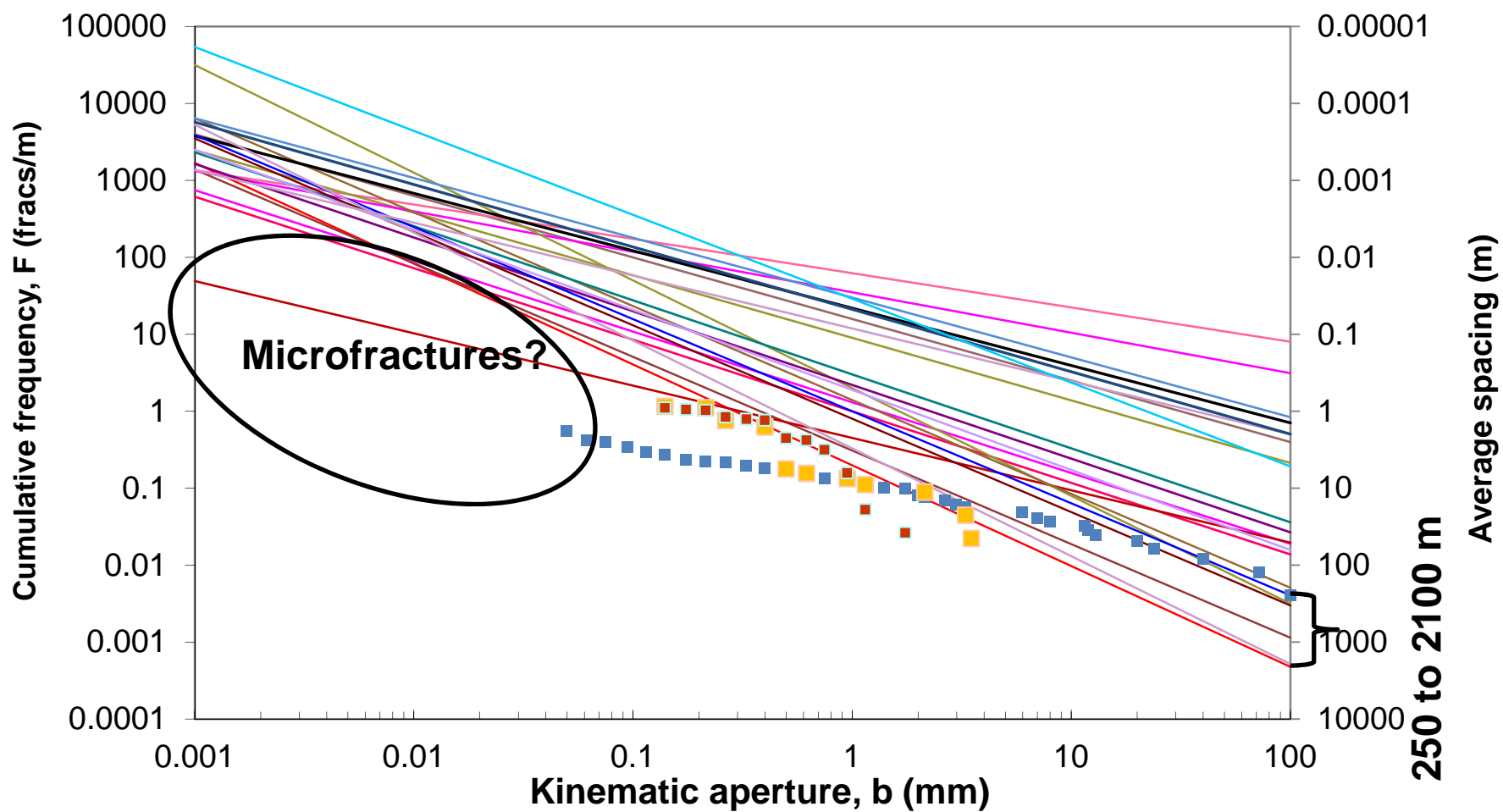
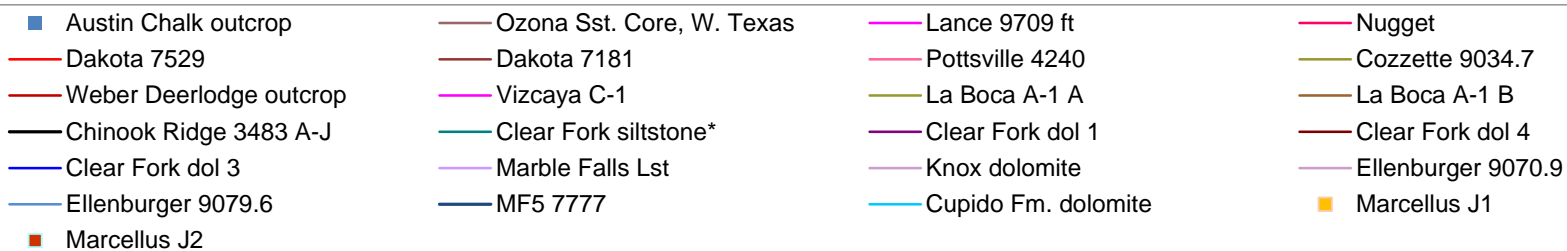
Barnett Shale

Microfractures

Widespread, Nearly Always Sealed



SEM-cathodoluminescence images



Microfractures

- Lack of sealed microfractures in most ion-milled SEM images of shale
- Direct observation of microfractures in shales (sealed and open) reported in literature
- Indirect, inferred evidence of fluid-filled microfractures: anisotropy of ultrasonic and seismic velocities

Microfractures

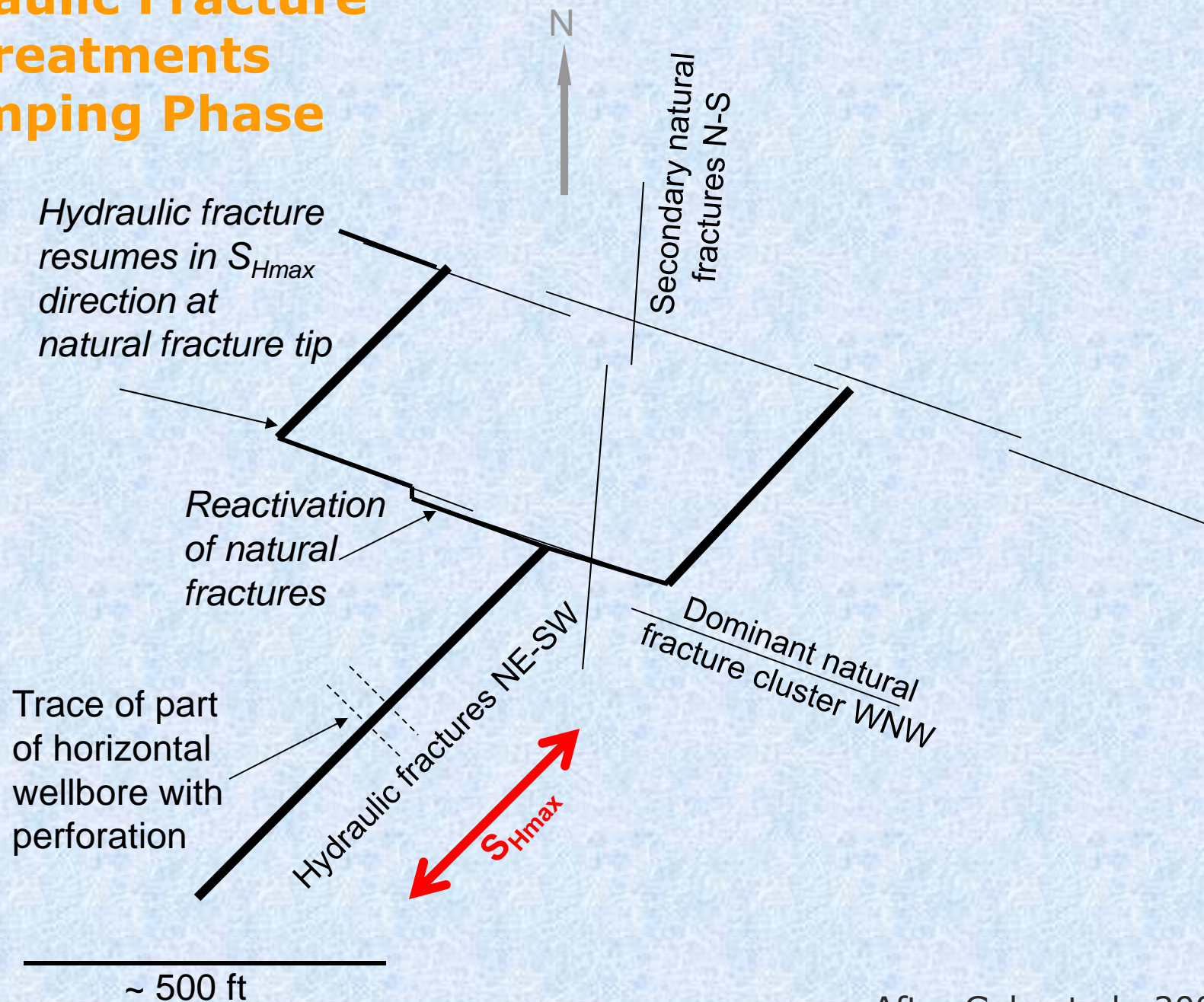
“The extent to which microfractures enhance mudstone permeability, both instantaneously and over longer periods of geological time, is poorly constrained.”

Dewhurst, Yang and Aplin, 1999, in Muds and Mudstones: Physical and Fluid Flow Properties, Geol Soc Spec Pub 158.

Basic Questions

- Are natural fractures present?
 - How abundant are they?
 - What is their intensity?
 - How many sets are there?
 - How large are they and are they connected?
- Do they affect production?
 - Do they interact with hydraulic fracture treatments?
 - Do they enhance permeability?
- Can we predict them?

Hydraulic Fracture Treatments Pumping Phase



After Gale et al., 2007

Weakly Bonded Fracture Cement New Albany Shale

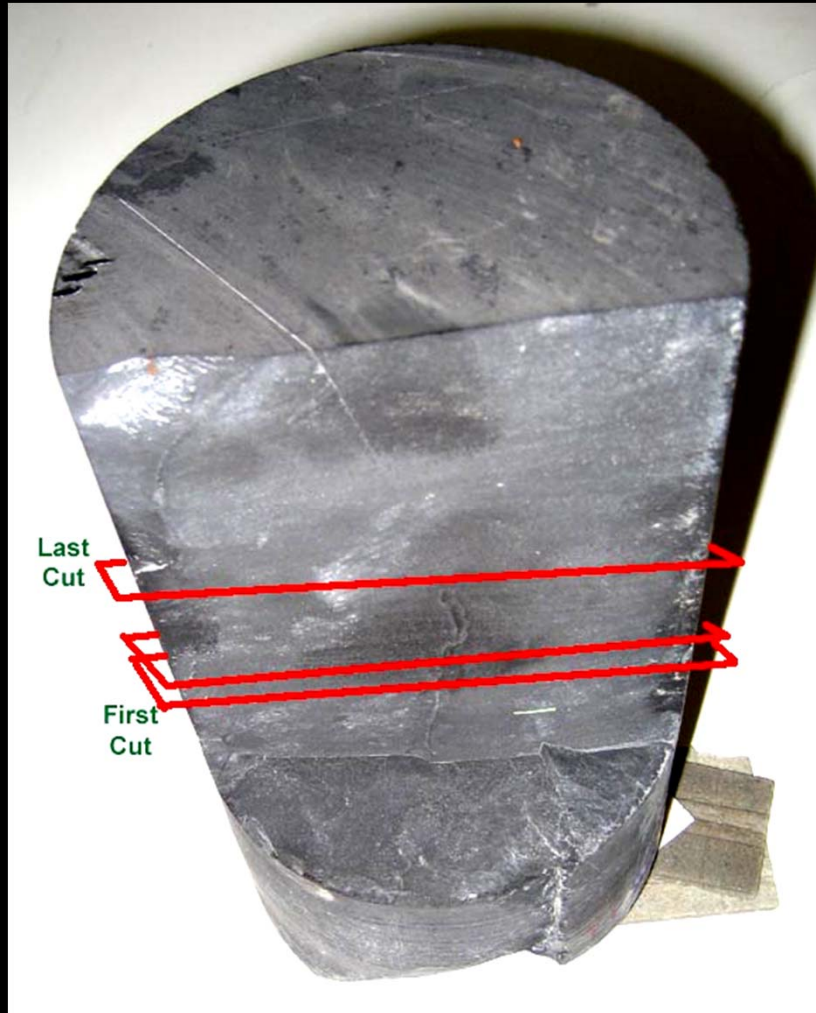


Tensile Testing

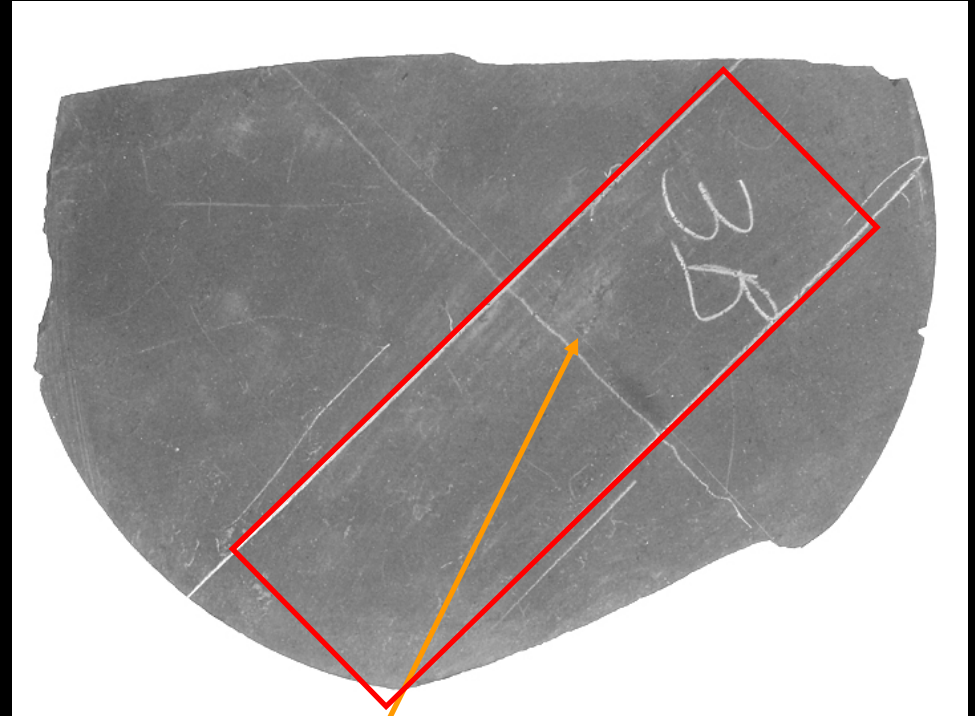
Sample Preparation

Step 1 Cut horizontal discs from core

Step 2 Mark and cut specimens



Sample from #2 T. P. Sims, 7,611 ft

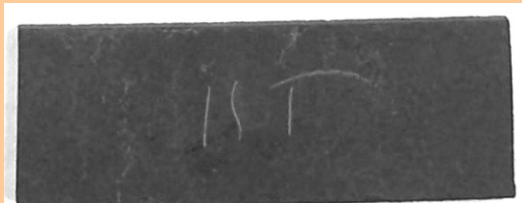
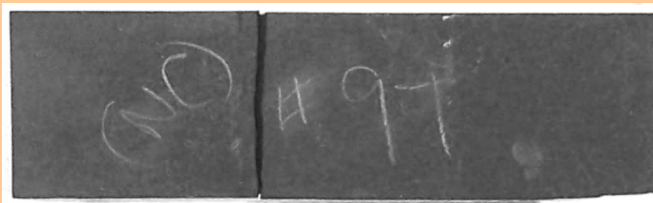
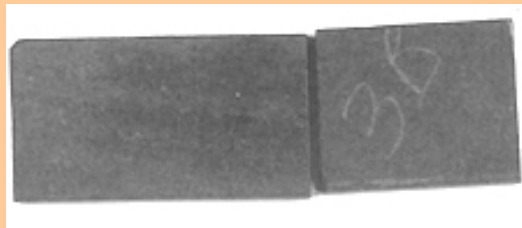
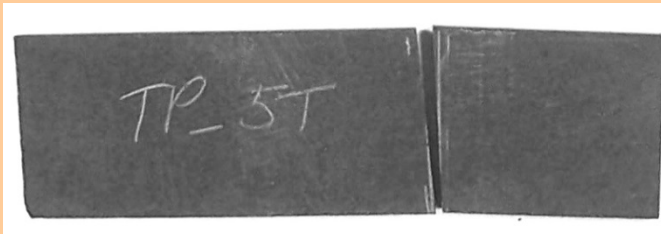
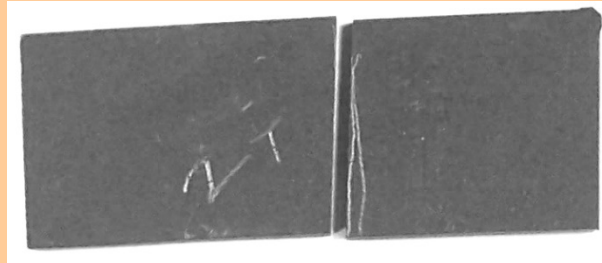


Natural, calcite-filled fracture

Tensile Testing Results

- Failure along fracture, EVEN THOUGH THESE ARE SEALED
- Specimens with natural fractures are half as strong as those without

Post-test specimens



Specimen

Rupture
(kpsi)

With natural fracture

2T

2.45

5T

3.86

3B

3.29

No natural fracture

9T

6.15

11T

6.41

Fracture Prediction

- How can we predict fractures in the interwell volume?
 - Outcrop analogs?
 - Geomechanical modeling
 - Seismic detection

Fractures in Outcrops

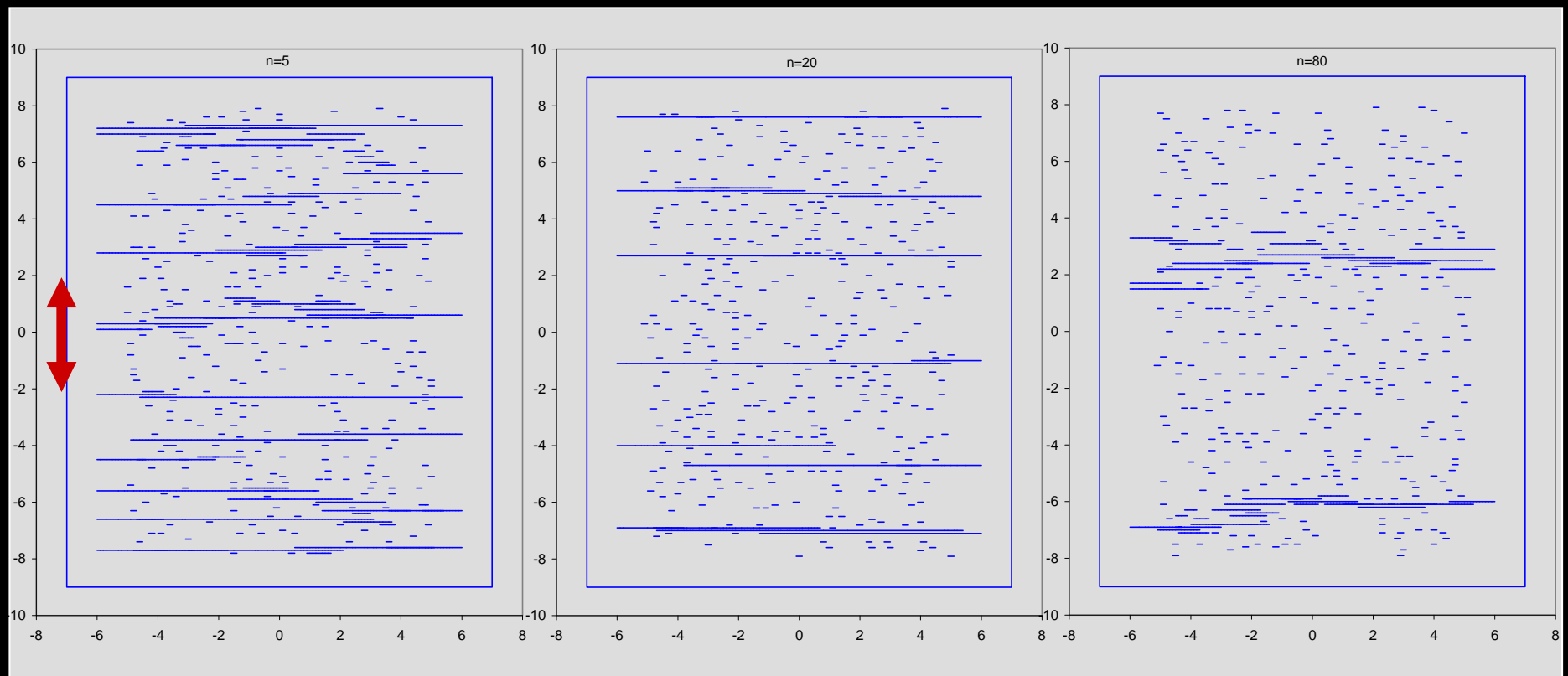
Useful Analogs for the Subsurface?

- Sometimes yes, mostly no
- Consider timing of fractures relative to burial
 - Stress history
 - Diagenesis of host rock
- Is there fracture cement? If not why not?
- How do lithologies of host rocks compare?
- How far away are the outcrops from the reservoir?

Subcritical Crack Index & Network Geometry

Geomechanical modeling by Jon Olson

Map views of fracture pattern models

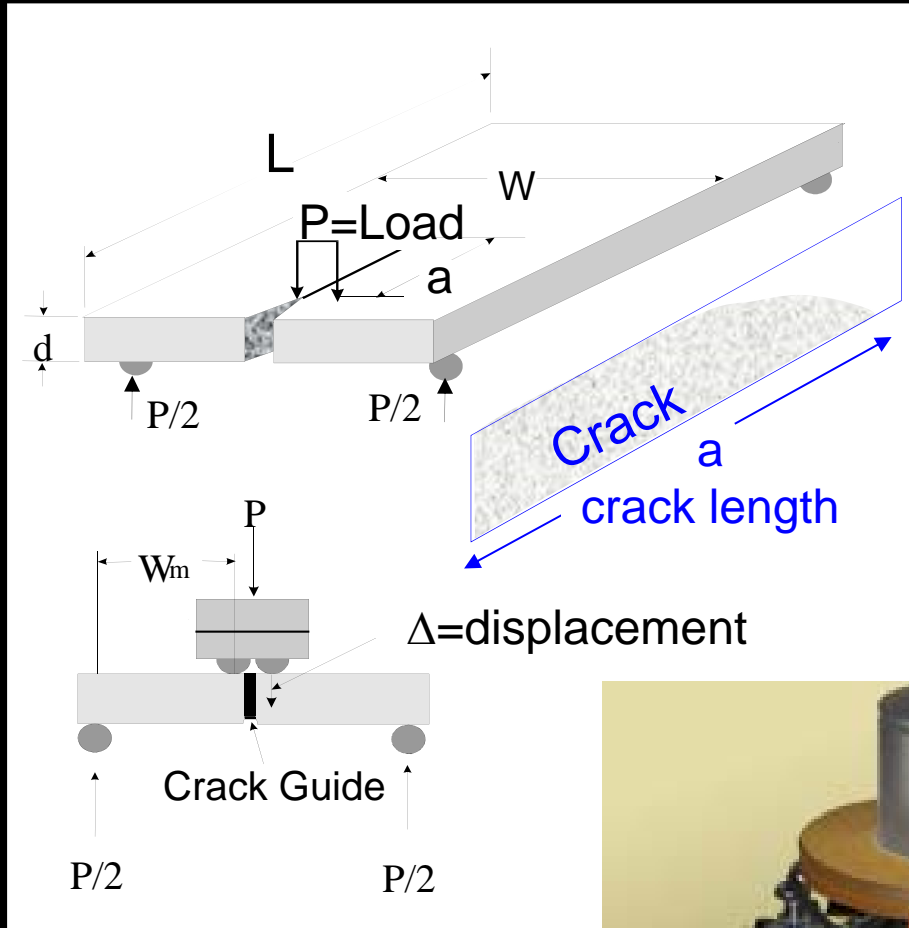


$n=5$

$n=20$

$n=80$

Measuring Subcritical Properties



- dual torsion test
- test in air, water, brine, oil, ...
- multiple tests per sample
- sample size 20 x 60 x 1.5 mm



JOINTS Modeling

Subcritical Index
and Fracture
Toughness:
Effect on
Fracture Patterns

Luke Fidler, MS
thesis
New Albany Shale

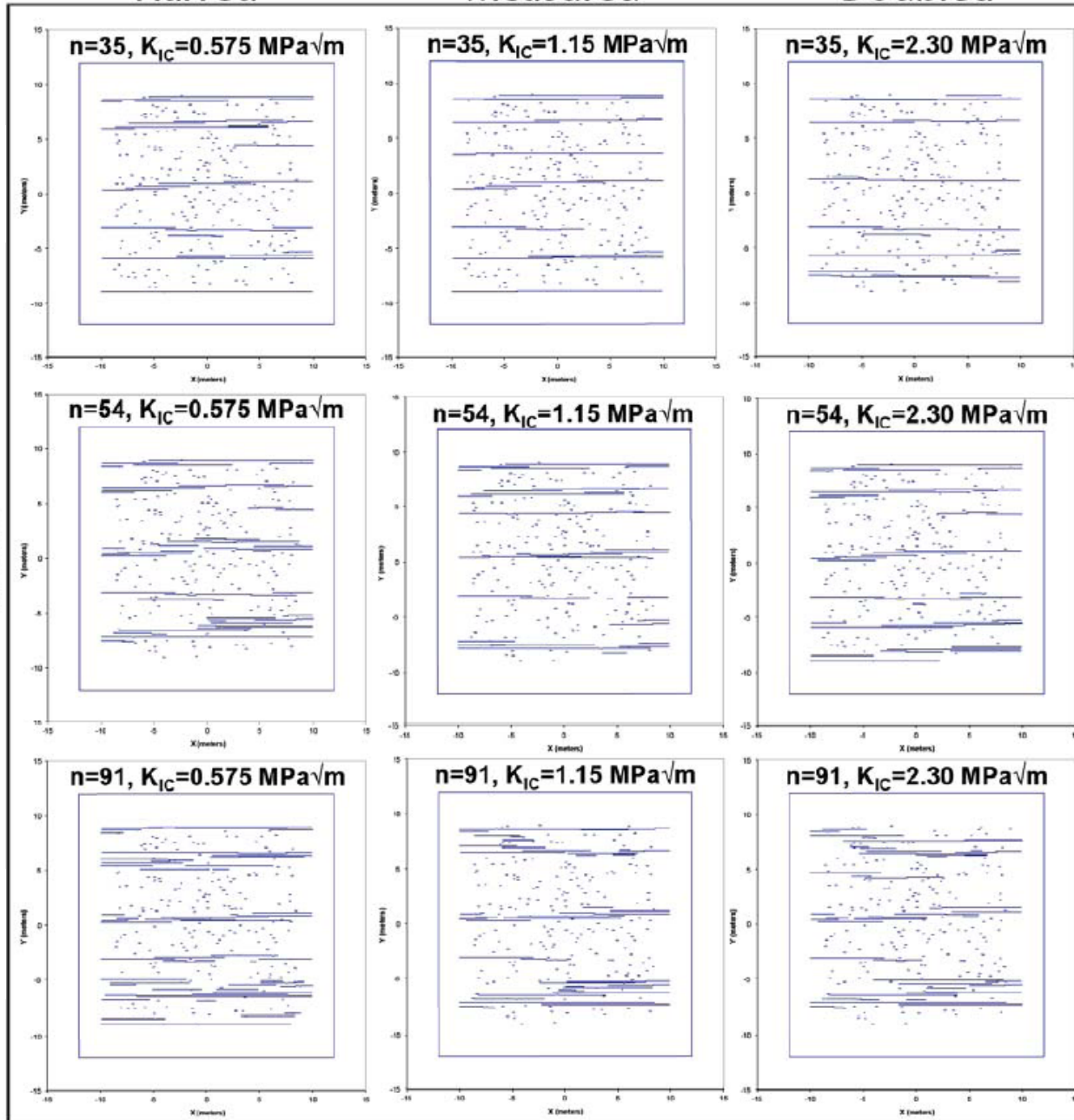
Fracture Toughness

Halved

Measured

Doubled

Subcritical Index
Low
Mean
High



Conclusions 1

- Natural fractures are abundant and have a role, even if they are sealed
- Distinct groups of fractures are present
 - Vertical (possibly more than one set)
 - Horizontal
 - Early compacted
 - Concretion-related
 - Faults
- Fracture cement geochemistry tied to burial history
 - insight into fracture/fluid flow in reservoir

Conclusions 2

- Fractures sampled in core may only represent part of population
 - Large fractures may be missed
 - Microfractures?
- Outcrops must be used carefully
- Geomechanical modeling provides testable prediction of frequency and spacing

Acknowledgments



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- GDL Foundation

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- Terry Engelder