Natural Fractures in Shales: Origins, Characteristics and Relevance for Hydraulic Fracture Treatments*

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Abstract

Most shales contain natural fractures. We review common fracture types and their characteristics based on core and outcrop studies from several different shales, including Devonian Woodford shales from the Permian basin and the Mississippian Barnett Shale of the Fort Worth basin. We measured the subcritical crack index of different shale facies. Geomechanical modeling using the index as an input parameter allows prediction of fracture clustering. To do this rigorously, however, requires an understanding of the diagenetic history as it relates to evolving mechanical rock properties, and the timing of fracturing. Thus it is necessary to integrate fracture work with other fundamental geologic knowledge. For example, there can be many different causes of fracturing over the lifetime of a shale. Some fracture sets in Woodford Shale cores are seen to have been deformed by compaction, whereas some others are later. The mechanical properties of the pre-compaction rock at the time of early fracturing are likely to be very different from those prevailing at a later, post-compaction stage. The resulting fracture patterns and sealing characteristics for the different fracture sets are likely to be different also. The relevance of natural fractures in these shale gas plays is that they are weak planes that reactivate during hydraulic fracture treatments. We have observed fracture planes only half as strong as the host rock during tensile testing. The first step towards understanding whether hydraulic fractures will be affected in a given zone is to predict the natural fracture patterns and measure the in situ stress.

Natural fractures in shales: origins, characteristics and relevance for hydraulic fracture treatments

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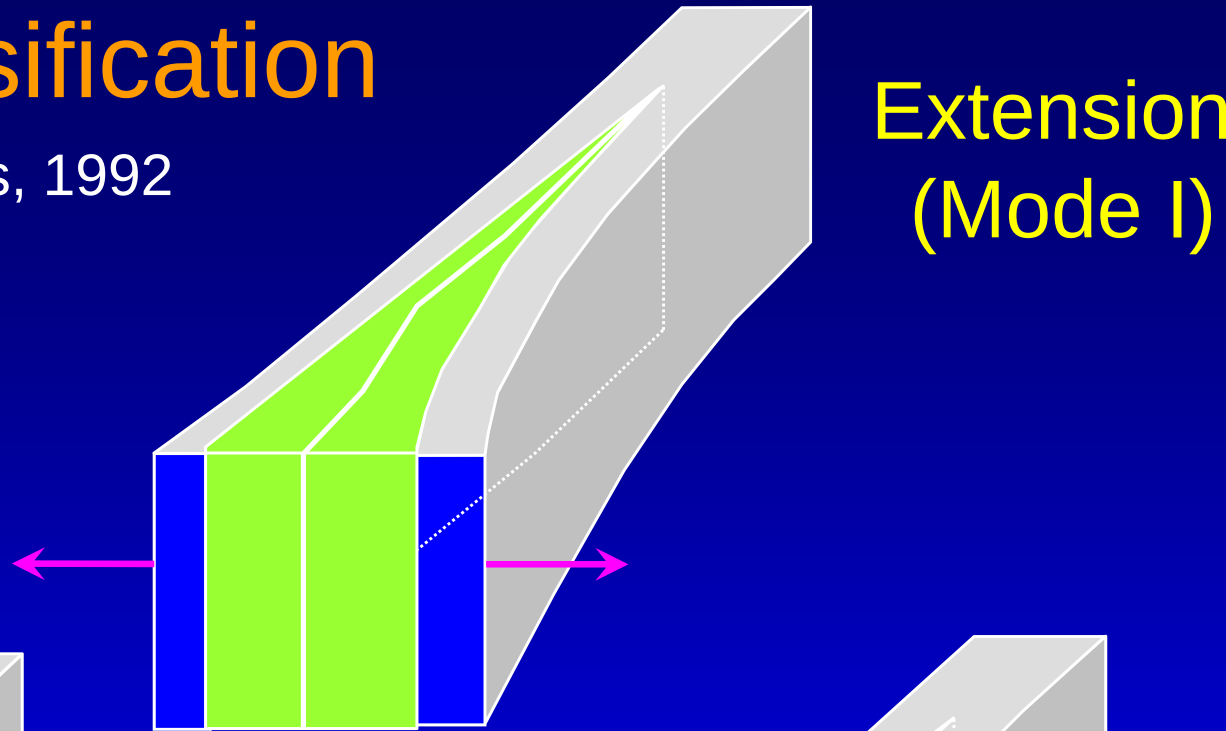
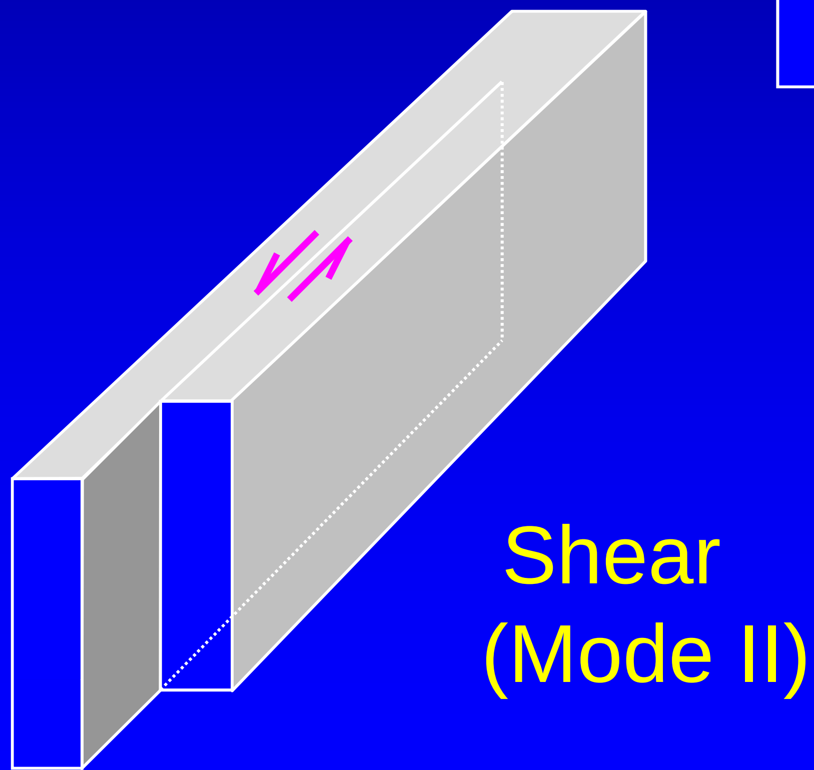
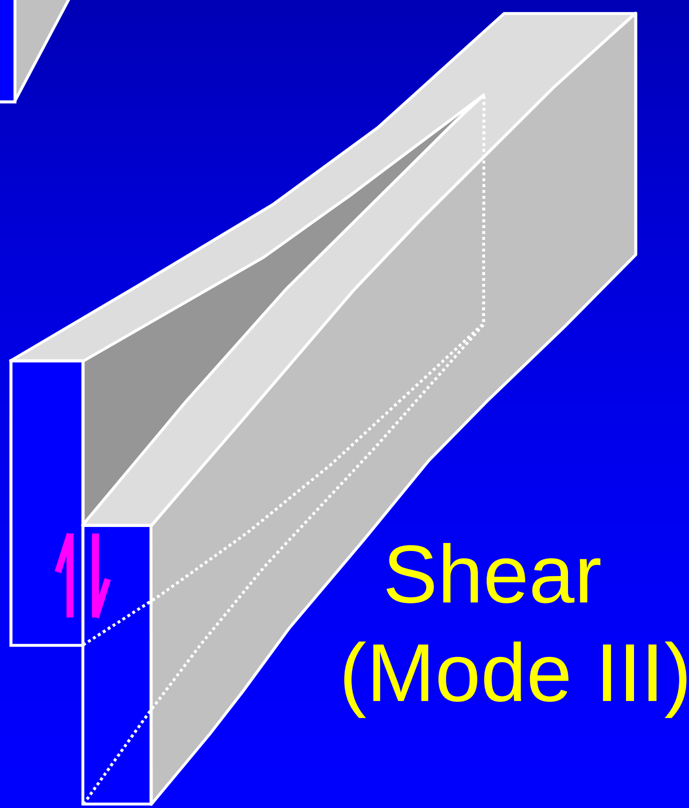
Fracture Classification

Twiss and Moores, 1992

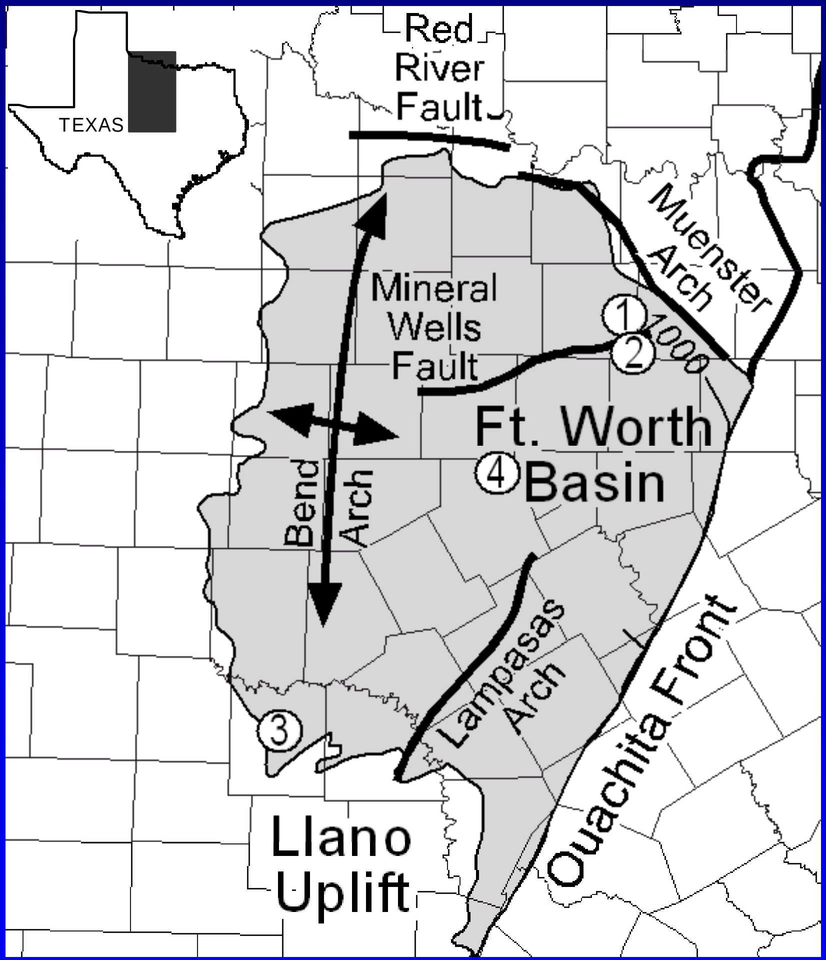






Origin of Opening-Mode Fractures

- Regional burial plus hydrocarbon generation
- Regional, tectonic stress
- Differential compaction
- Local effects of major faults and folds
- Sag features associated with underlying karst
- Stress release during uplift



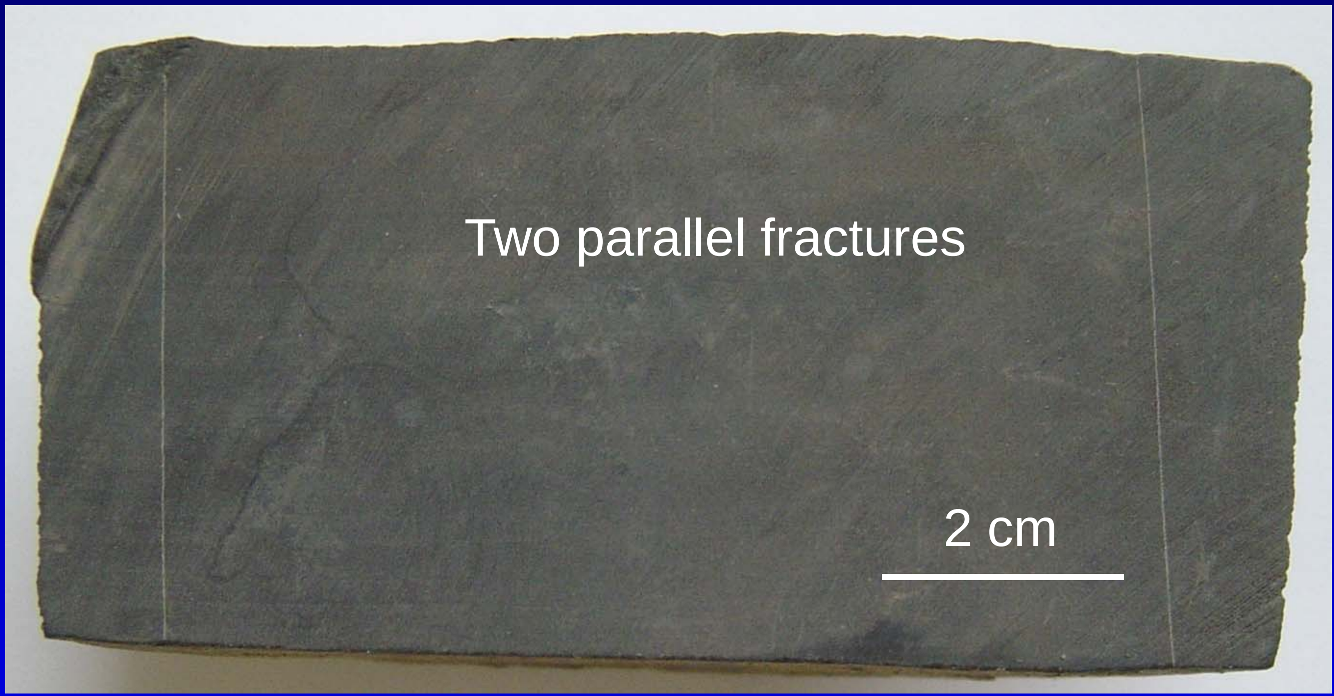
En Echelon Opening-Mode Fractures

- Steeply dipping
- Right- and left-stepping examples
- Sealed with calcite

Devonian Woodford Fm., Permian Basin

Pan American Seagler #1-A, Cochran Co.

Northwestern Shelf, dark, non-fissile mudstone



Fractures in this core are:

Tall (> 0.5 m)
Narrow (< 0.05 mm)
Sealed with calcite
Undeformed

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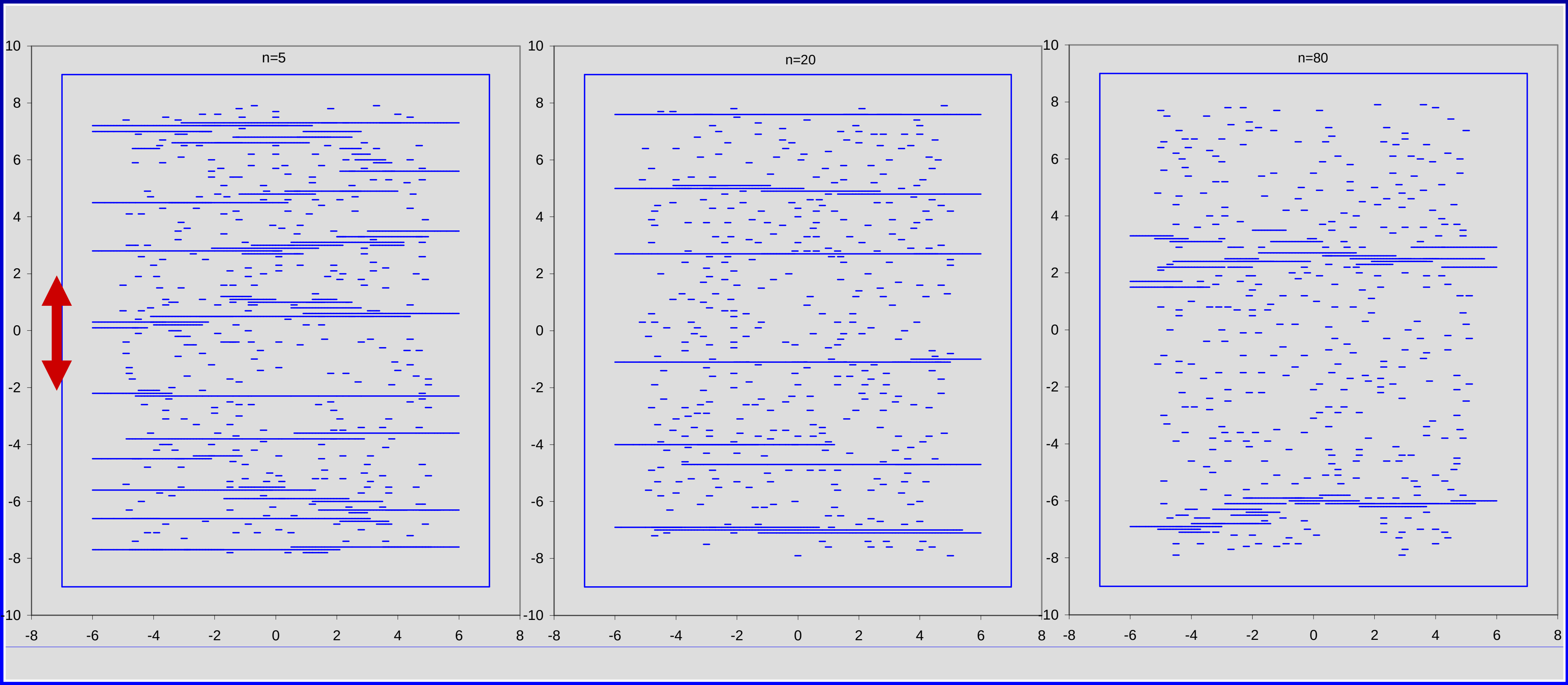
AAPG Annual Meeting San Antonio, April 2008

Subcritical Crack Index & Network Geometry

Geomechanical modeling by Jon Olson (FRAC)

Map views of fracture pattern models



n=5 n=20 n=80

Subcritical Crack Index Results

Core samples from #2 T. P. Sims

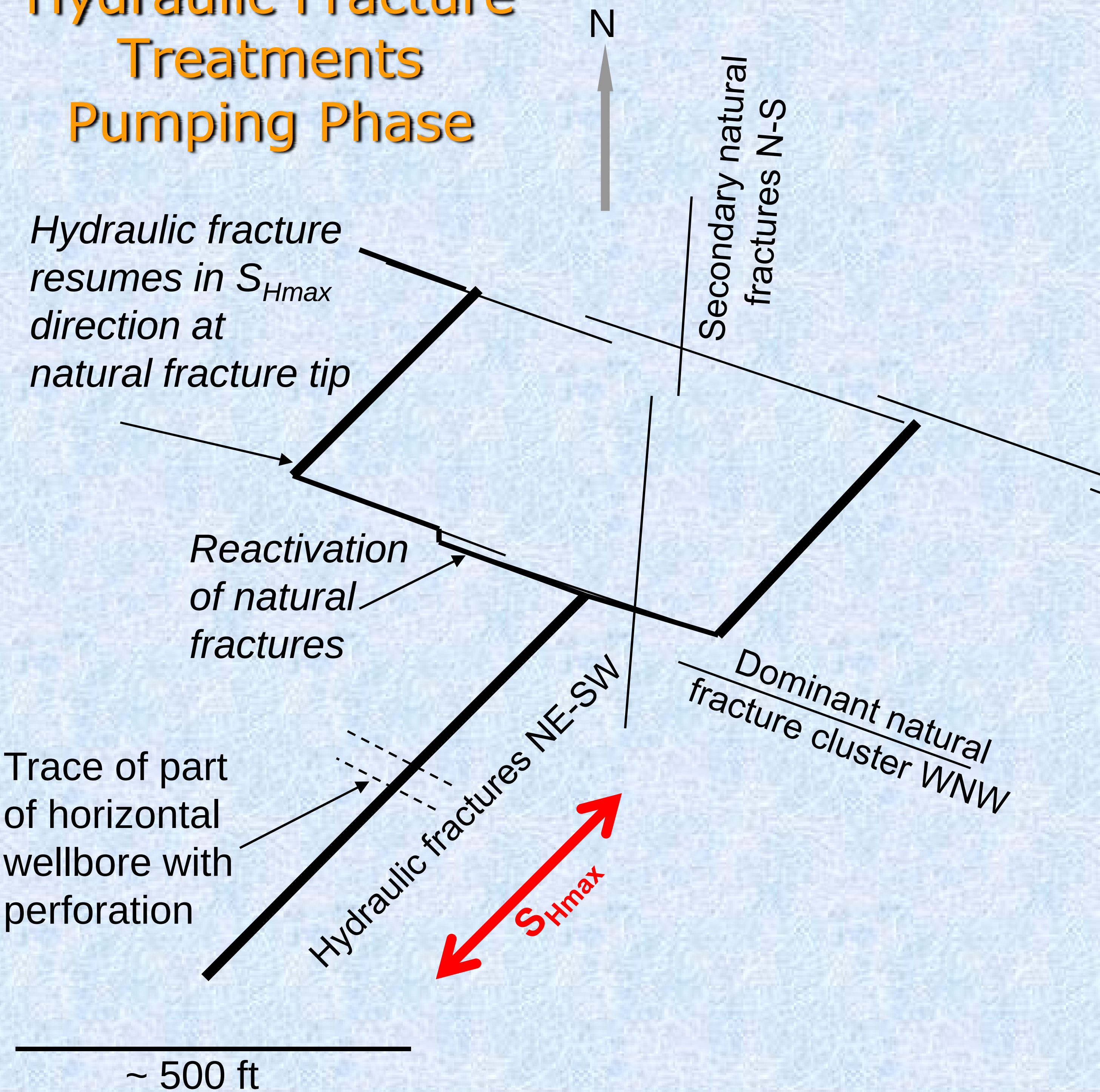
Depth (ft)	Specimen	Index	Average
7,692	1-8B1	227	
	1-10B1	232	
	1-12A1	326	
	1-13B1	318	276 ± 54
7,749	2-7B	145	
	2-7B3	109	
	2-7B4	111	122 ± 20

High subcritical crack index

Fractures strongly clustered

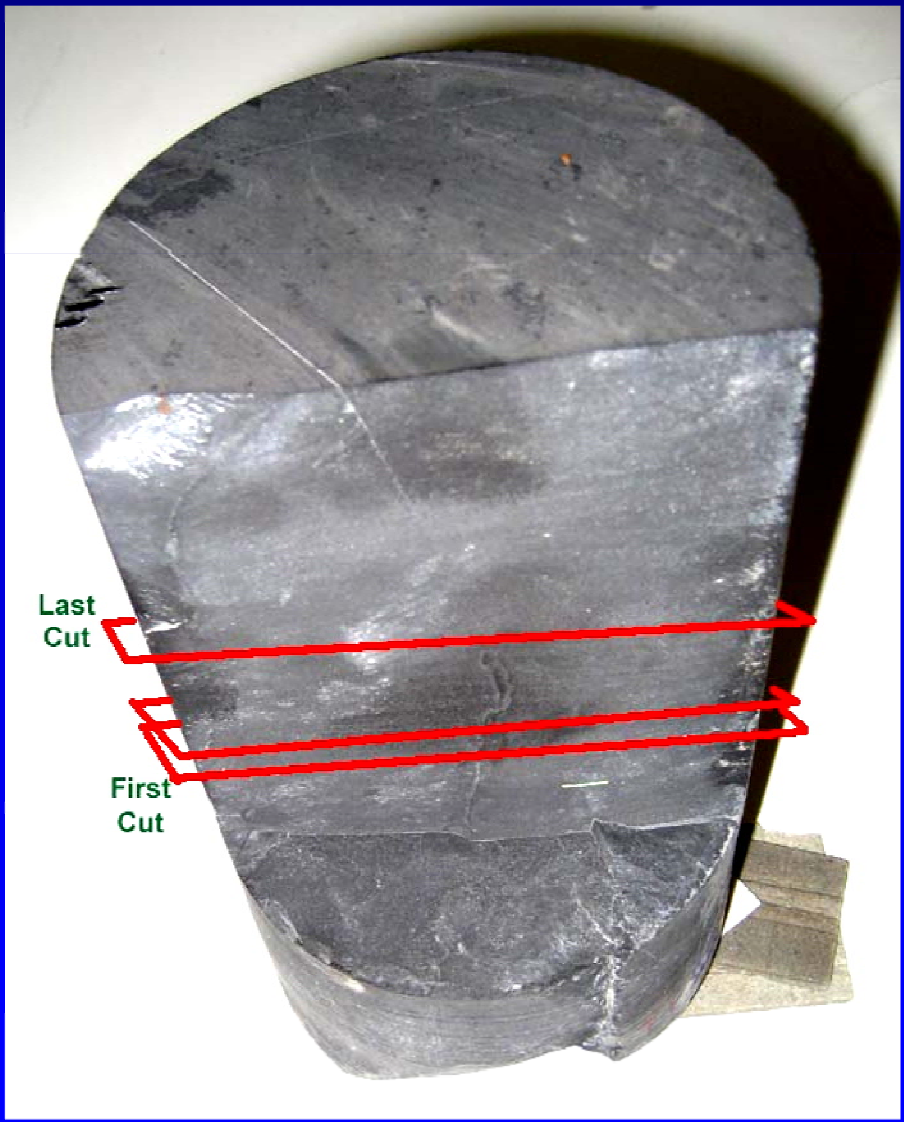
En echelon arrays

Hydraulic Fracture Treatments Pumping Phase



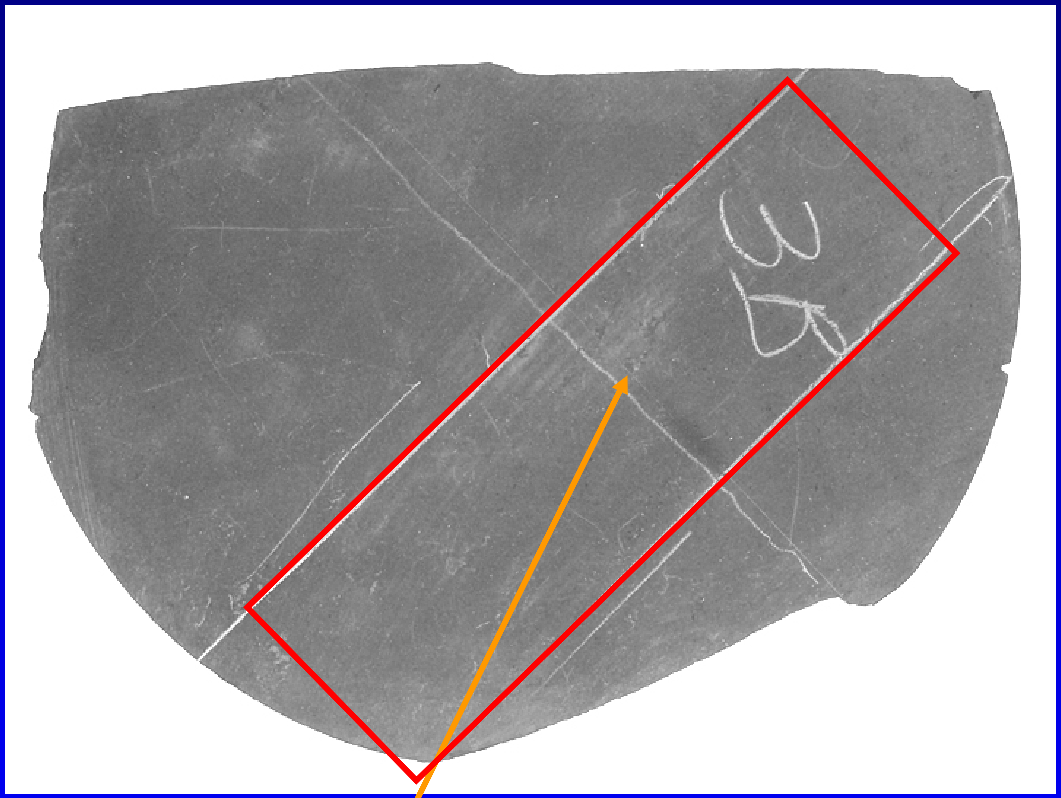
Tensile Testing
Sample Preparation

Step 1 Cut horizontal discs from core



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

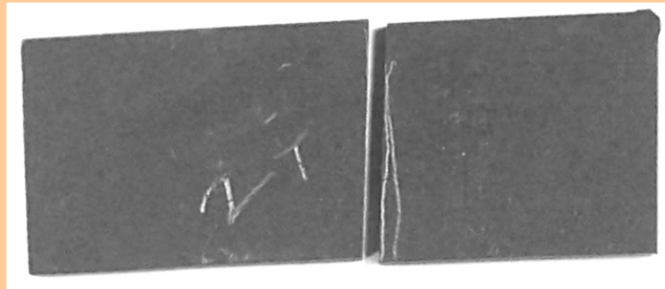
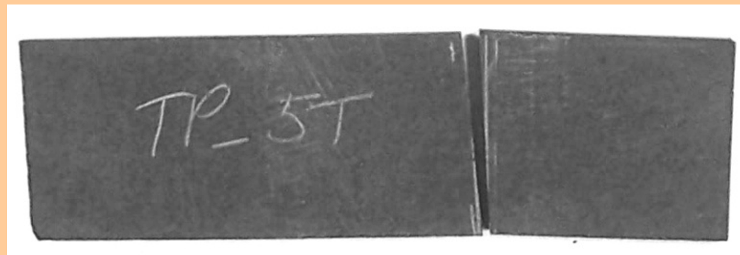
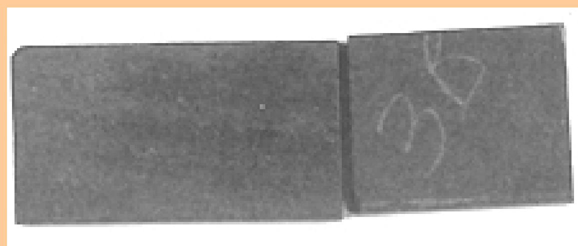
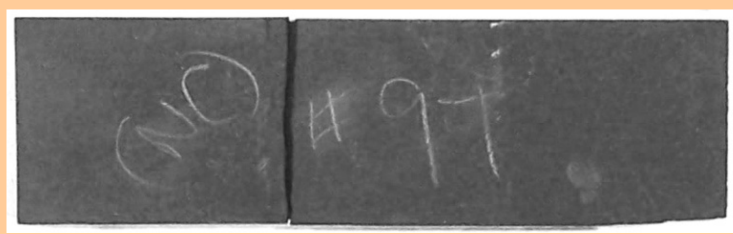
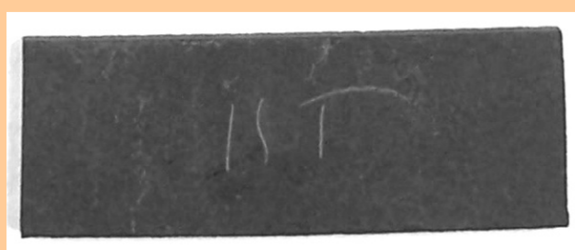
Step 2 Mark and cut specimens



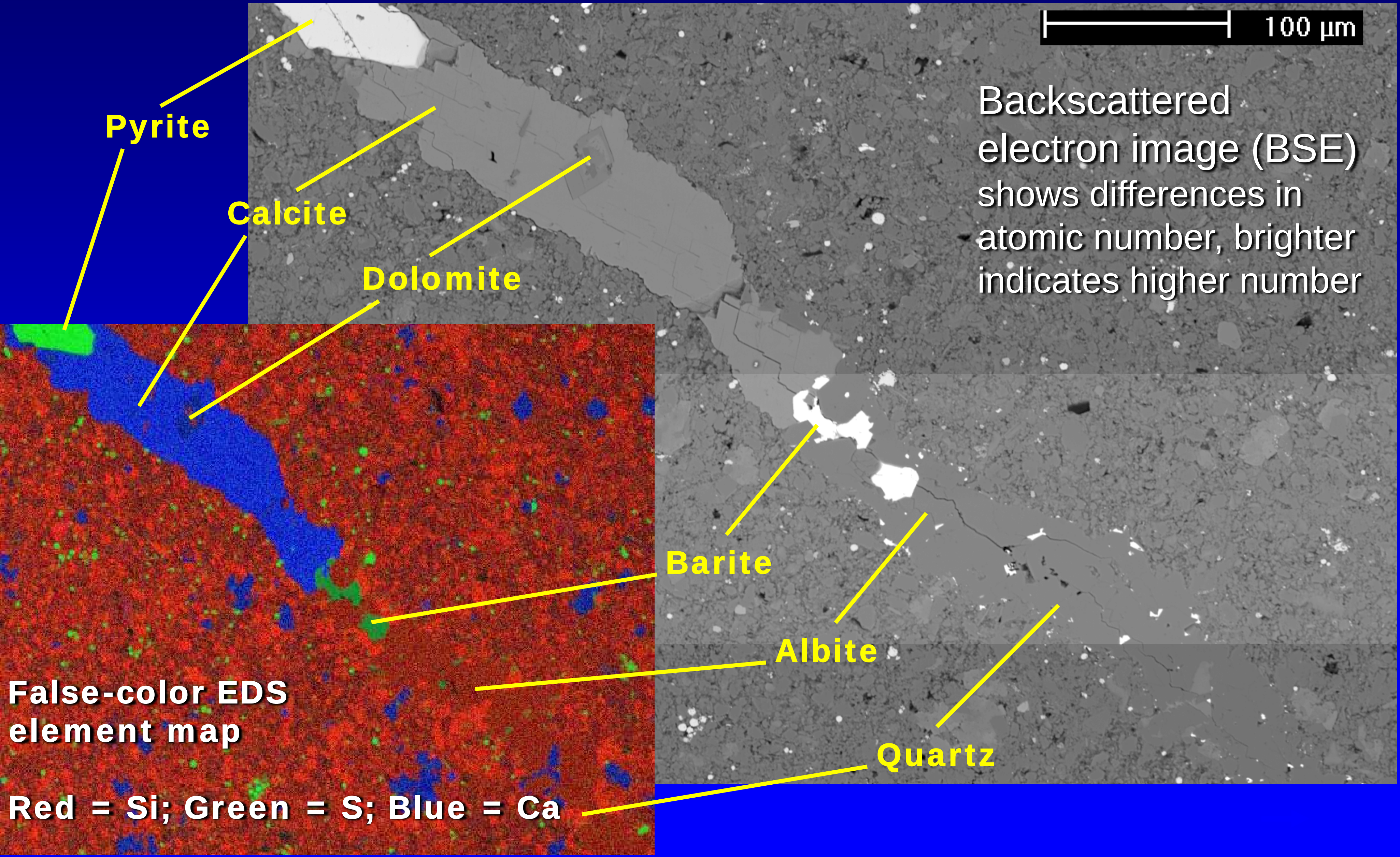
Natural, calcite-filled fracture

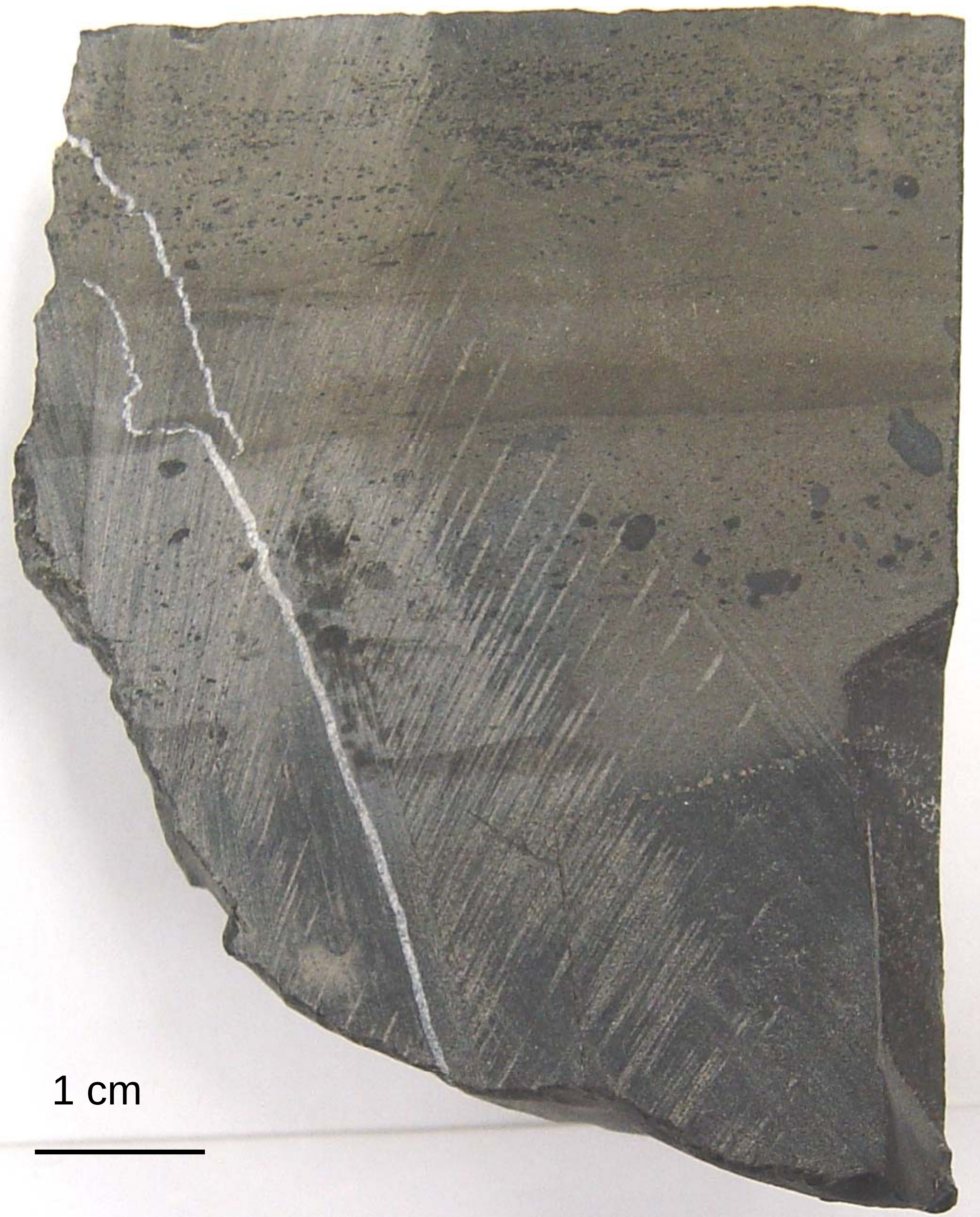
Tensile Testing
Results

- Failure occurs along fracture, EVEN THOUGH THESE ARE SEALED
- Specimens with natural fractures are half as strong as those without
- Failure occurs at various positions along length of test specimen

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

SEM Imaging of Fractures





Early Fractures and Differential Compaction

Woodford Shale, Permian Basin

Fracturing styles
Bedding-parallel fractures

Timing??

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

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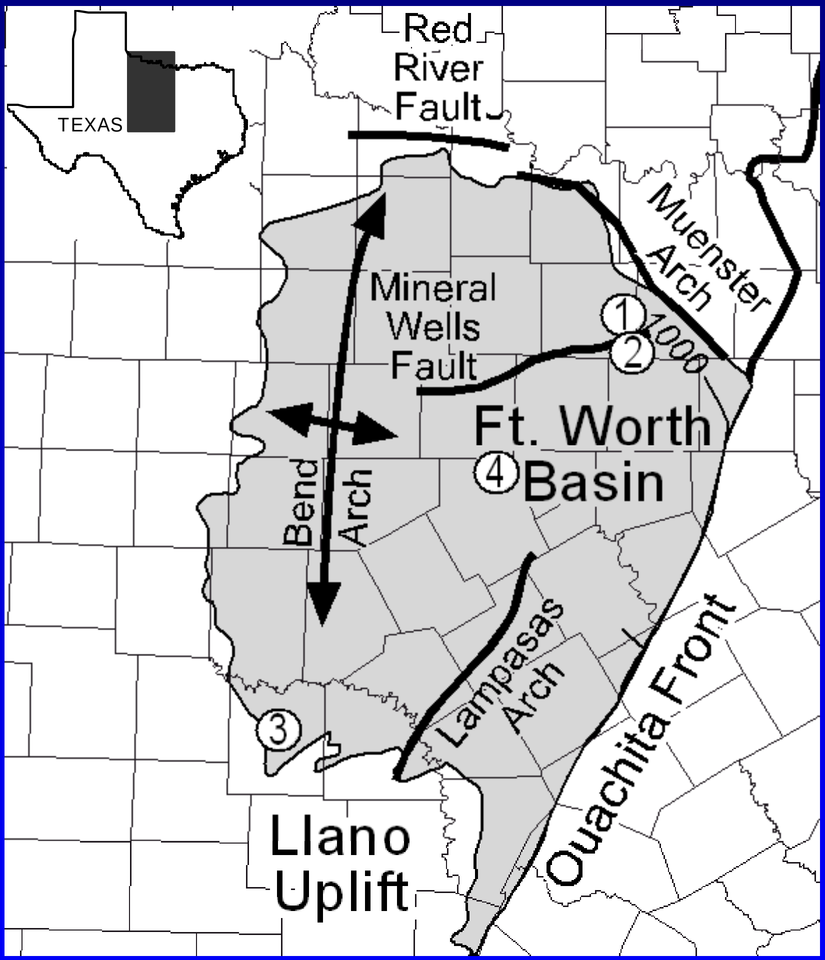
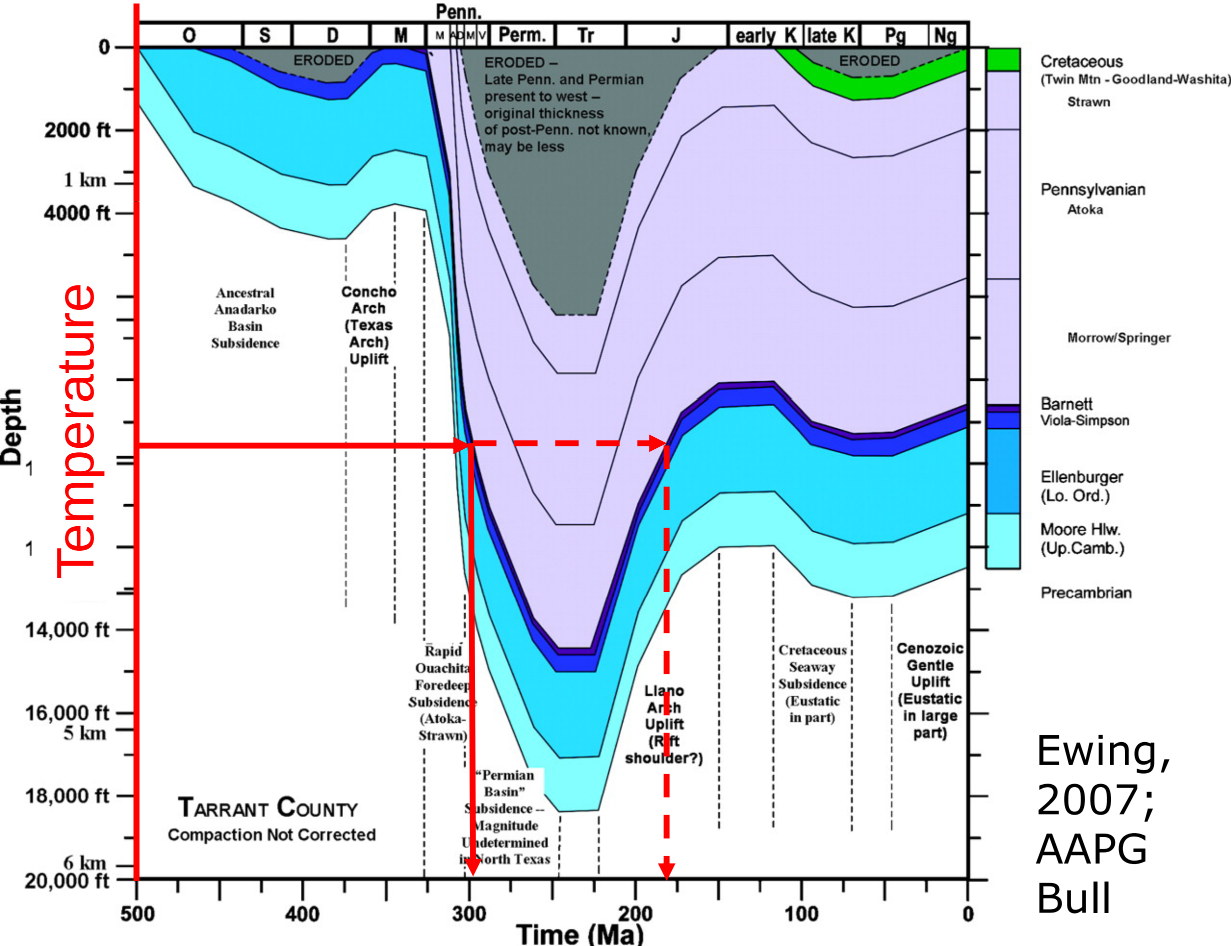
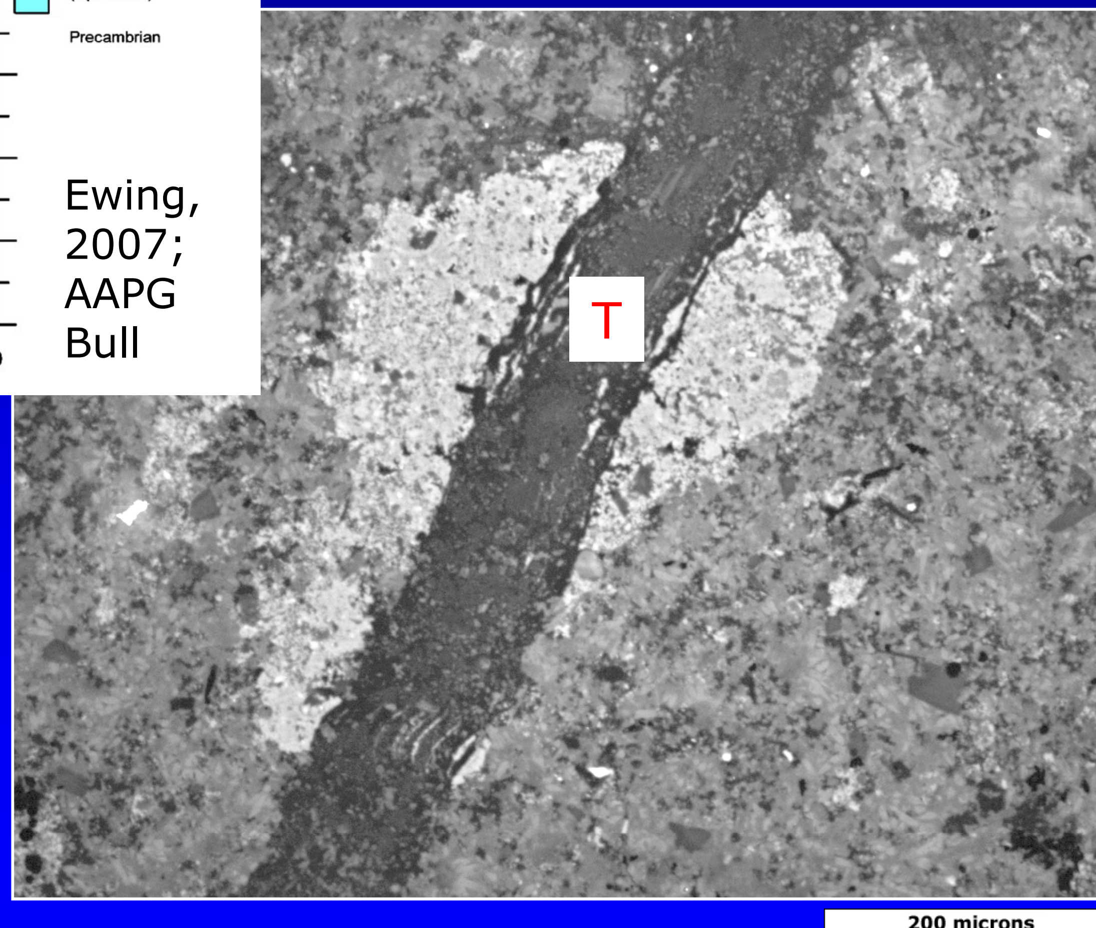


Crack-Seal Texture

Synkinematic cement fluid inclusions plus burial history may give fracture timing



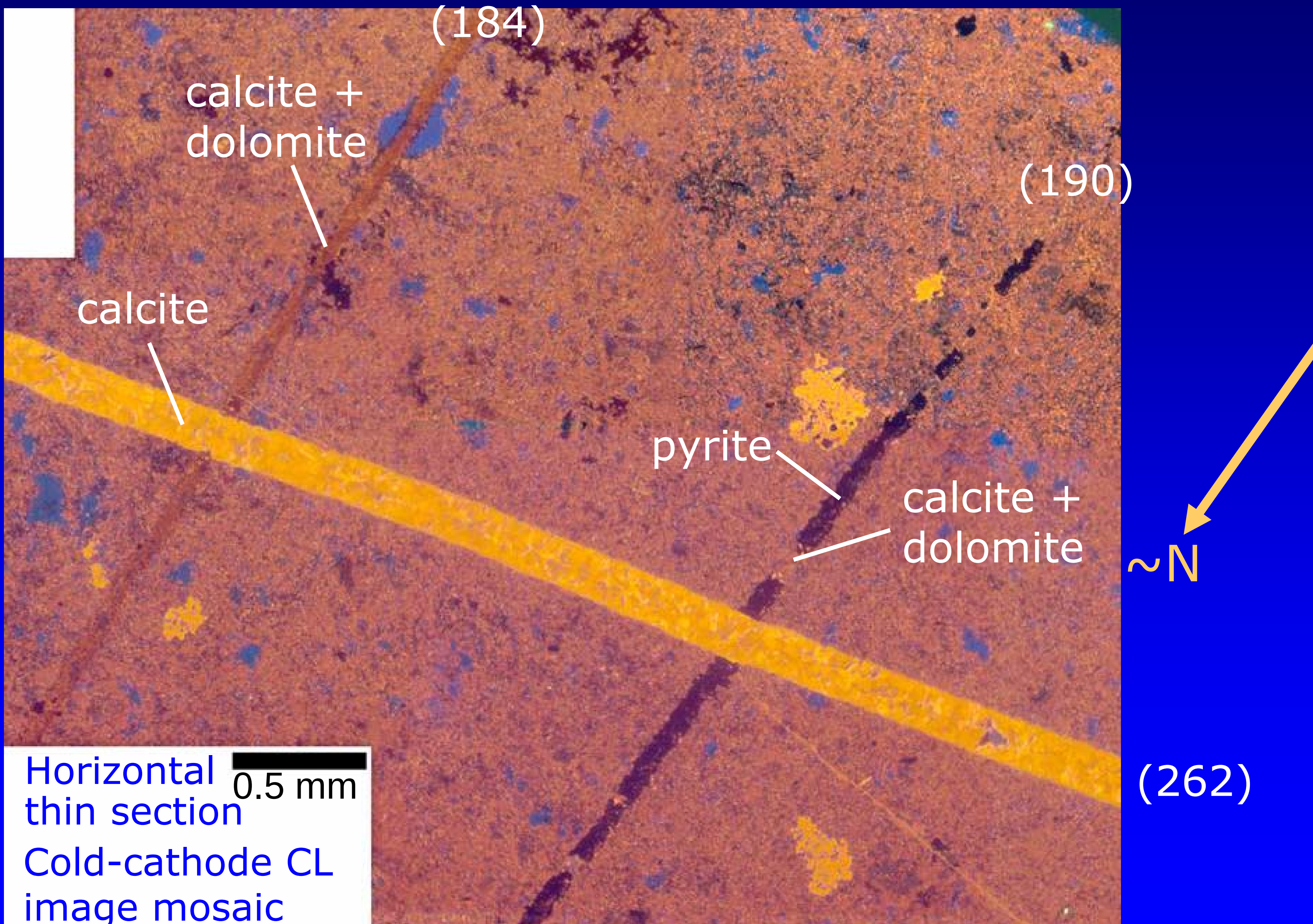
Ewing, 2007; AAPG Bull



Time 1 or Time 2 ?

Early NS-trending fracture in dolomitic layer (UV-blue CL)

Crosscutting Relationships



Conclusions
Barnett Shale, Fort Worth Basin

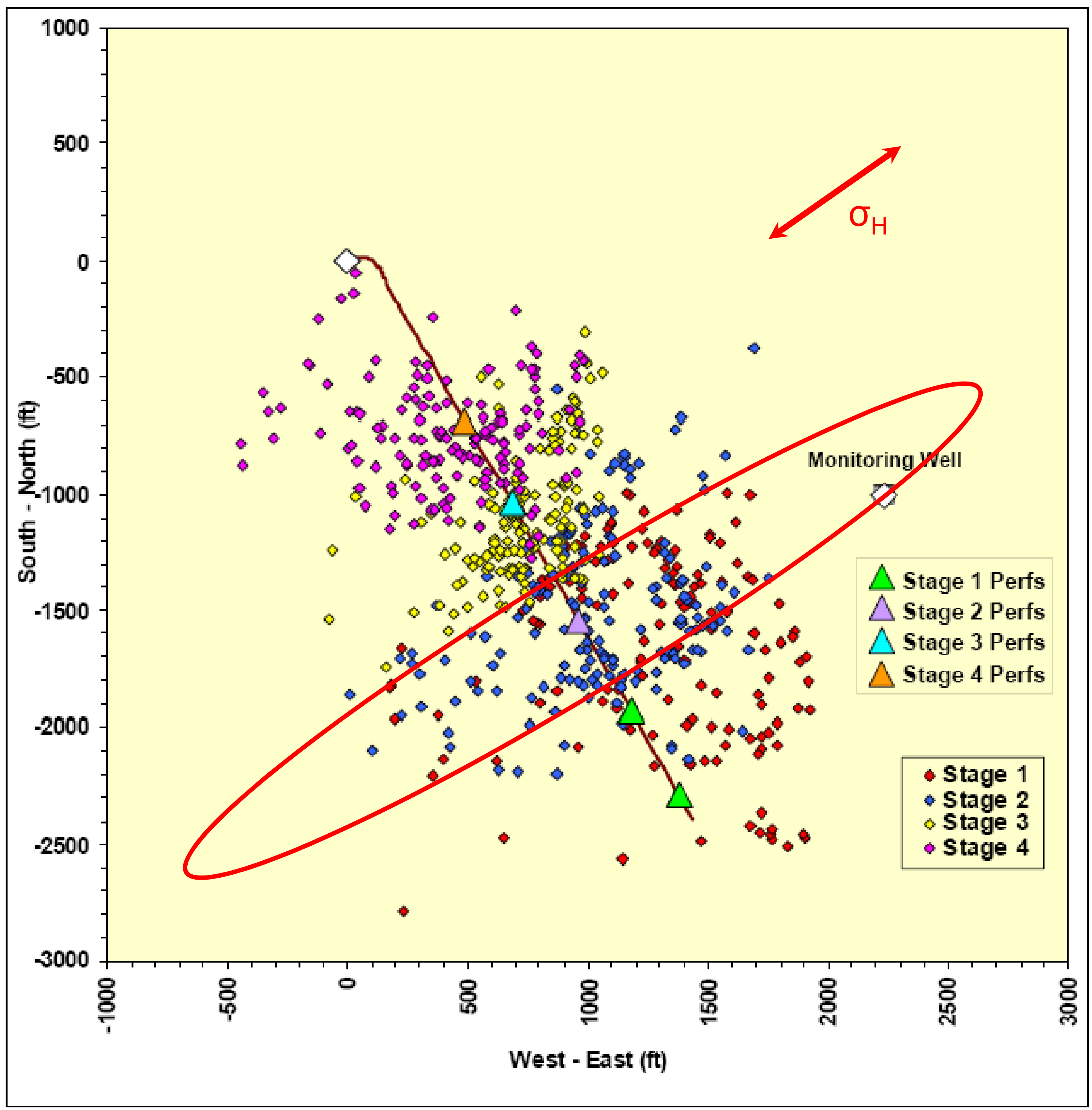
- Many narrow, sealed natural fractures
  - Intrinsic fracture storage capacity low, BUT,
  - Reactivate during hydraulic fracturing
- Fractures are likely clustered
  - High subcritical index
  - Spacing of clusters on order of hundreds of meters
- Fractures may act as weak planes
  - Tensile strength half that of host rock for Barnett Shale samples
  - Need to test combinations of fracture mineral fill/host rock composition

Conclusions
Fractures in Shale-Gas Reservoirs

- Host ‘shales’ highly variable
- Fracture types highly variable
  - Multiple origins
- In situ stress variable
  - On regional scale
  - On local scale
- Fracture importance
  - Positive or negative for hydraulic fracture treatments
  - Positive for unstimulated wells

Next Phase
Fundamental Goals

1. To know which processes operated, when, and to what extent fractures were produced
2. To predict fracture attributes and recognize differences for different fracture sets
3. To predict how fracture attributes will affect hydraulic fracture treatments



Map of microseismic events during staged hydraulic stimulation of horizontal well

Figure from Waters et al., 2006, SPE 103202

Barnett Shale and Austin Chalk

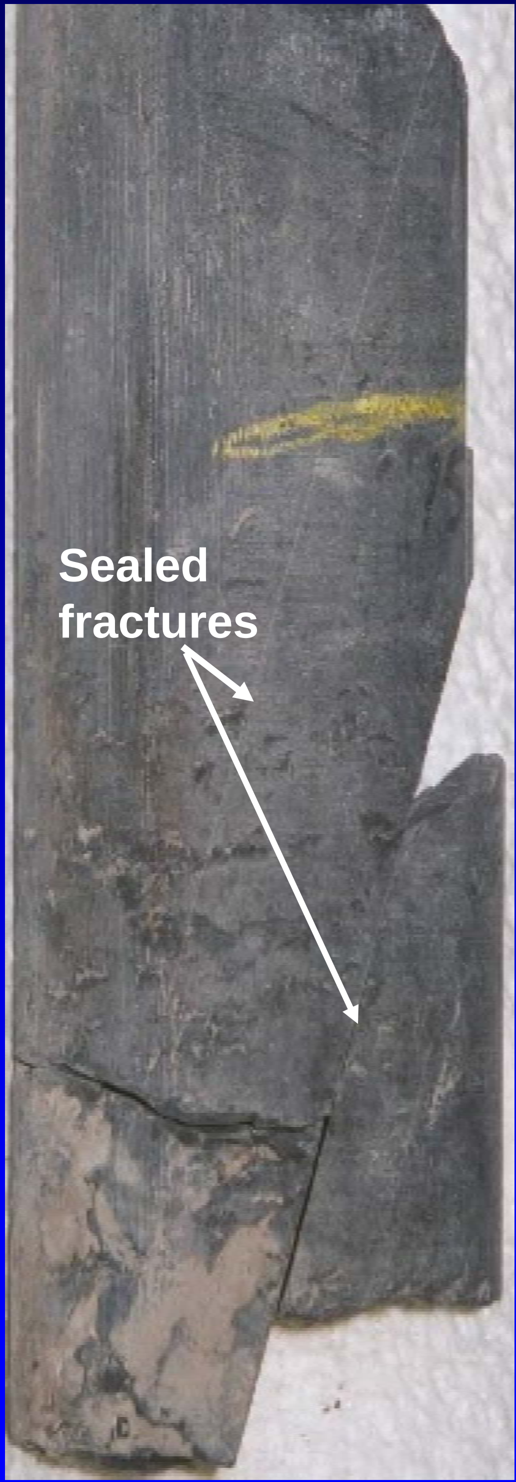
Mechanical Rock Properties

Lithology	Young's modulus (static) (GPa)	Poisson's ratio	Subcritical crack index (in air)
Barnett 'Shale'	† 33.0	* 0.2-0.3	† 109-326
Other shales	** 4.5 – 61.0	** 0.03 – 0.3	Similarly high
Austin Chalk	** 48.0	** 0.1-0.4	†† 95-124
Other chalks	** 25.6 – 65.0	** 0.24	no data

† Data from Gale et al. (2007)
†† Data from Holder et al. (2001)
* Data from Hill (1992)
** Data from Rijken and Cooke (2001)

Comparison of fractures in Barnett Shale and Austin Chalk

(Fine grained mudrock with carbonate layers & chalk with marl layers)

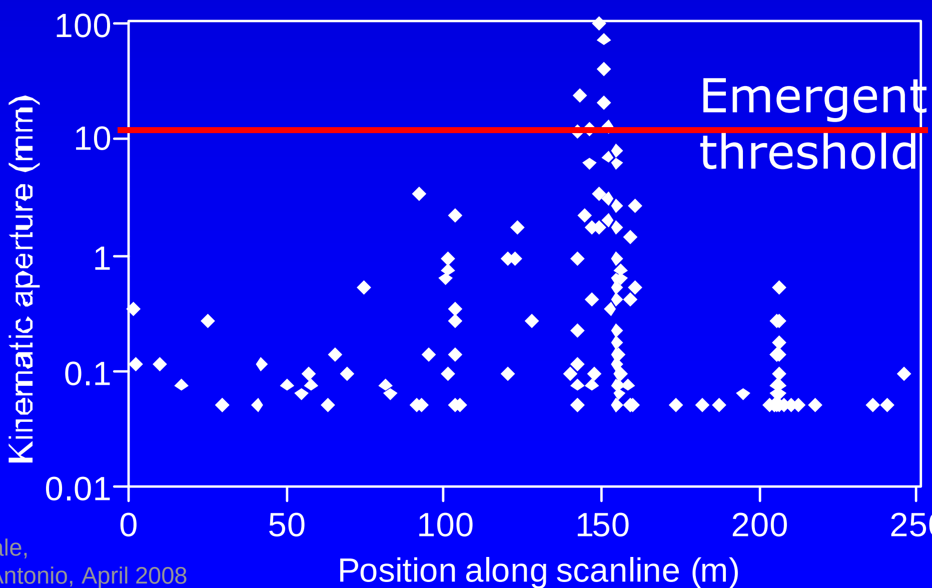


Austin Chalk

Barnett Shale

Narrow sealed fractures

Large open fractures Austin Chalk outcrop



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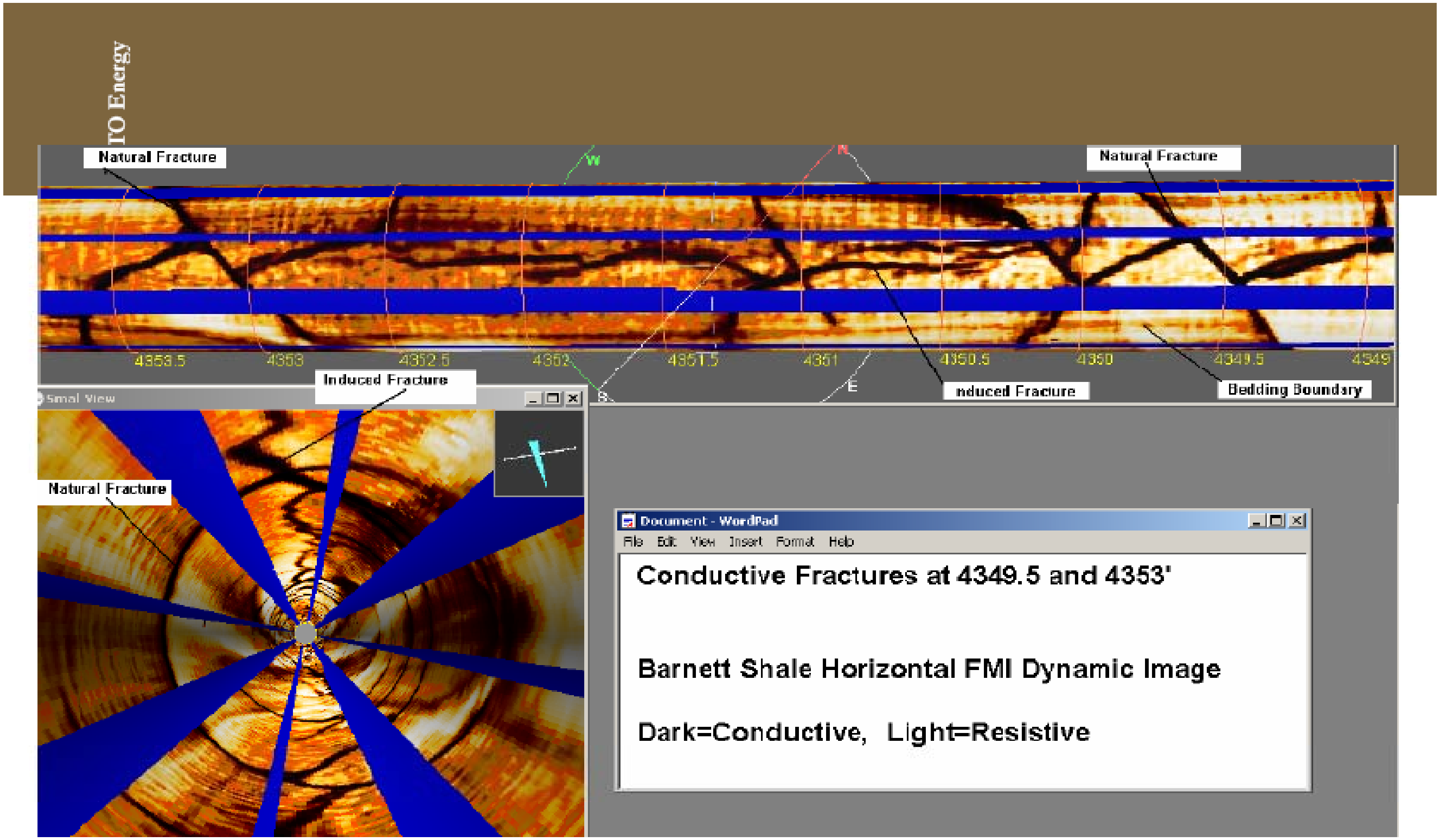
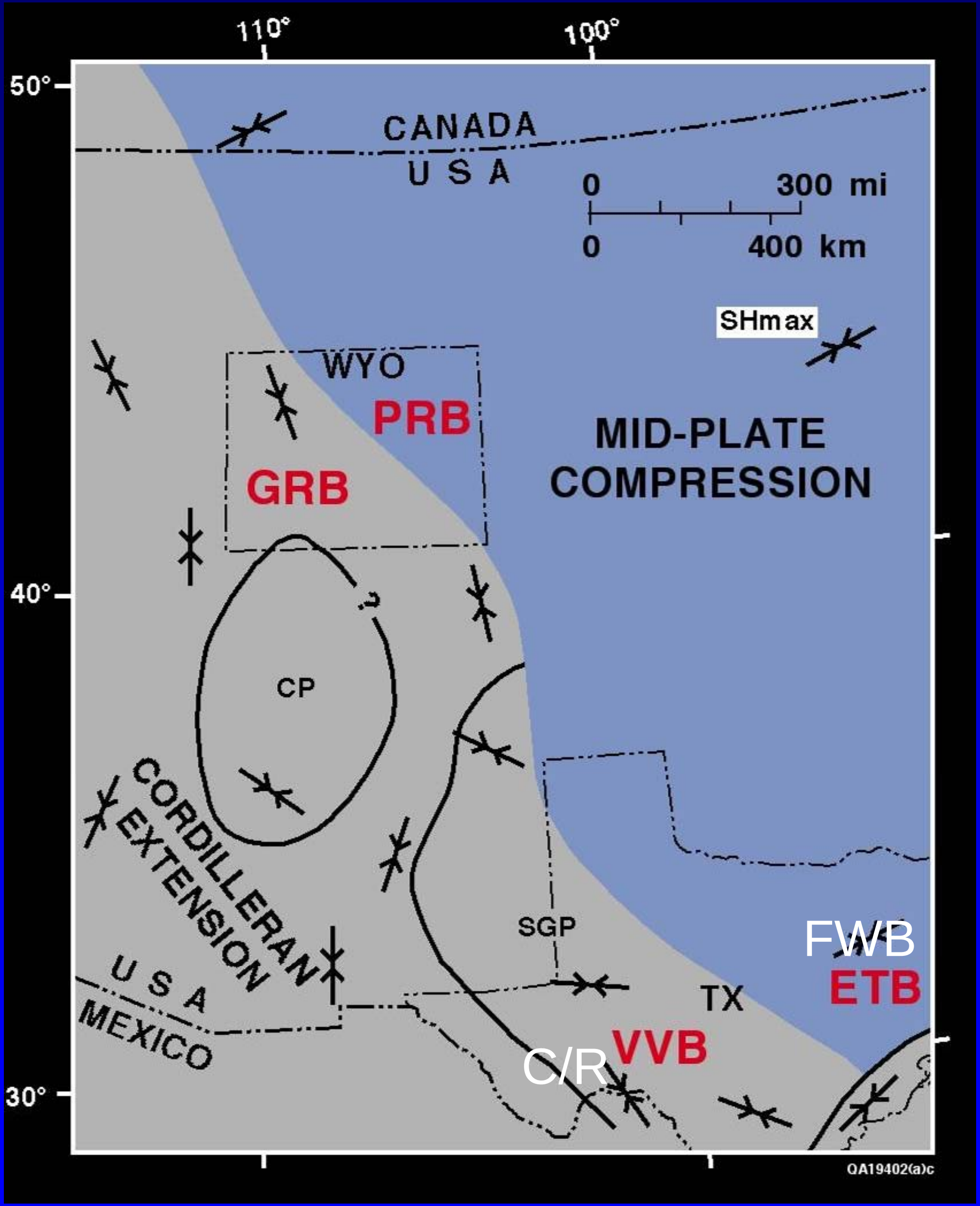
Open Natural Fractures in Image Logs?



Copy of slide from Andrée Griffin, XTO Energy
Horizontal Drilling in the Barnett Shale, AAPL April 2006

In situ stress



Map modified from Zoback and Zoback (1989) and Laubach et al. (2004)

Present day in situ stress controls hydraulic fracture orientation

Fort Worth Basin
- in Mid-Plate Compression province

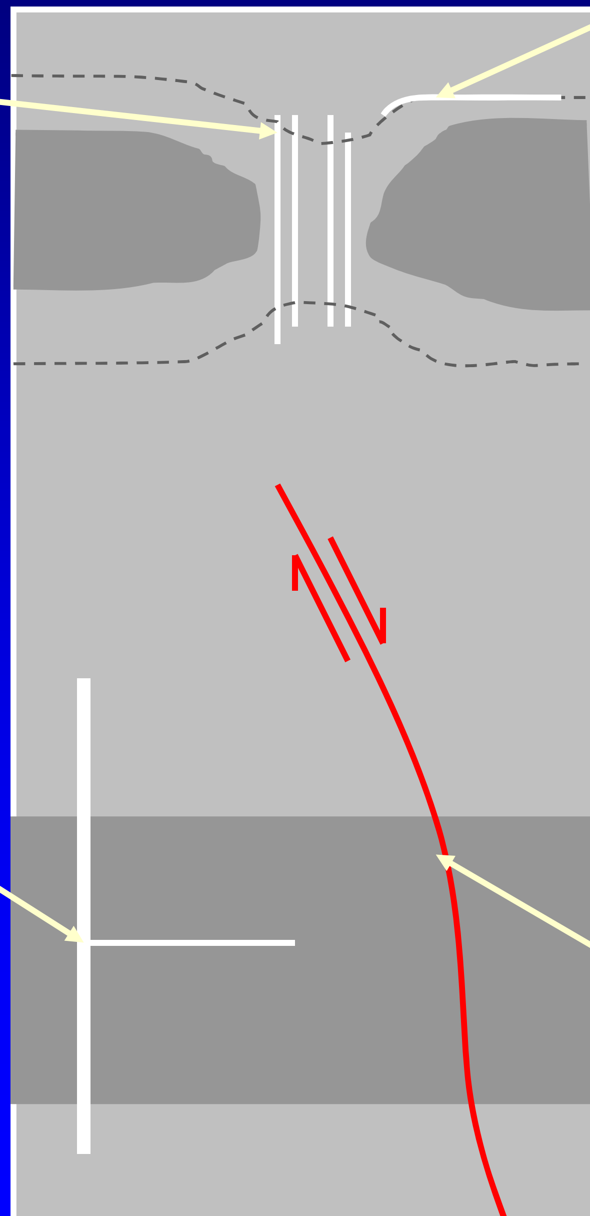
West Texas, Permian Basin
- at boundary between Cordilleran Extension and Southern Great Plains (SGP) provinces
- need to carefully establish S_{Hmax}

Fracturing styles

Adjacent to carbonate concretions and layers

Steep fractures in 'neck' region between concretions

Steep fractures may branch along bedding planes



Bedding-parallel fractures track deformed layers

Small faults change dip across layers

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