Natural Fractures and its Implications to Engineering Design*

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Abstract

The successful development of unconventional fields heavily depends on how efficiently hydraulic fractures stimulate in-situ open fracture networks. With a field case and outcrops, this presentation demonstrates the steps of identifying open natural fractures, their effect on rock heterogeneity, and the challenges to well planning and hydraulic fracturing design. It highlights the importance of integration of multiple disciplines including geology, geophysics, and engineering when developing unconventional reservoirs.

Conclusions

- Sedimentary rock always has discontinuities.
- In-situ natural fracture is critical in integrated development of unconventional reservoir: no fracture, no commercial play.
- Identifying open fractures needs to incorporate seismic, logs, cores, outcrops, with well test results in order to deliver a map of permeability.
- Natural fractures impact various engineering applications.
    - Wellbore stability in drilling
    - Open hole or cased hole completions
    - Fracture propagation and containment in stimulation
    - Stimulated/enhanced volume in production and reservoir engineering

Natural Fractures and its Implications to Engineering Design

Dr. Gang Han
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July 16, 2013

Outline

- Characterize In-Situ **Open** Fractures
  - Outcrop
  - Seismic
  - Logs
  - Core
  - **Well Test (PTA or RTA)**
- Engineering Implications
  - Reservoir Engineering
  - Drilling
  - Completion
  - Hydraulic Fracturing

Mapping In-Situ Fractures - Outcrops

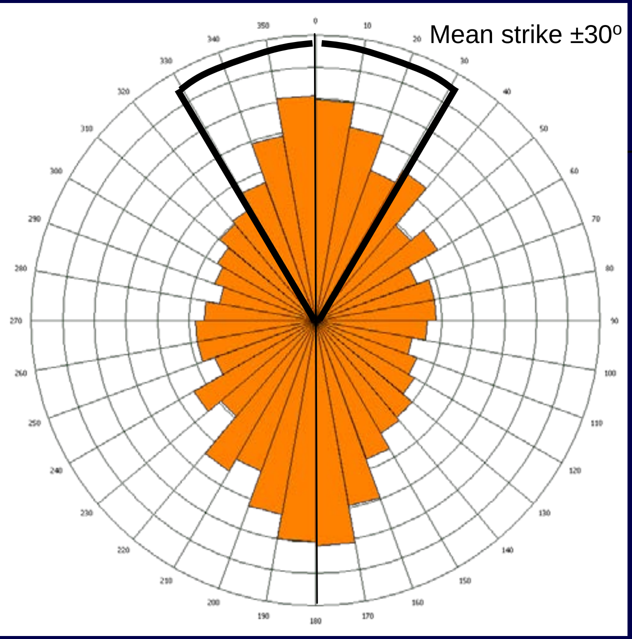
Courtesy of Dr. Paul Nickolson

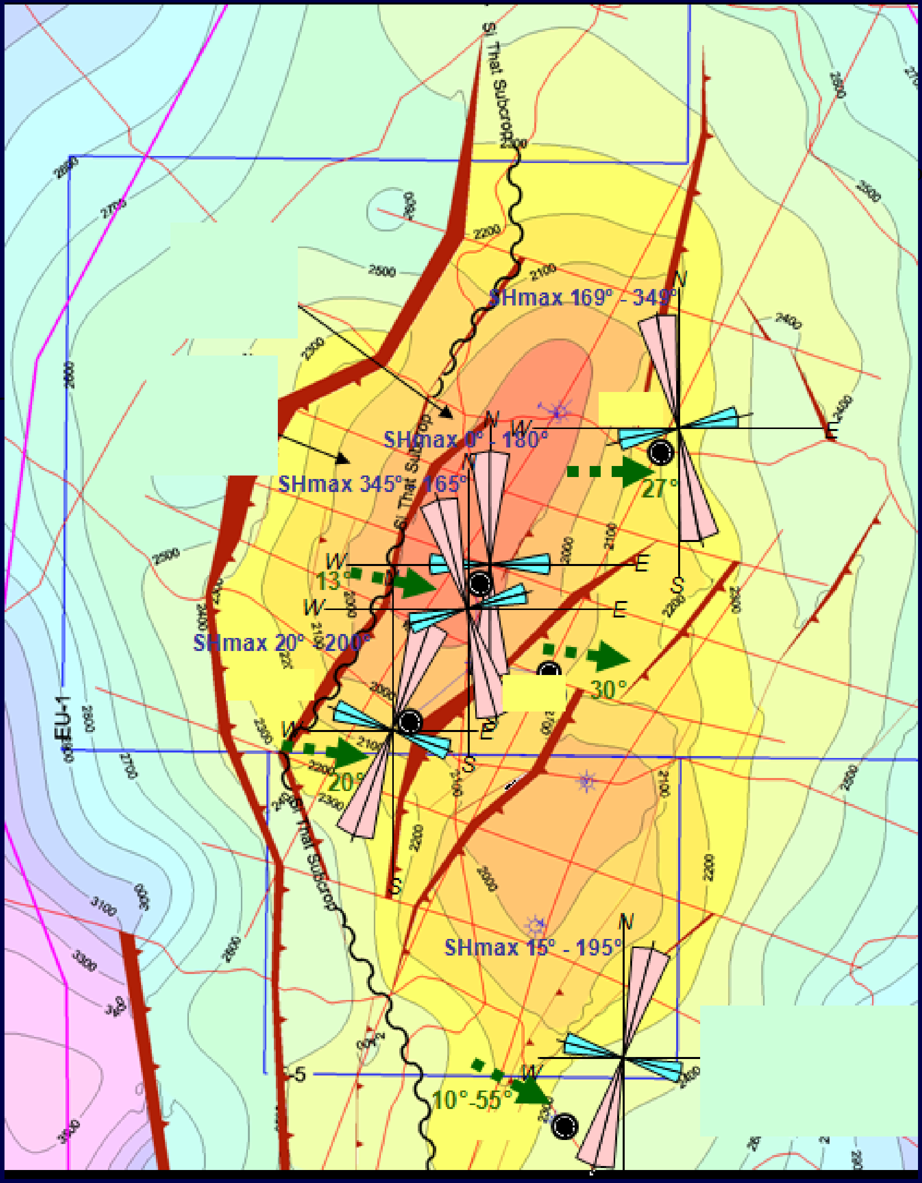
Fractures from a Marcellus Core (Union Spring)

Courtesy of Prof. Terry Engelder

Stress and Fracture Orientations from Image Logs

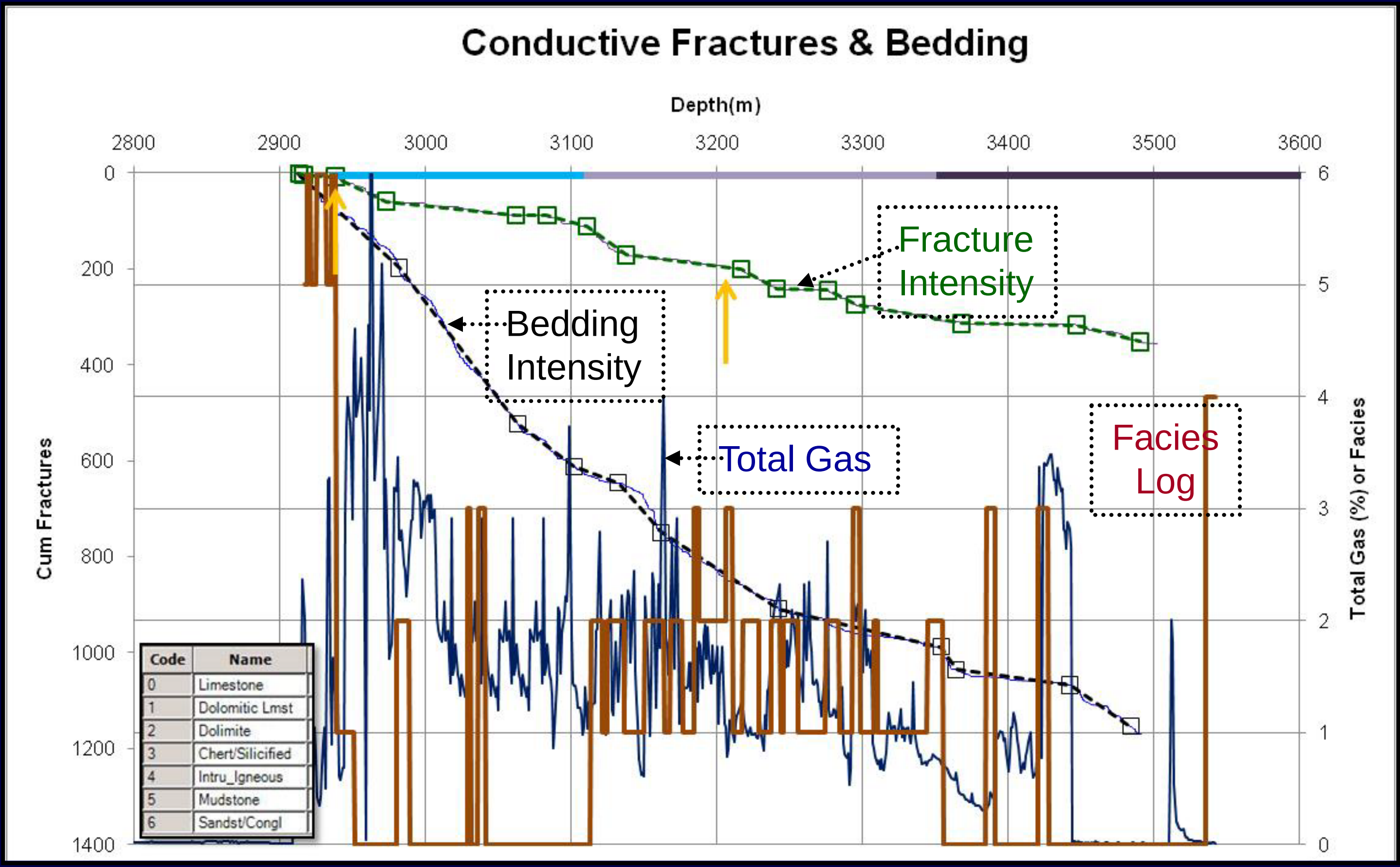
Reservoir present-day SHmax variation from NNW to NNE





(ARMA 12-668)

Conductive Fracture Intensity Analysis



For this well no clear relationship between total gas % and:

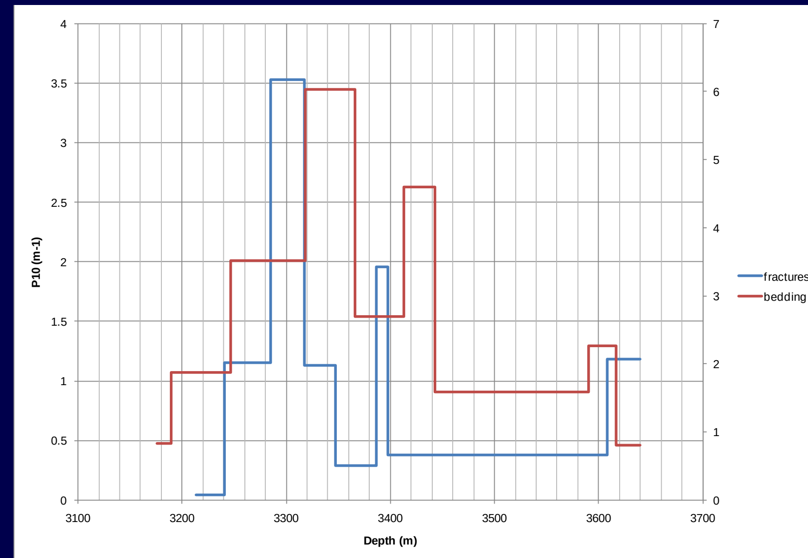
- Fracture intensity
- Change in fracture intensity
- Fault location
- Facies

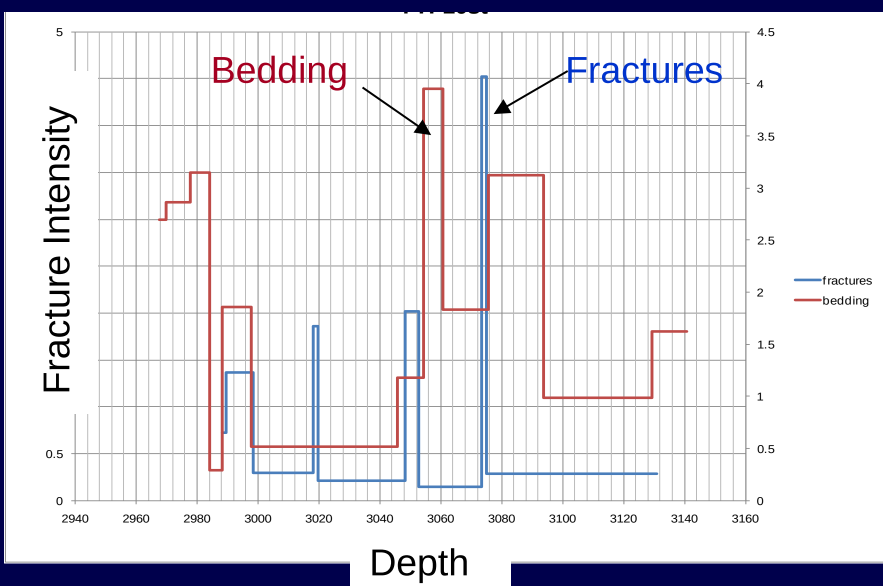
Fracture Intensity vs. Bedding

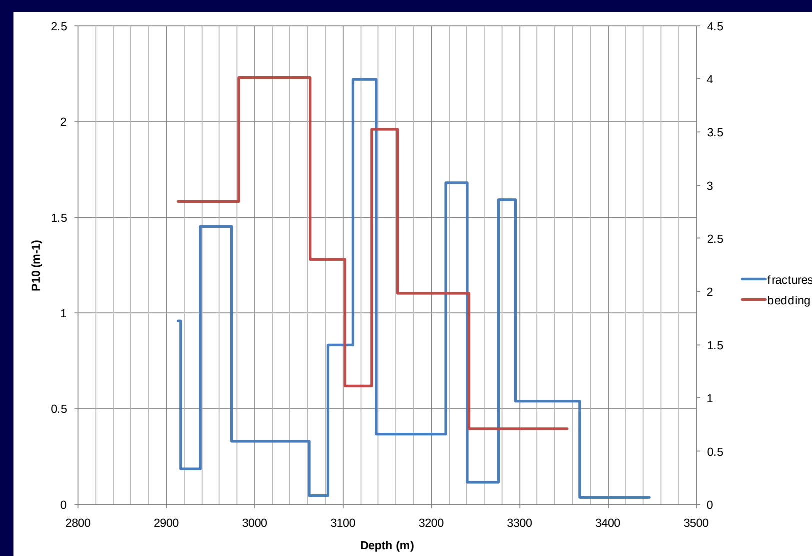
Fracture systems in carbonate reservoirs:

- Massive carbonate with fracture distribution controlled by rock properties;
- Layered carbonate system bed thickness is the primary control

CFI plots indicate only one well shows any strength in correlation. It is likely that the reservoir behaves more like a massive carbonate with fractures

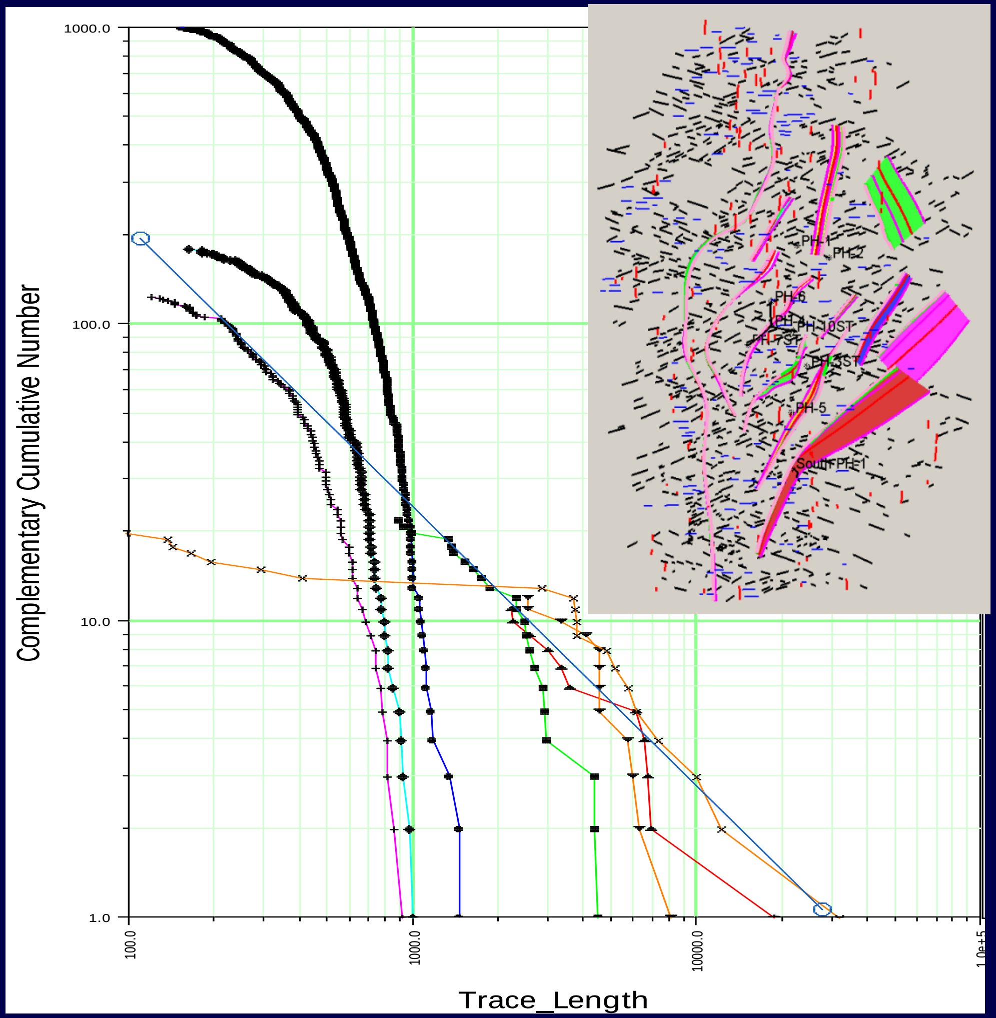






Fracture Intensity vs. Satellite Lineament & Fault

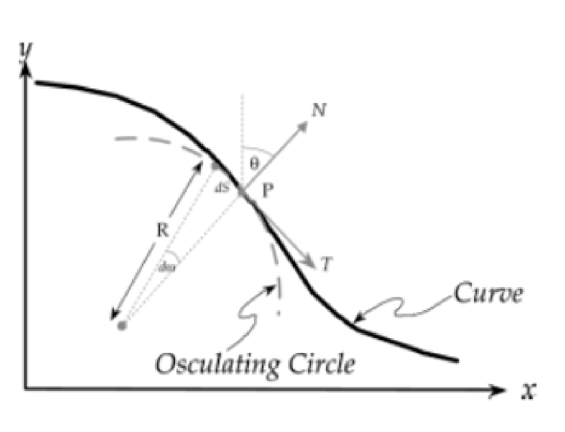
- The best structural length info typically comes from interpreted 3D seismic surveys including manually interpreted seismic faults, automatically picked faults (e.g. ant tracking) and curvature features
- Power law analysis of these data shows that a common trend (Gradient D=0.94) can be applied to a range of proposed fracture lineaments (E-W and N-S)
- With only 2D seismic lines available, the accuracy of these analysis is reduced

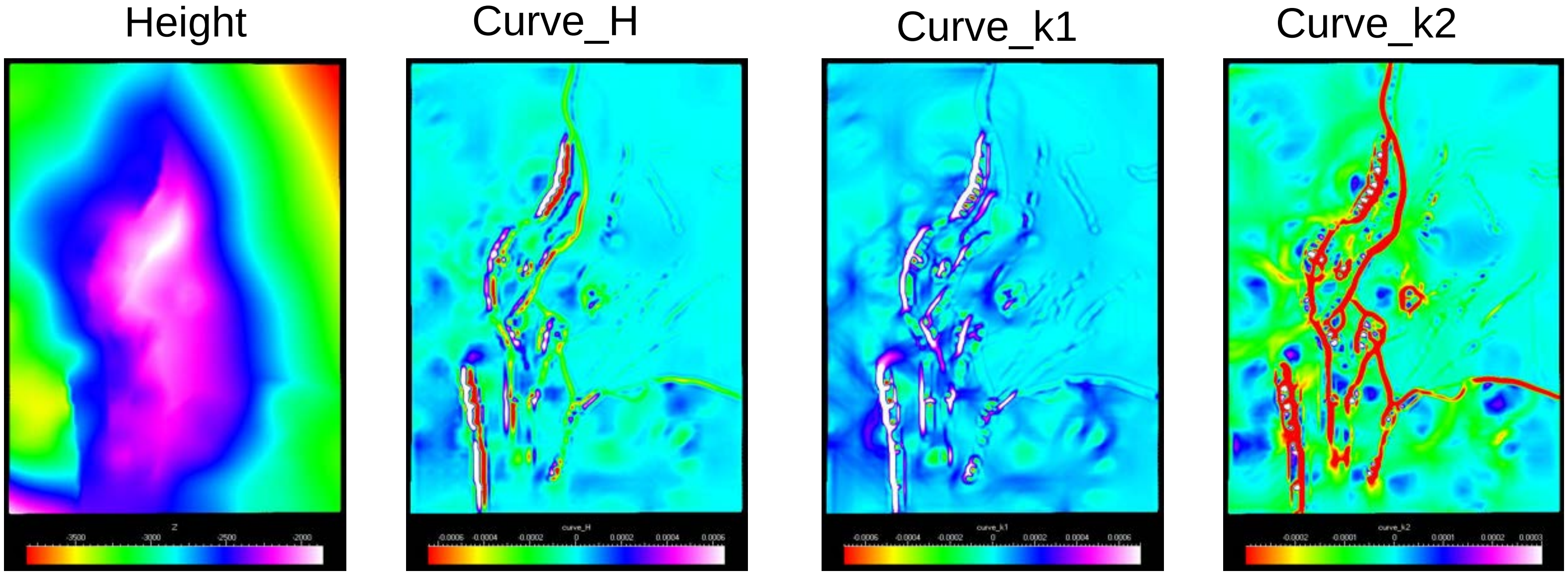


Fracture Intensity vs. Surface Curvature

General Observation: In many cases the more “bent” a layer (i.e. surface curvature) the greater the degree of fracturing

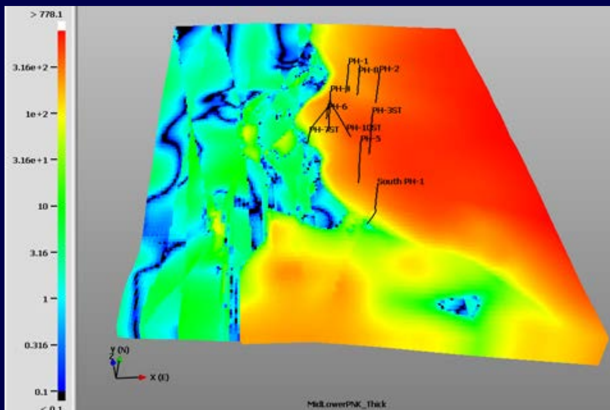
Can be extracted as a 3D volume or 2D surface. From 2D seismically derived surfaces curvature attributes were calculated for 3 surfaces: Upper, Mid and Lower Reservoir



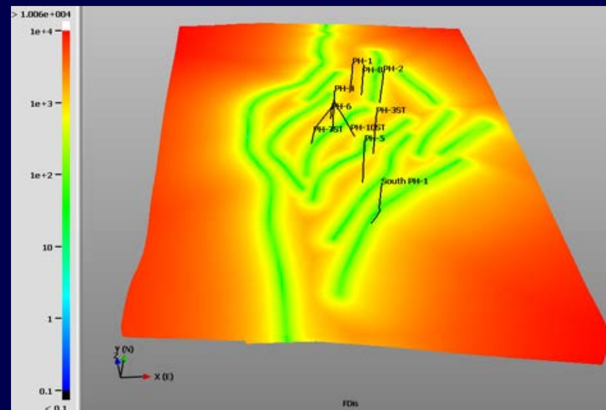


Fracture Intensity vs. Structural Properties

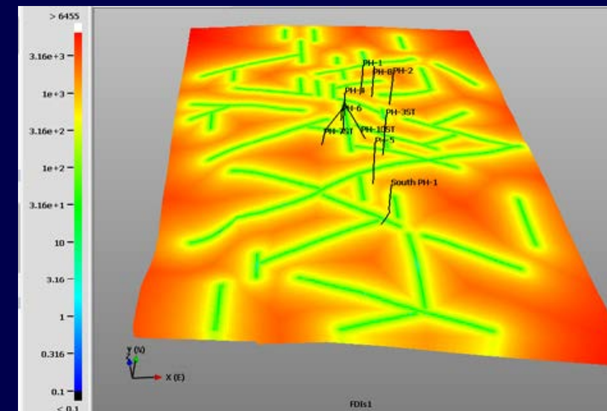
Dol (Dolomite Thickness)



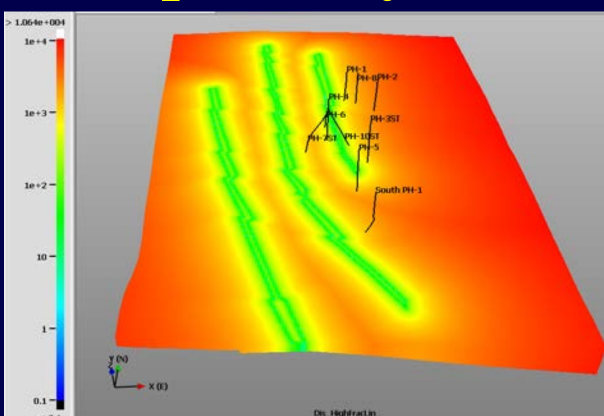
FDis (Distance to Seismic Faults)



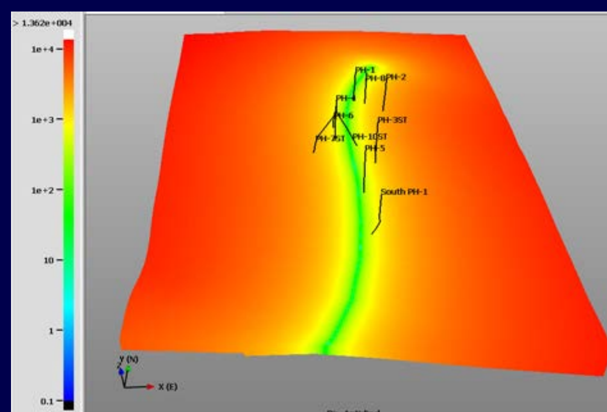
FDis1 (Distance to Remote Sensing Faults)



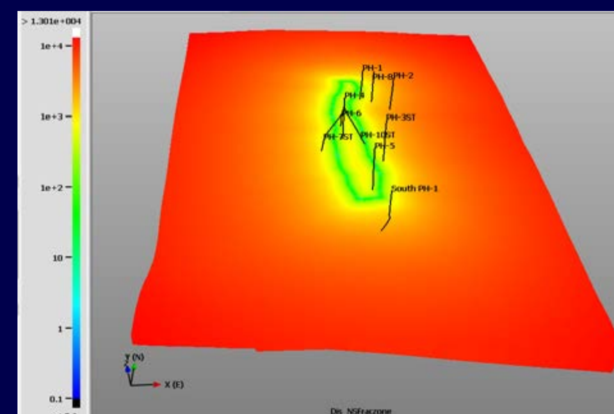
Dis_Remote Sensing Lineaments



Dis_Anticlinal Crest



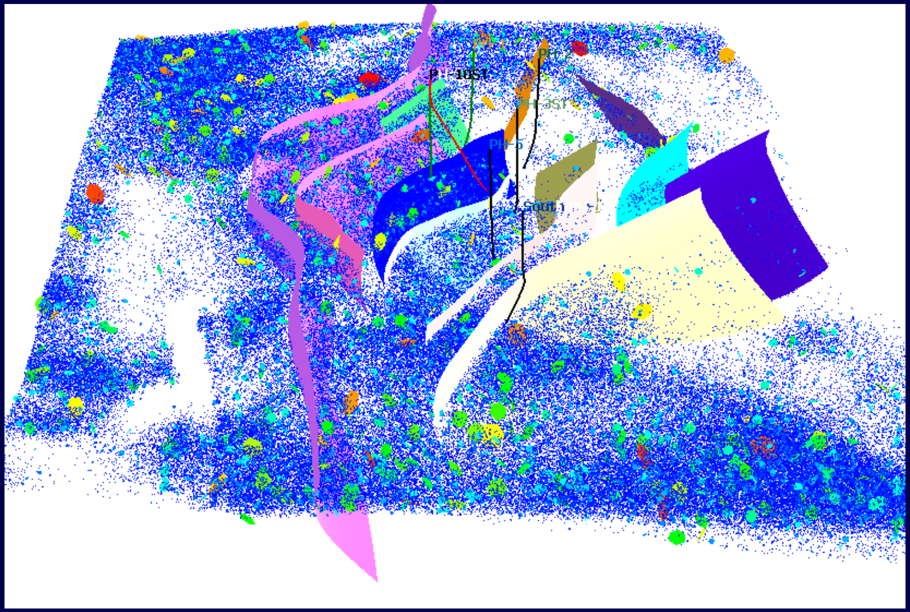
Dis_NSFraczone

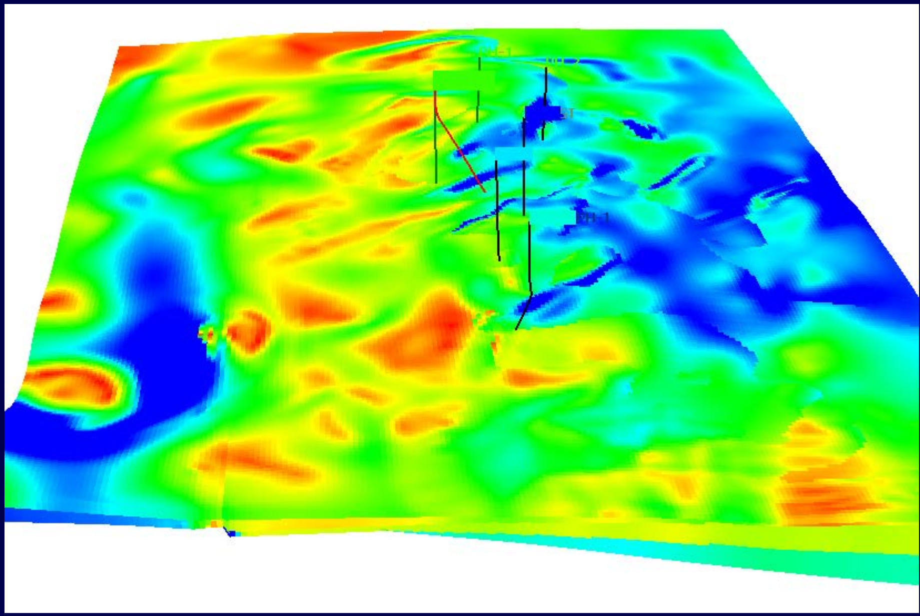


Full Field DFN Model

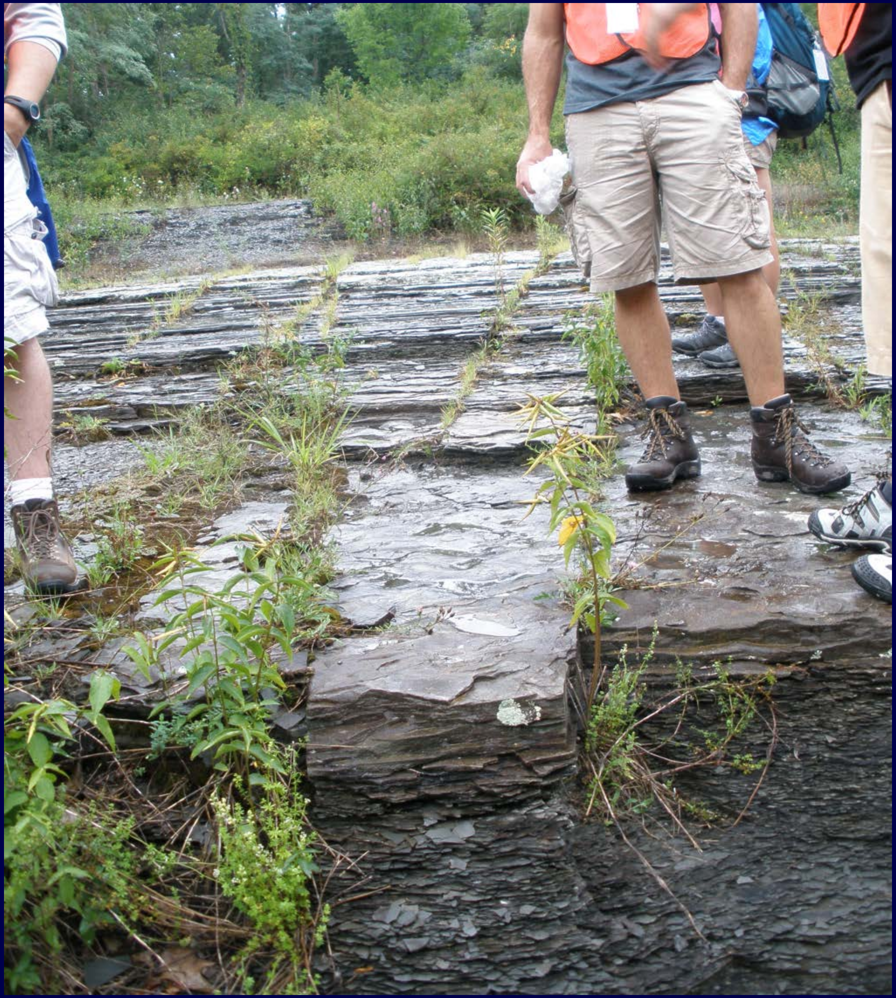
A DFN model has been built based on the following:

- Fracture intensity has been controlled by curvature and fault zone intensity;
- Fracture size has been guided using scaling laws from the lineament data;
- Fracture orientation has been constrained using open fracture orientations from image log data.

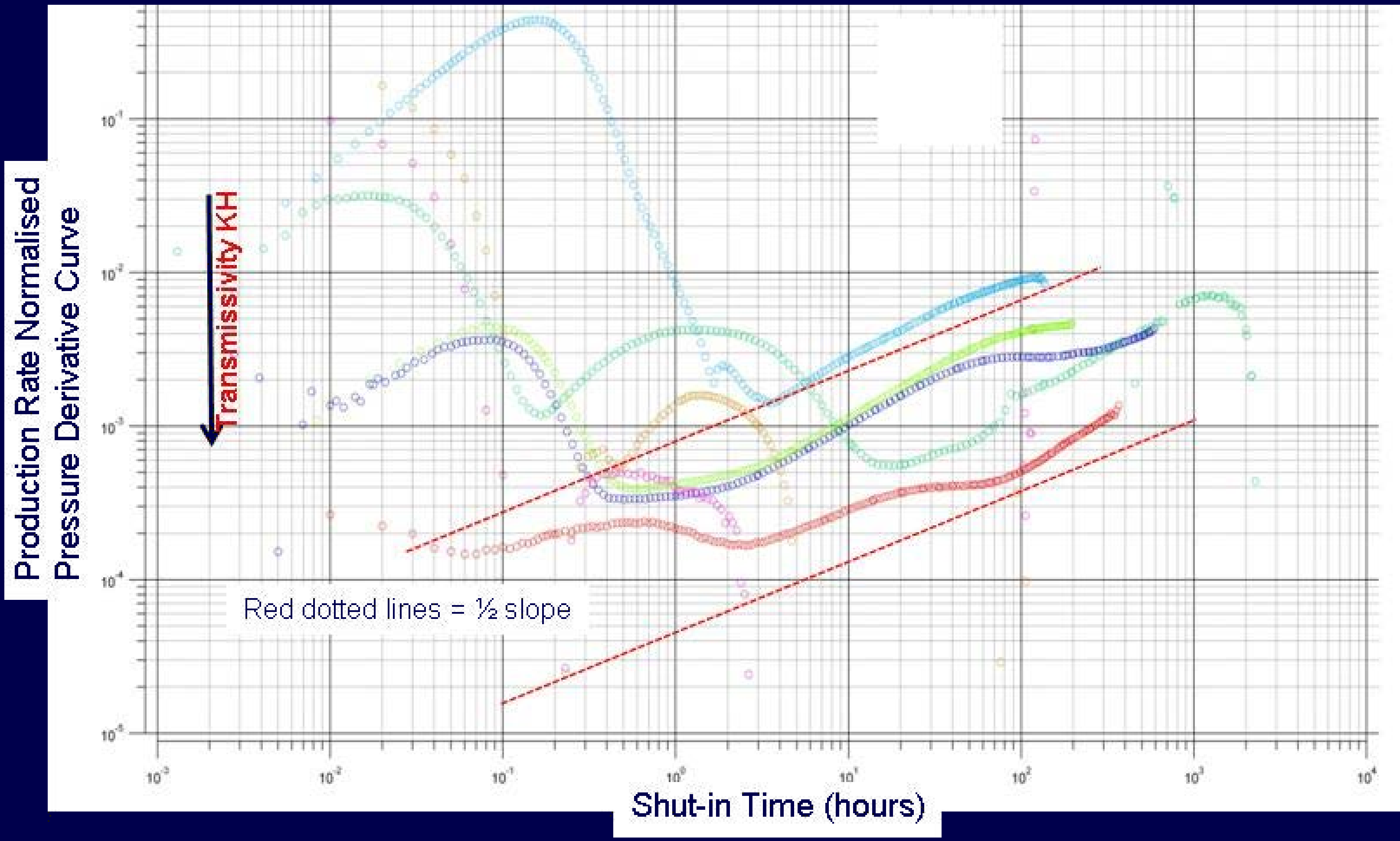




Open Fractures Underneath the Surface



Fracture Conductivity from PTA/RTA



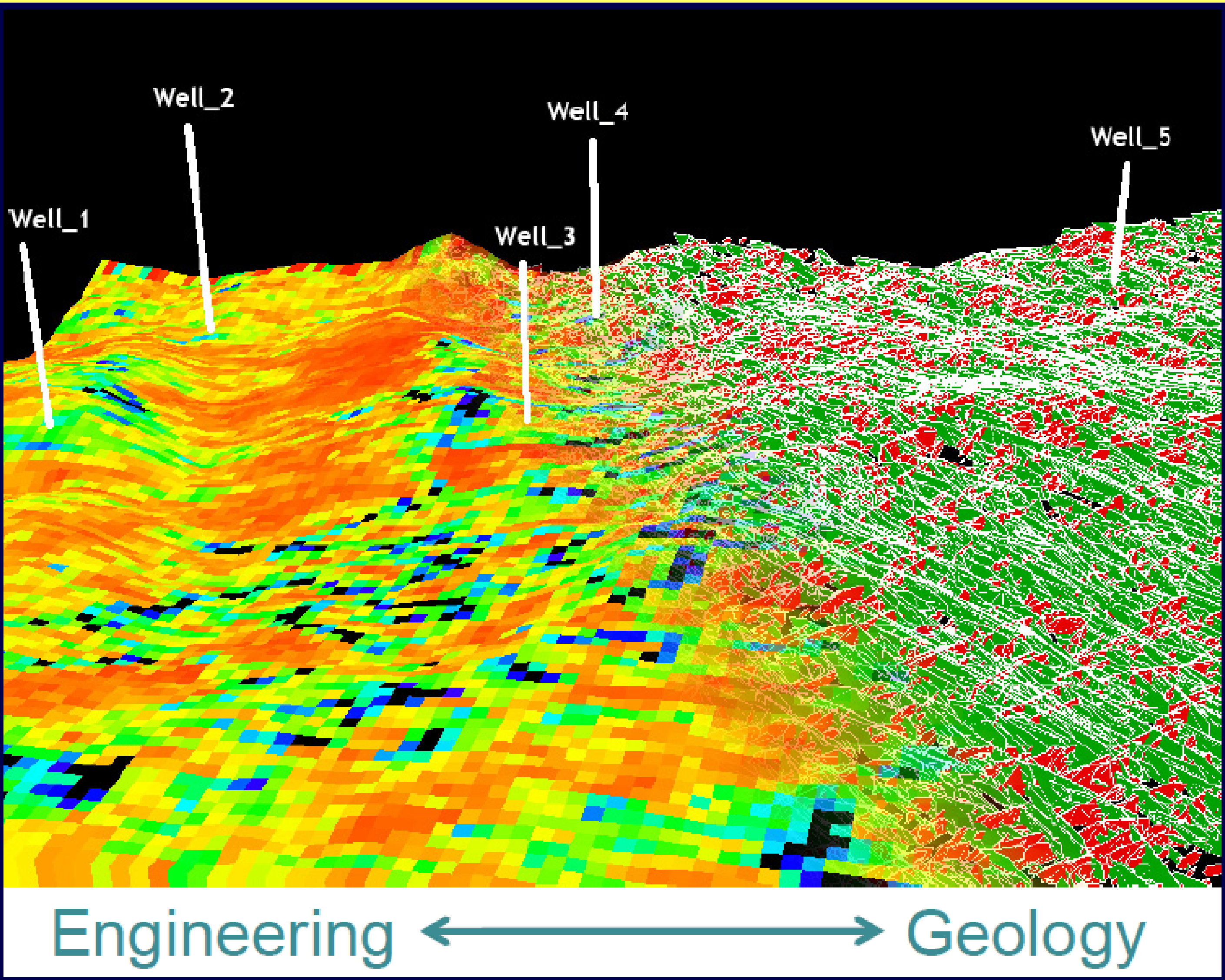
- All of the curves show a strong linear flow shape (a positive half slope) which is consistent with a channelized system or low-connectivity fracture network;

Outline

- Characterize In-Situ **Open** Fractures
  - Outcrop
  - Seismic
  - Logs
  - Core
  - **Well Test (PTA or RTA)**
- Influence of Natural Fractures on Engineering Applications
  - Reservoir Engineering
  - Drilling
  - Completion
  - Hydraulic Fracturing

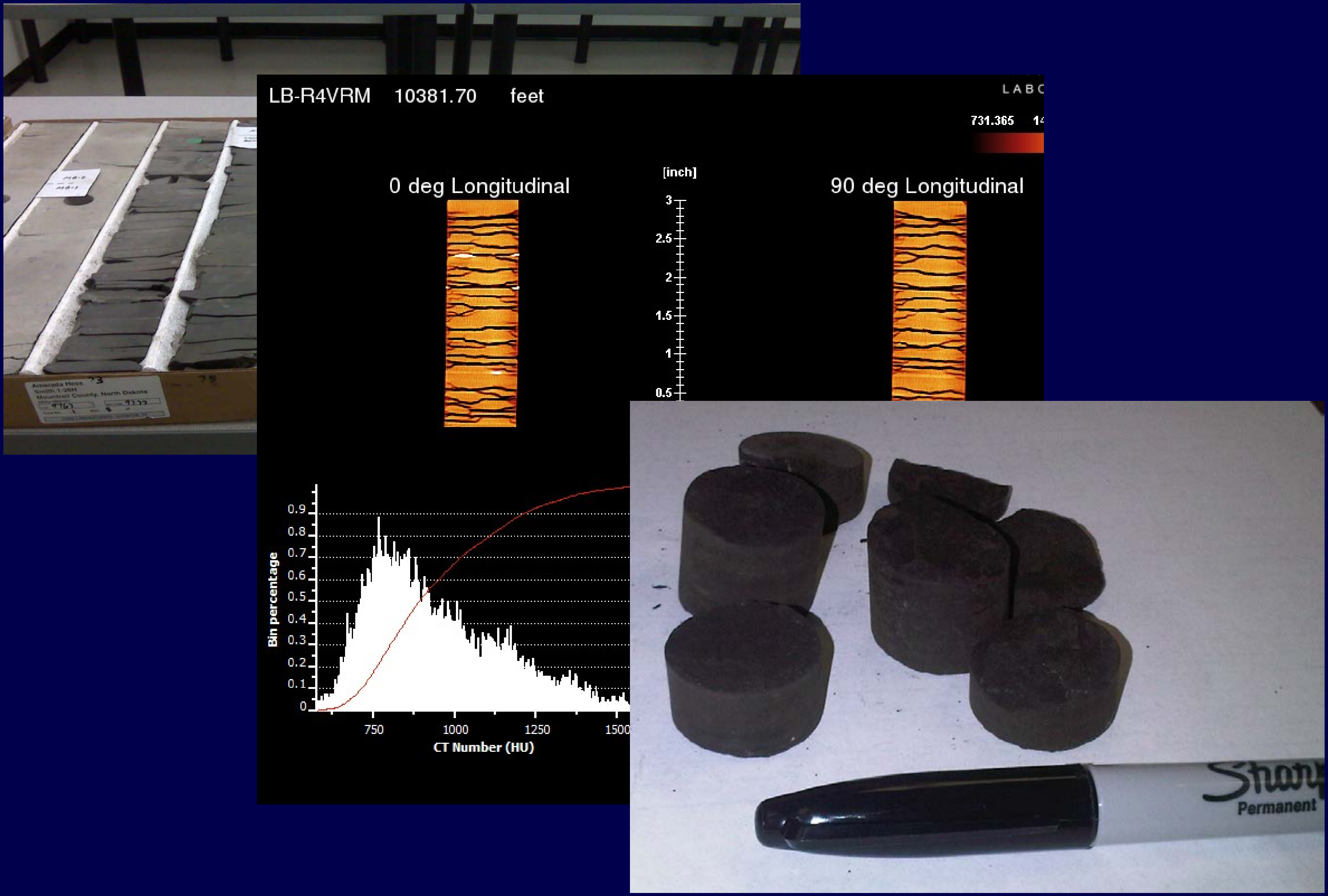
(ARMA 11-509 and ARMA 12-668)

Impact of In-Situ Fractures on Reservoir Engineering

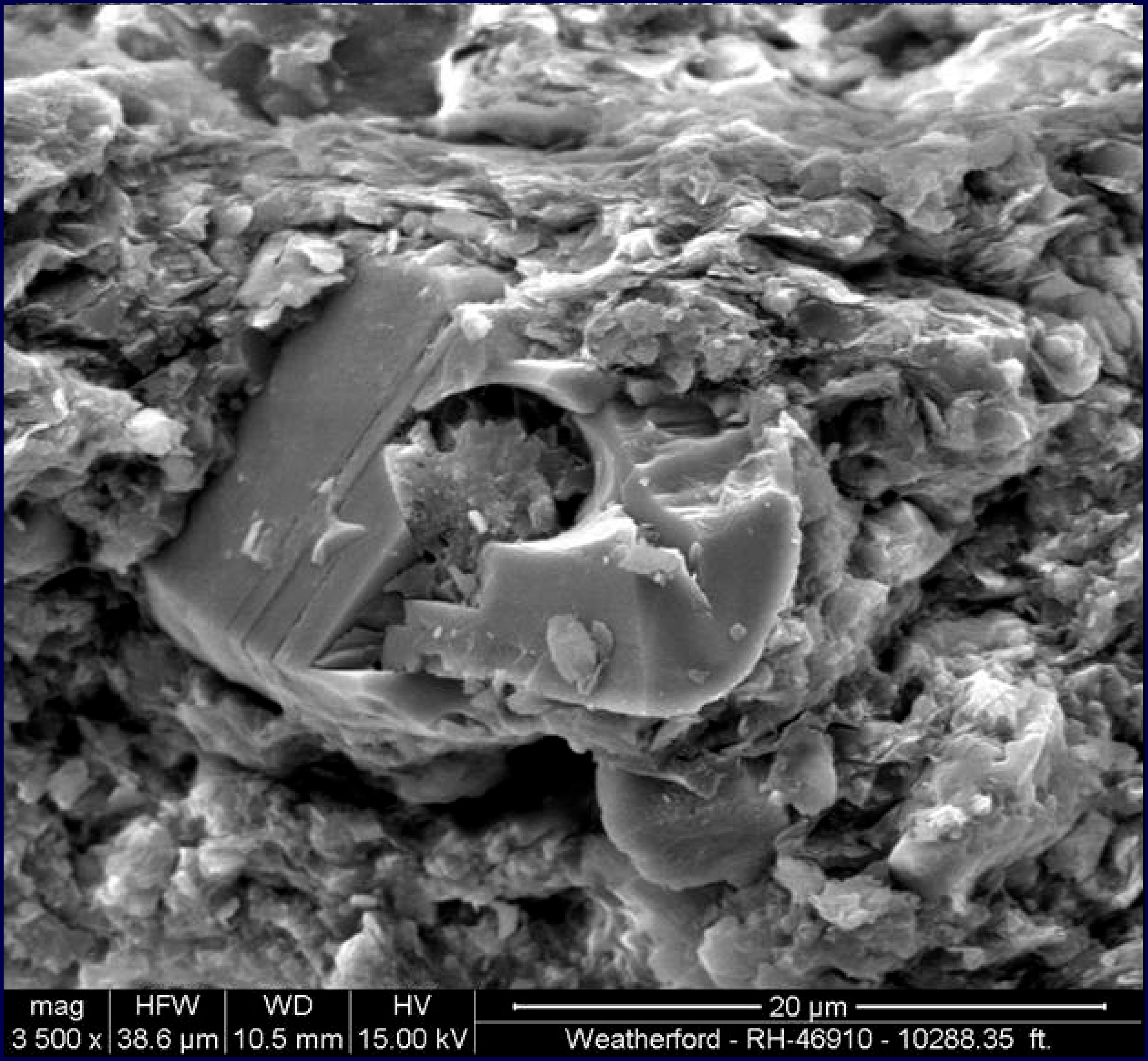


Courtesy of Golder

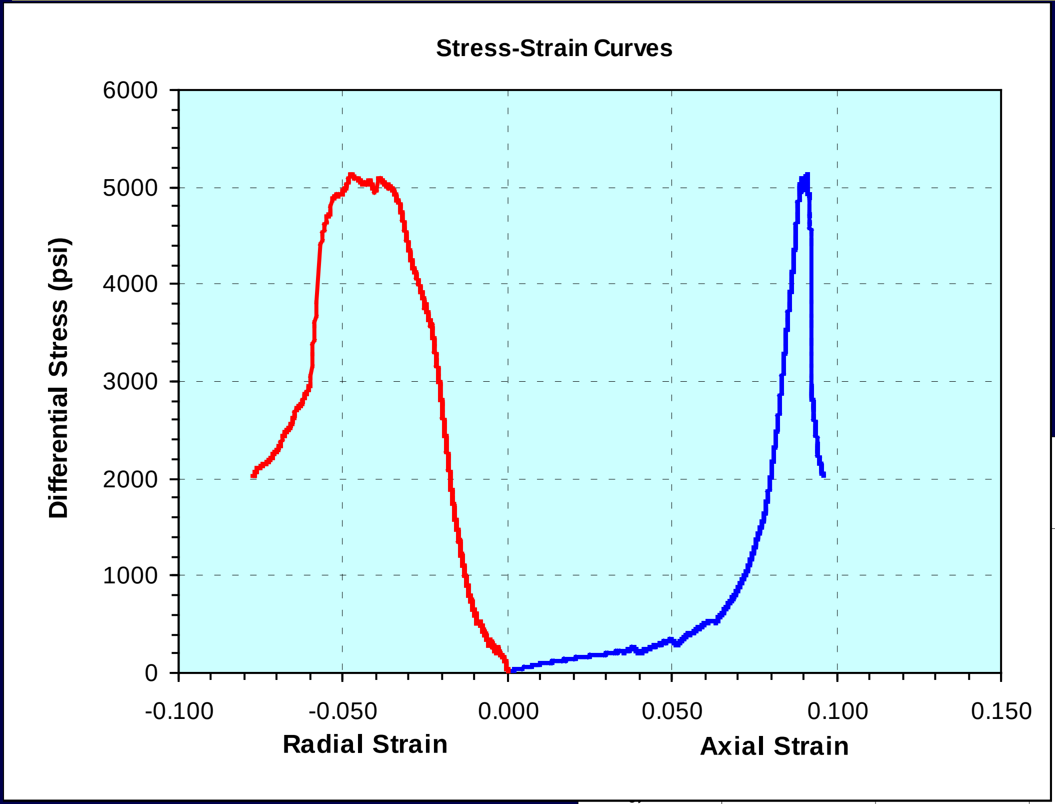
Impact on Shale Plugging

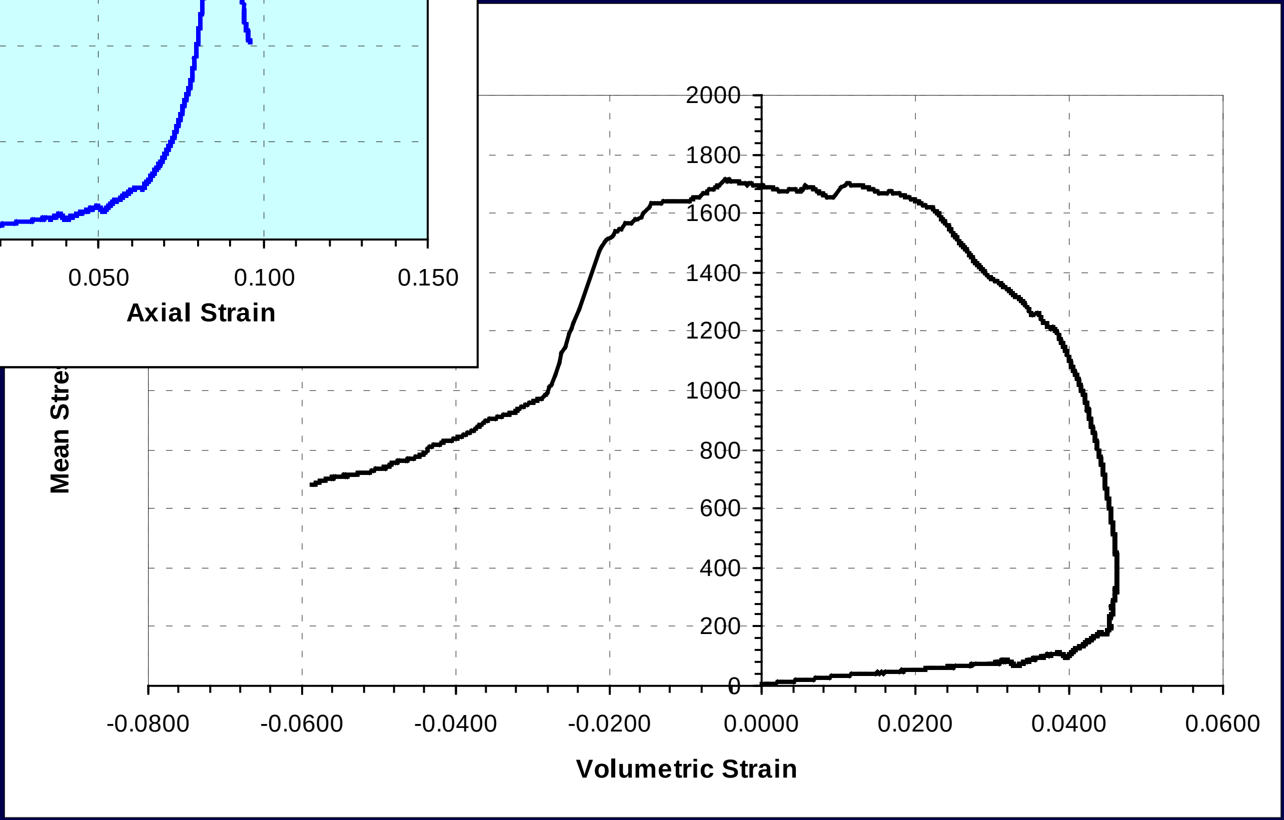


SEM from a Shale Formation



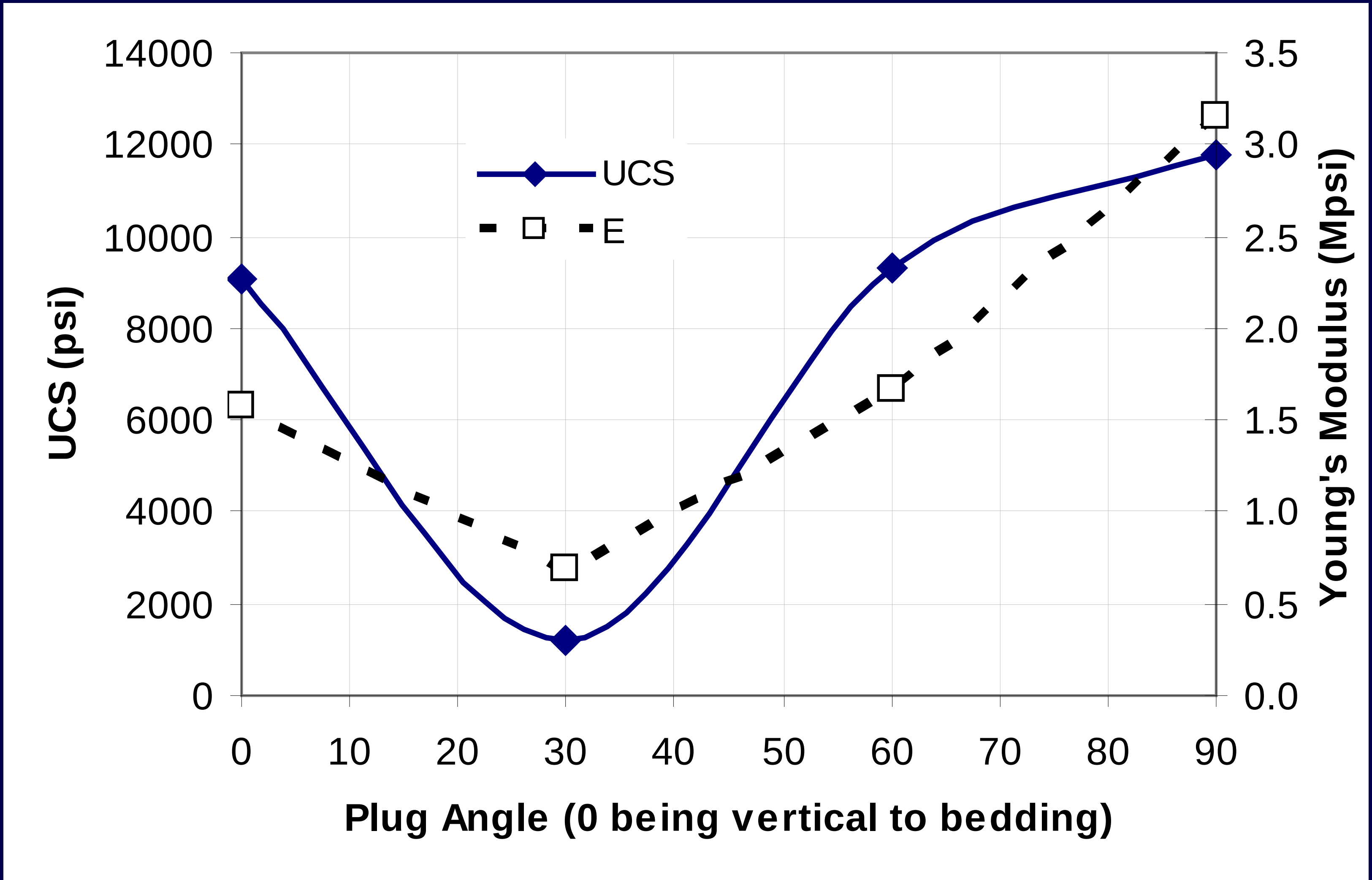
Impact on Mechanical Behavior



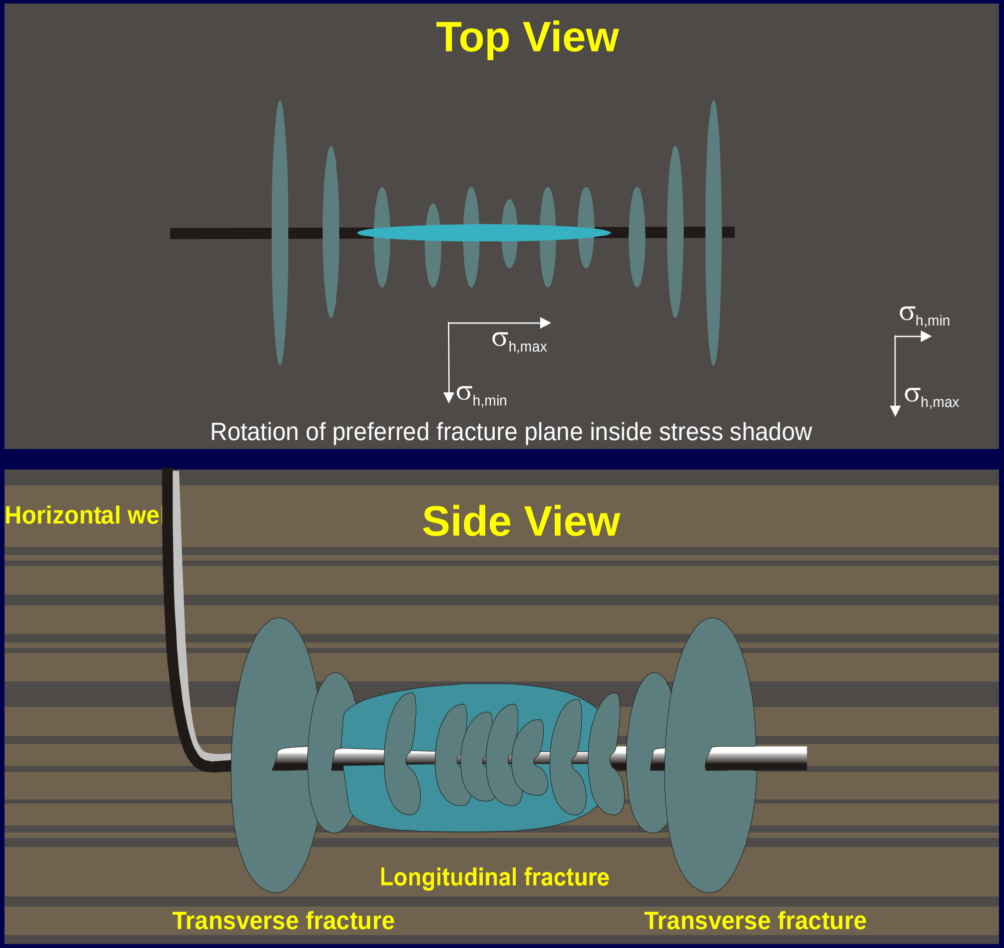


Shale Failure w/o Oil-Saturated Fluid

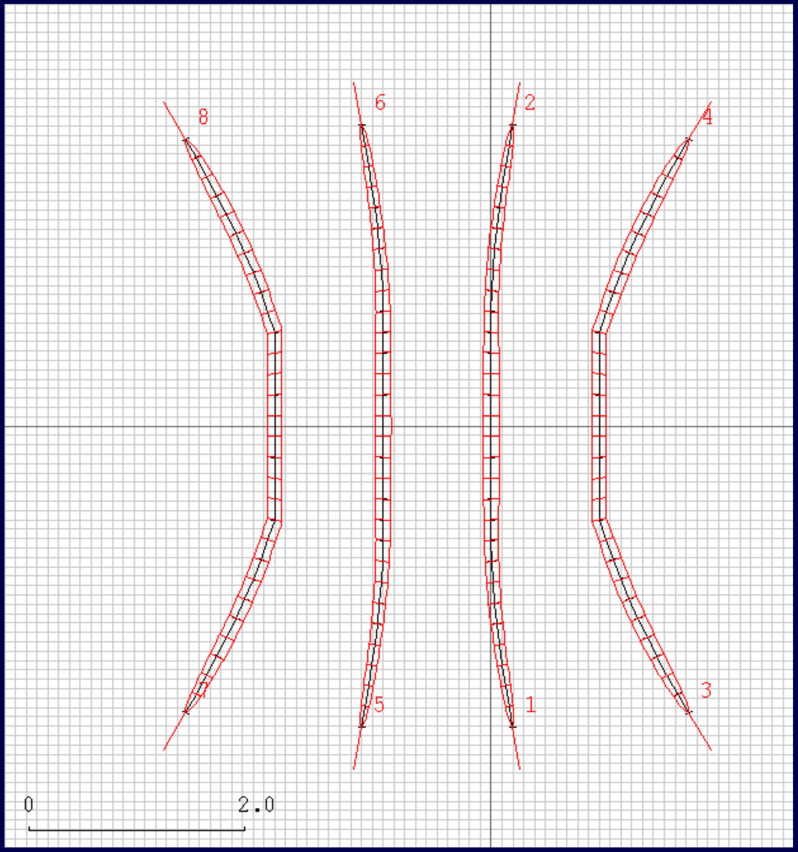
Impact on Rock Hetereogeneity



Impact on Hydraulic Fracture Modeling

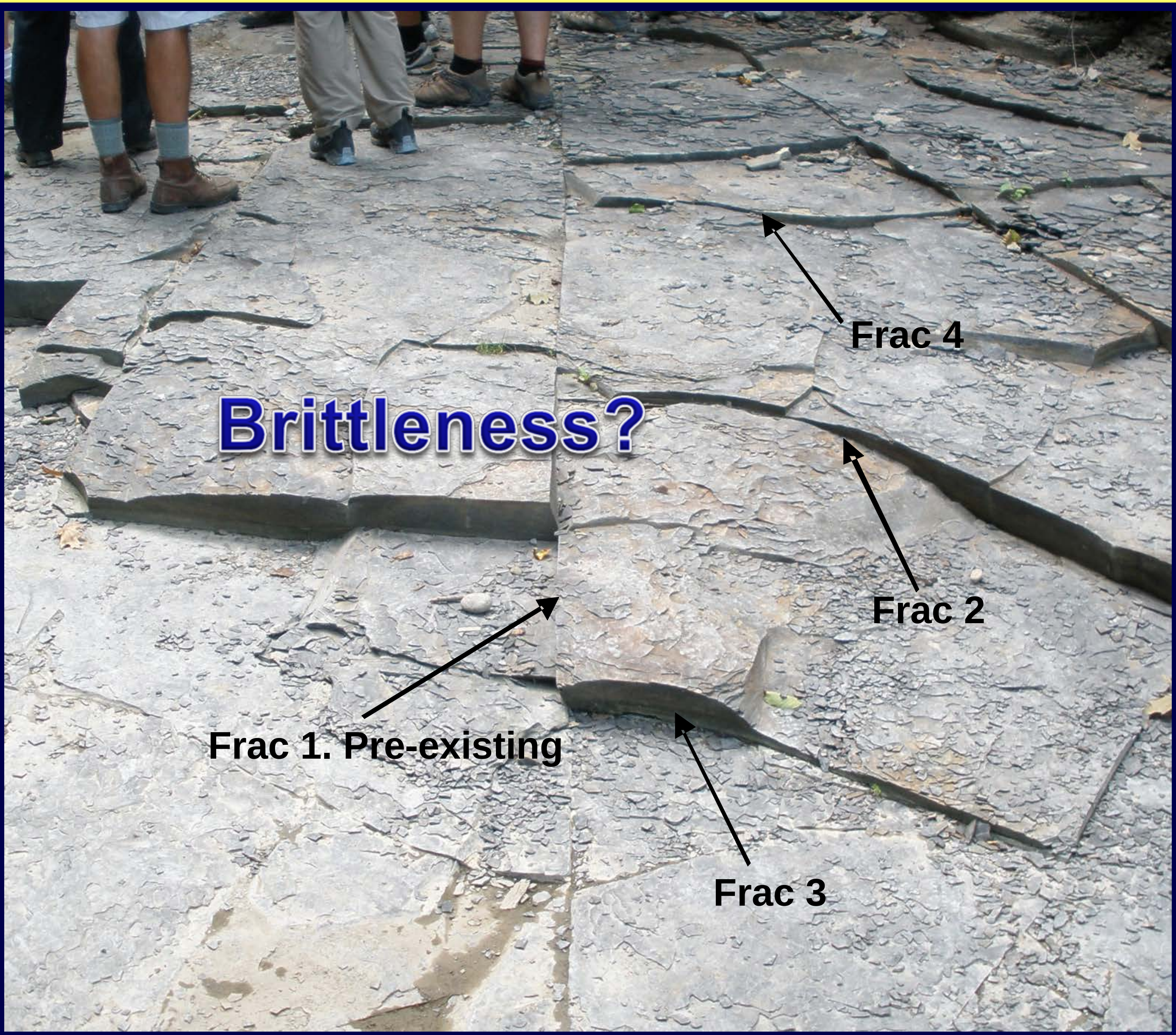


Courtesy of Halliburton

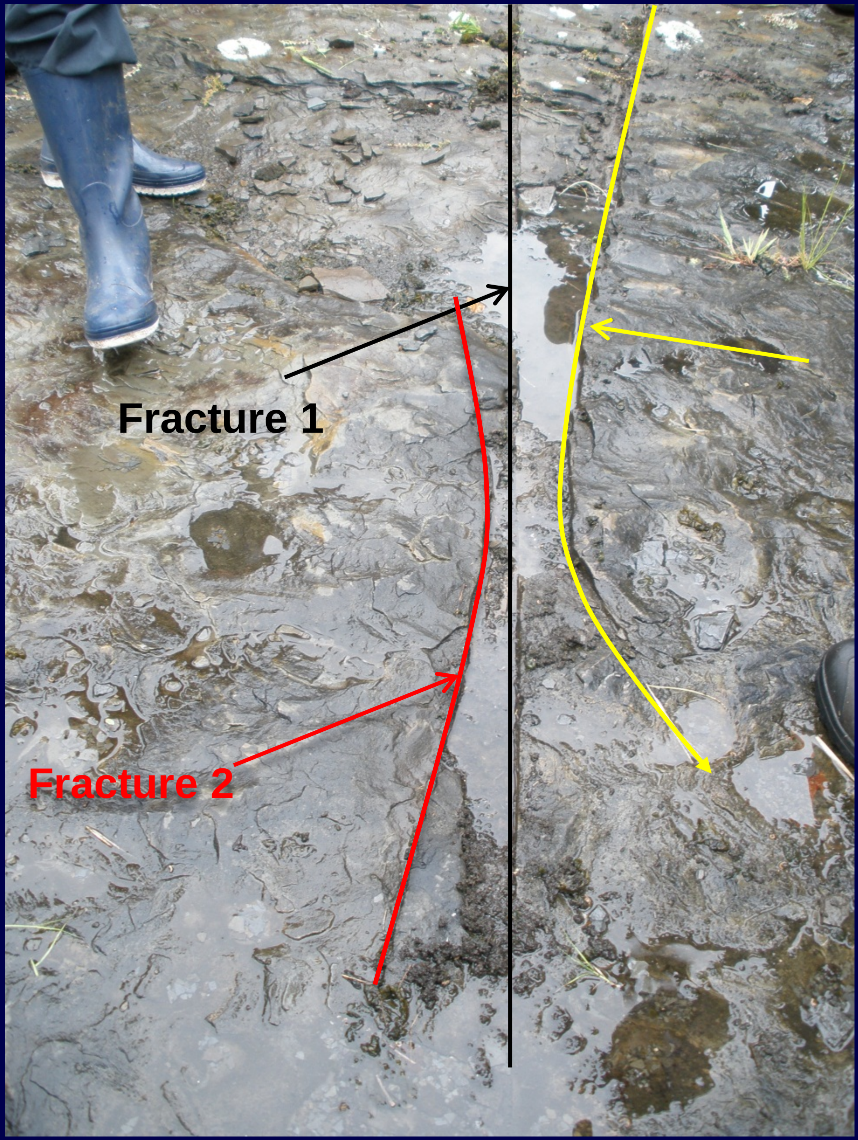


Courtesy of Prof. Ghassemi

Impact on Fracture Propagation: High Angle Case

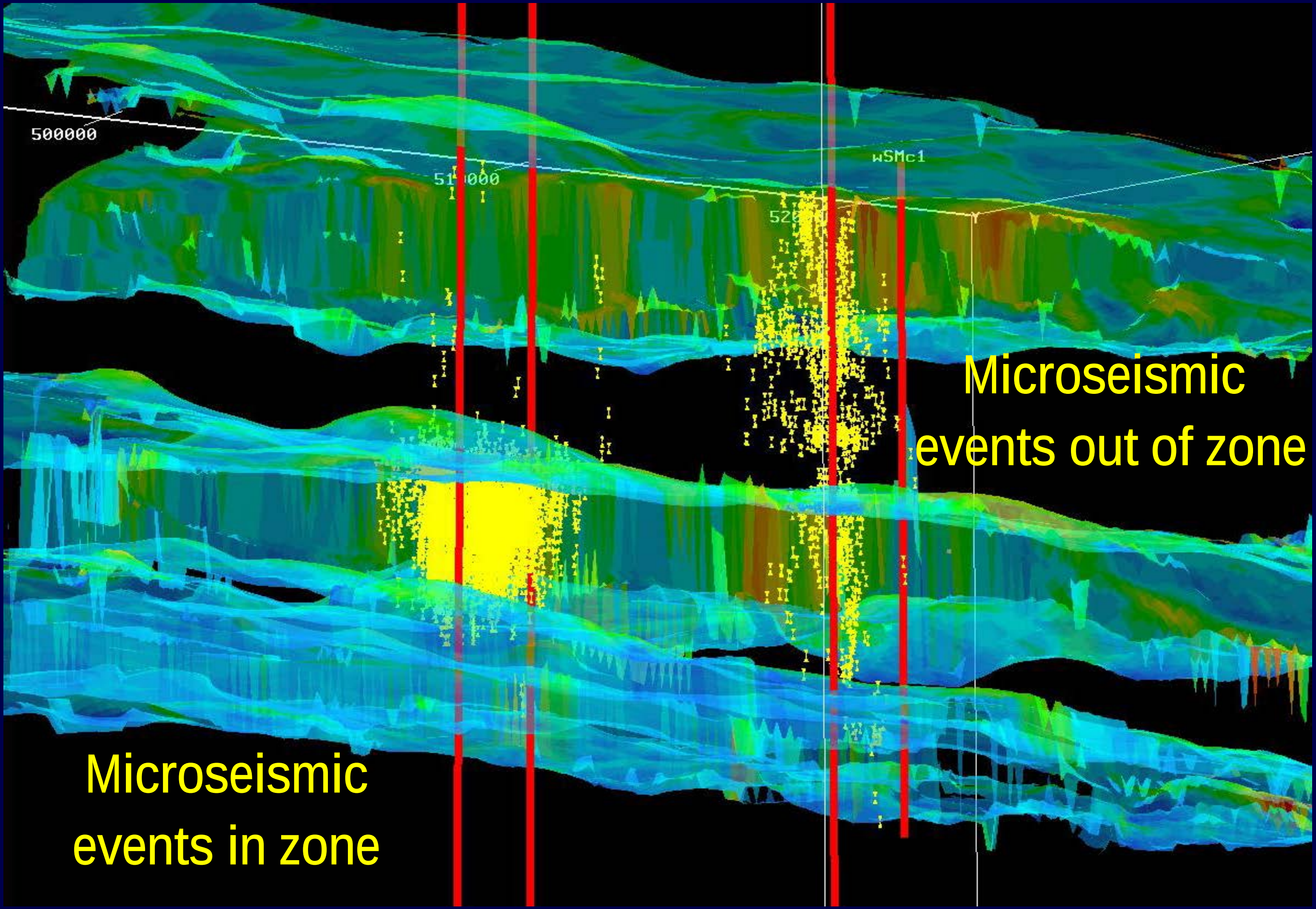


Impact on Fractures: Low Angle Case



Impact on Completion

Impact on Fracture Containment



Courtesy of Schlumberger

Conclusions

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Acknowledgements

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- Paul Fejer from Hess Corporation, and Steve Rogers from Golder Associates
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