

# Natural Fracture Behavior Under Increasing Confining Pressure, Applying Helical CT Scanning Technology\*

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## Conclusion

- Kinematic aperture is not sufficient data.
- Core must be pressurized for accurate porosity calculations.
- With advances in CT scanning and software we can:
  - Visualize 3D volumes of materials within fractures,
  - Quantify fracture porosity,
  - Bring core closer to reservoir conditions by pressurizing samples,
  - Find the porosity volume preserved in a partially cemented fracture,
  - Distinguish between kinematic and effective aperture in the subsurface.
- Are all fractures closed under stress? -Not really.

## Reference

Nelson, R.A., 2001, Geologic Analysis of Fractured Reservoirs: Second Edition, 352 p.



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LABORATORIES

AAPG GTW Baltimore, July 2013

# Natural Fracture Behavior Under Increasing Confining Pressure

Applying Helical CT Scanning Technology

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**40 LABORATORY LOCATIONS IN 22 COUNTRIES**

#### NORTH AMERICA

Canada  
United States

#### EUROPE

Norway  
United Kingdom  
Kazakhstan

#### LATIN AMERICA

Brazil  
Mexico  
Trinidad  
Venezuela  
Argentina

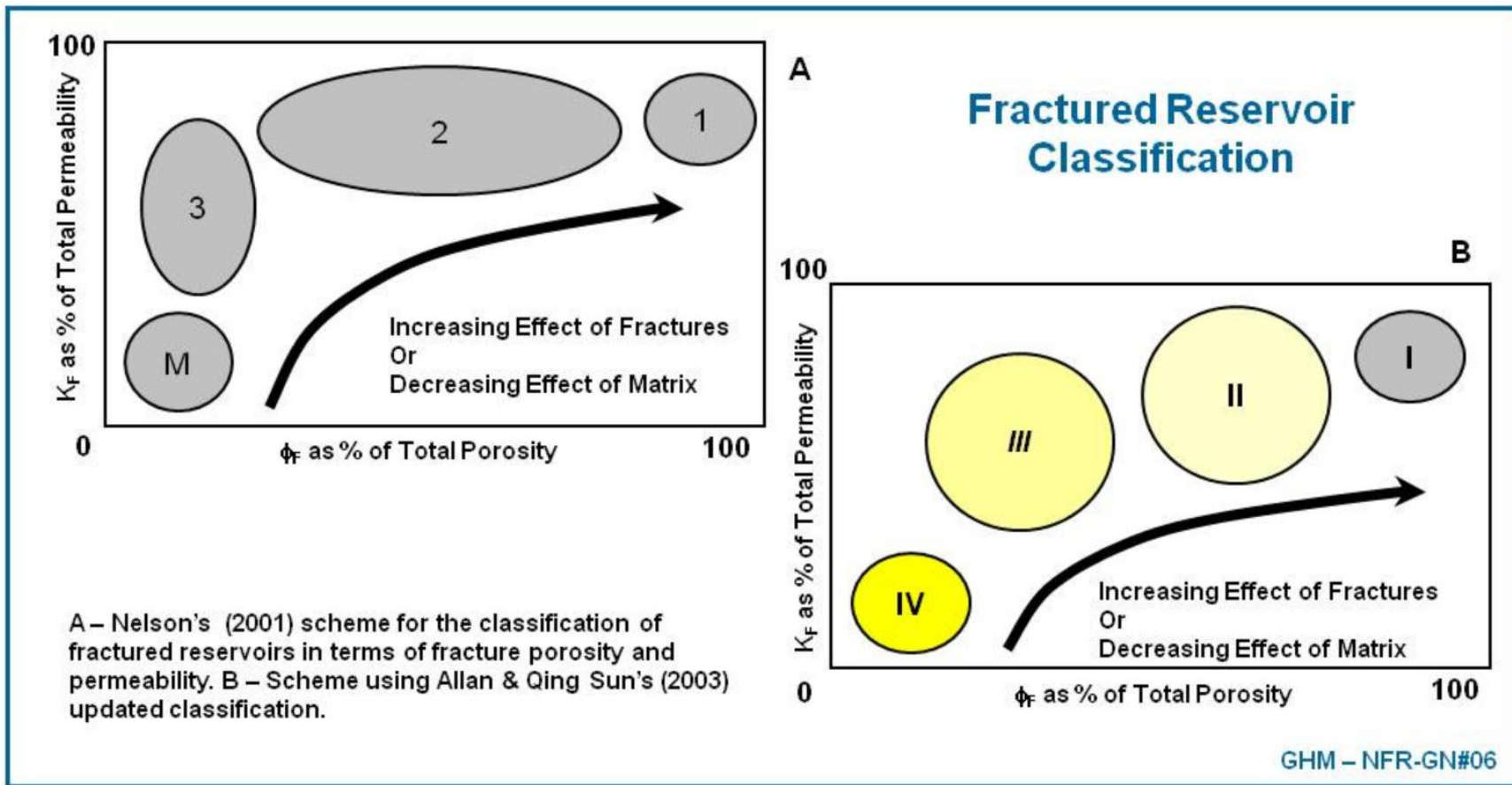
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Libya  
Oman  
Saudi Arabia  
United Arab Emirates  
Iraq

#### ASIA PACIFIC

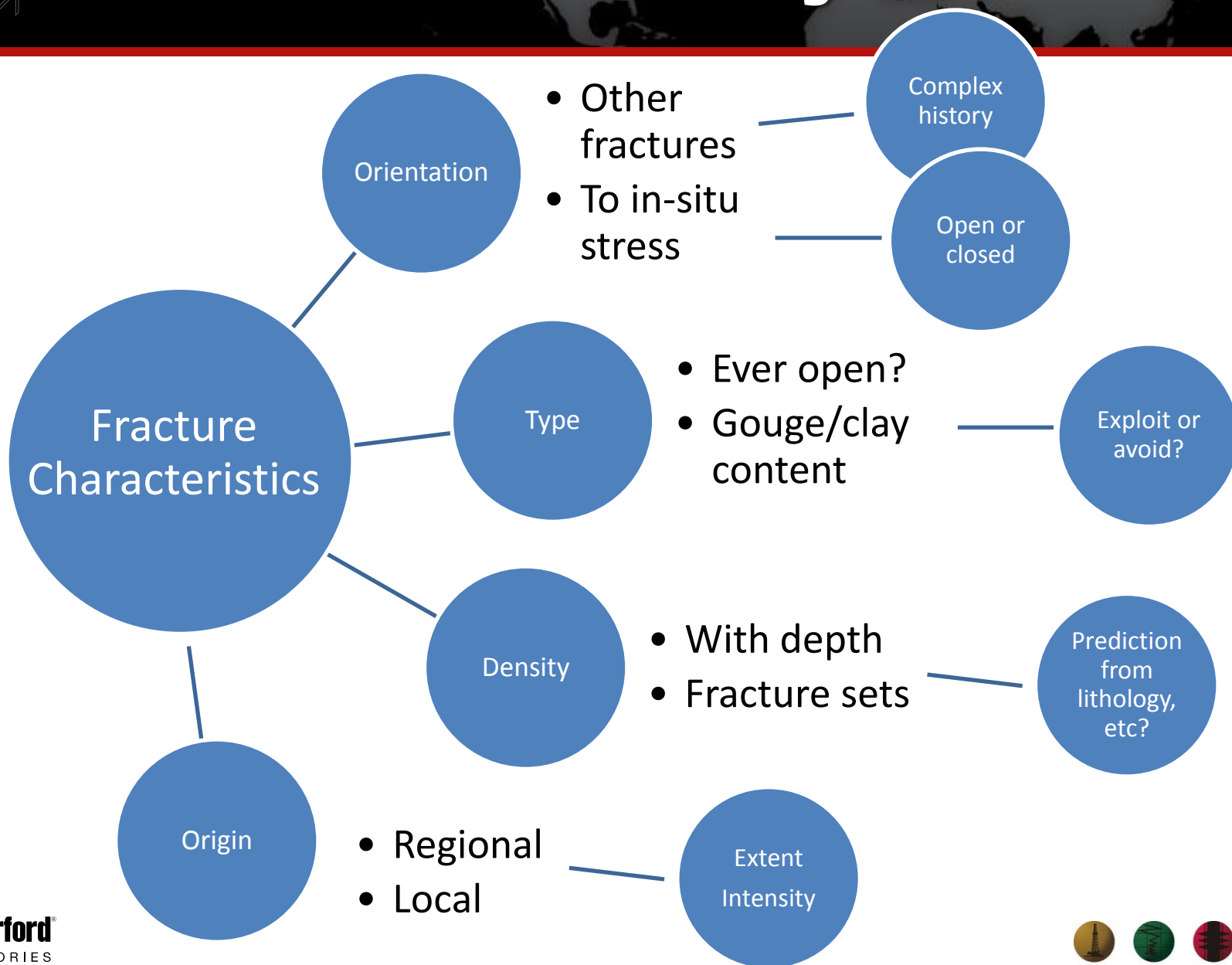
Australia  
India  
Malaysia  
Thailand  
New Zealand  
Indonesia

# Fractured Reservoir Classification



A) Nelson (2001); B) Allan and Qing Sun (2003)

# Natural Fracture Analysis in Core



# Natural Fracture Permeability

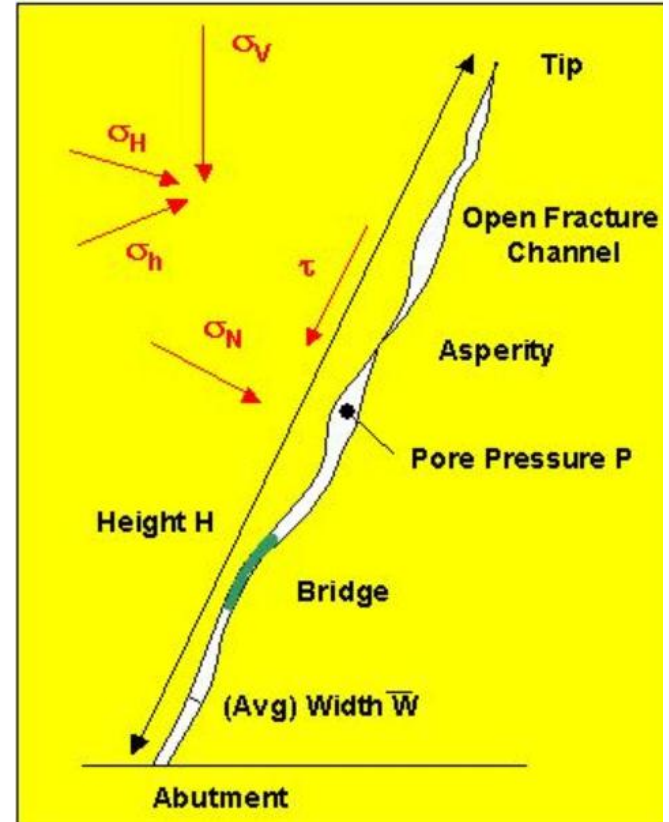
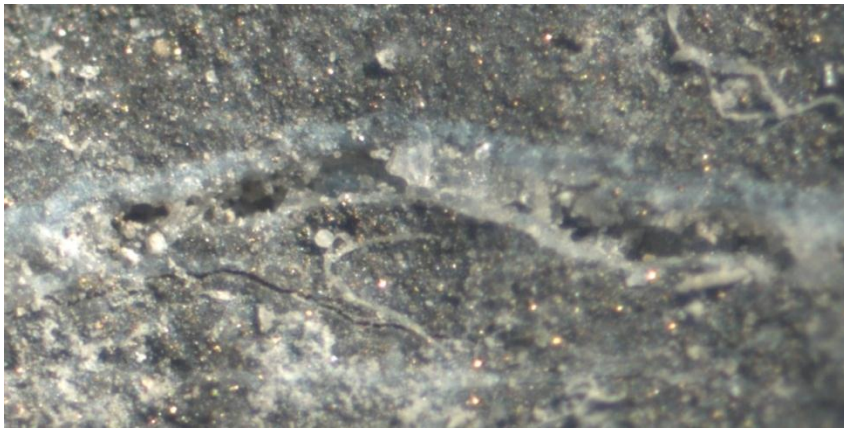
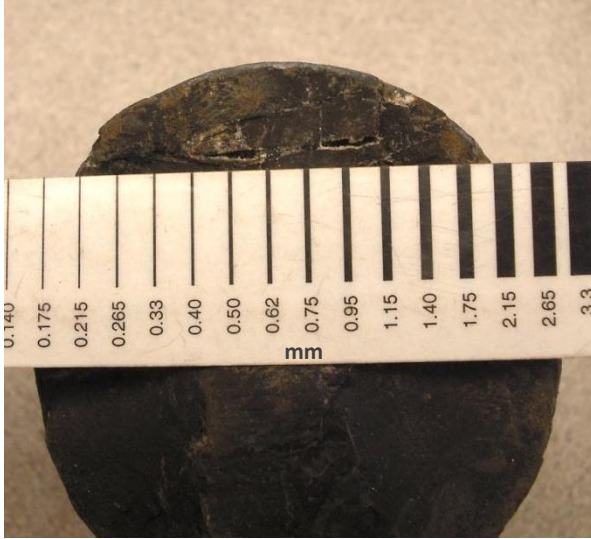
- Dependent on:
  - Orientation of fracture plane
  - *In situ* stress
    - $S_{Hmin}$  normal to plane
    - $S_{Hmax}$  oblique to plane
  - Pore fluid pressure within fracture
    - Overpressured is best
    - Hydrostatic pressure is neutral
    - Underpressured is bad
  - Fracture roughness



***How do we determine fracture  $\phi$  and  $k$  for fracture sets?***



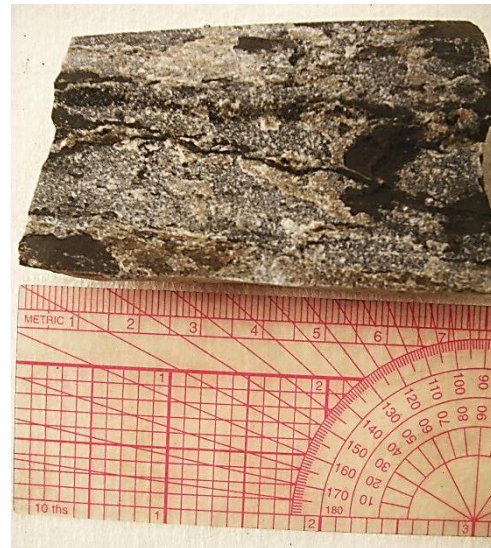
# Fracture Morphology



[makel.org](http://makel.org)



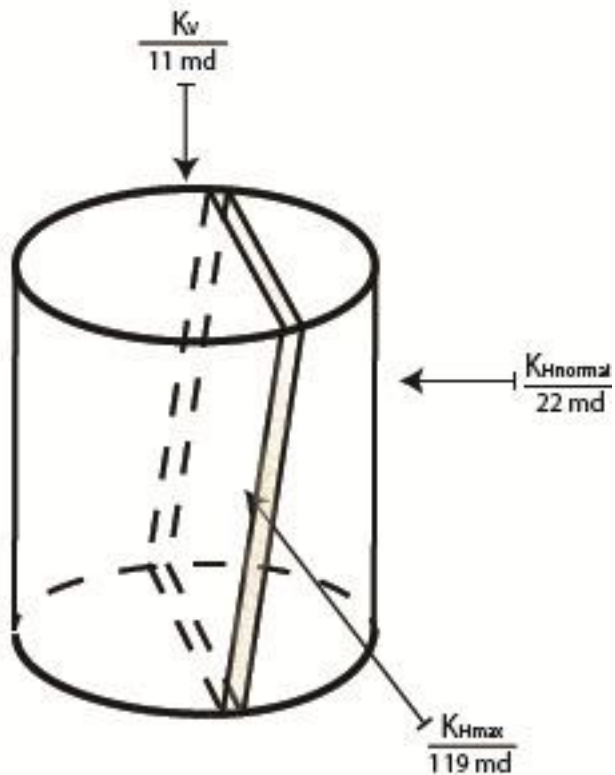
# Fracture / Matrix Permeability



# Fault Permeability Effect

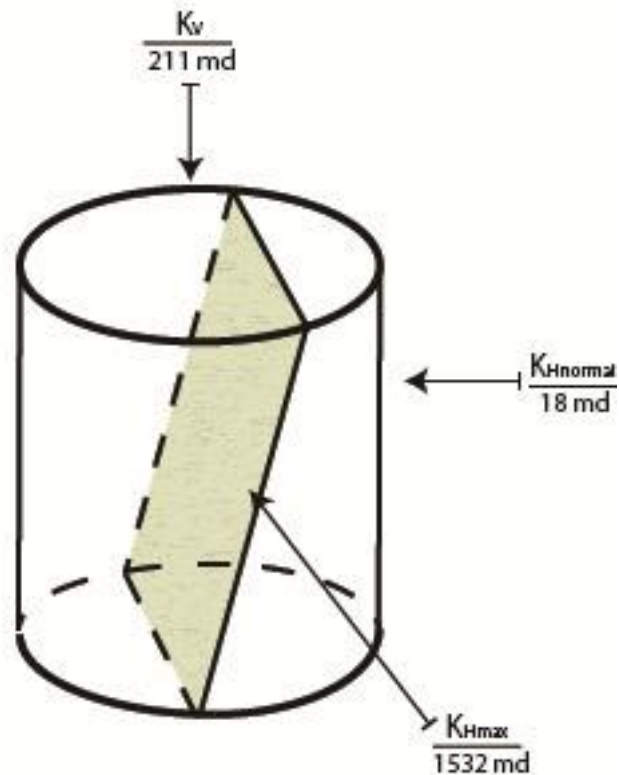
Gouge-filled Fracture

Depth 7691-92'  
Porosity 17.4%



Slickensided Fracture

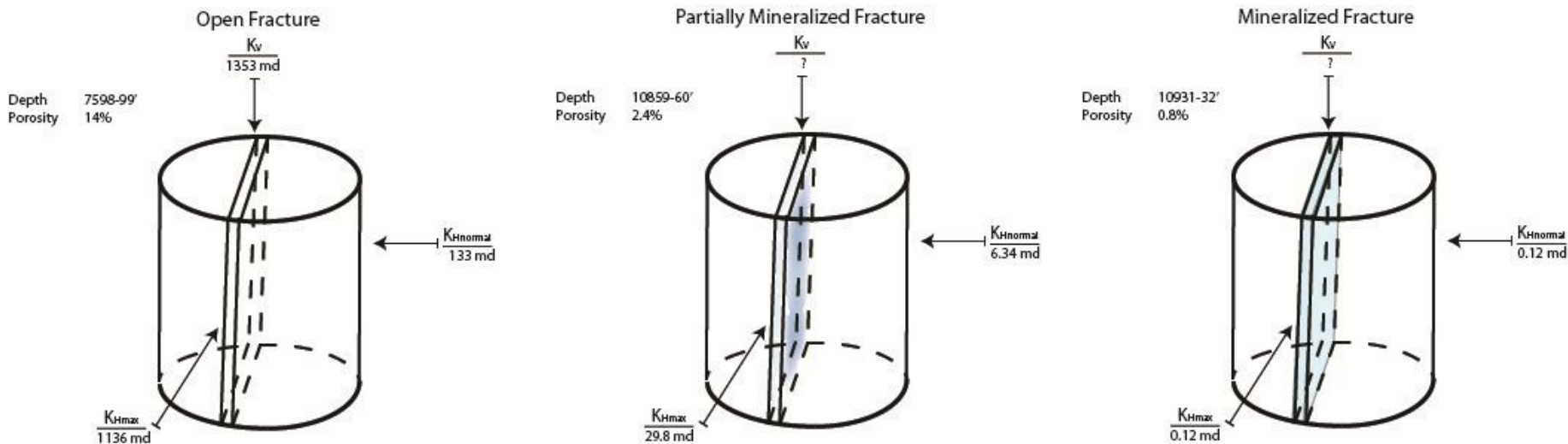
Depth 7677-68'  
Porosity 13.7%



After Nelson, 2001



# Joint Permeability Effect



After Nelson, 2001

Large uncertainty in determining the permeability of partially and fully mineralized joints!

# Aperture

- Partially or fully mineralized
- Often irregular (asperities, bridges, etc.)
- Measured in core or thin section
- Calculated in image logs
- Kinematic aperture versus effective aperture
- Related to porosity and permeability
- Changes with stress-state
  - Dependent on cement strength

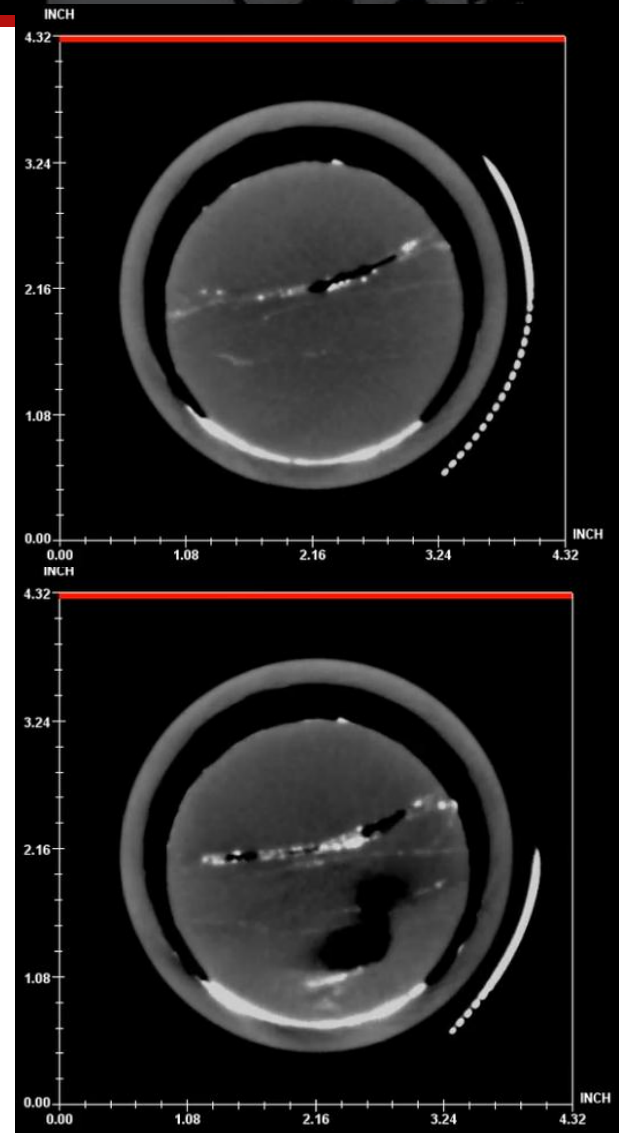
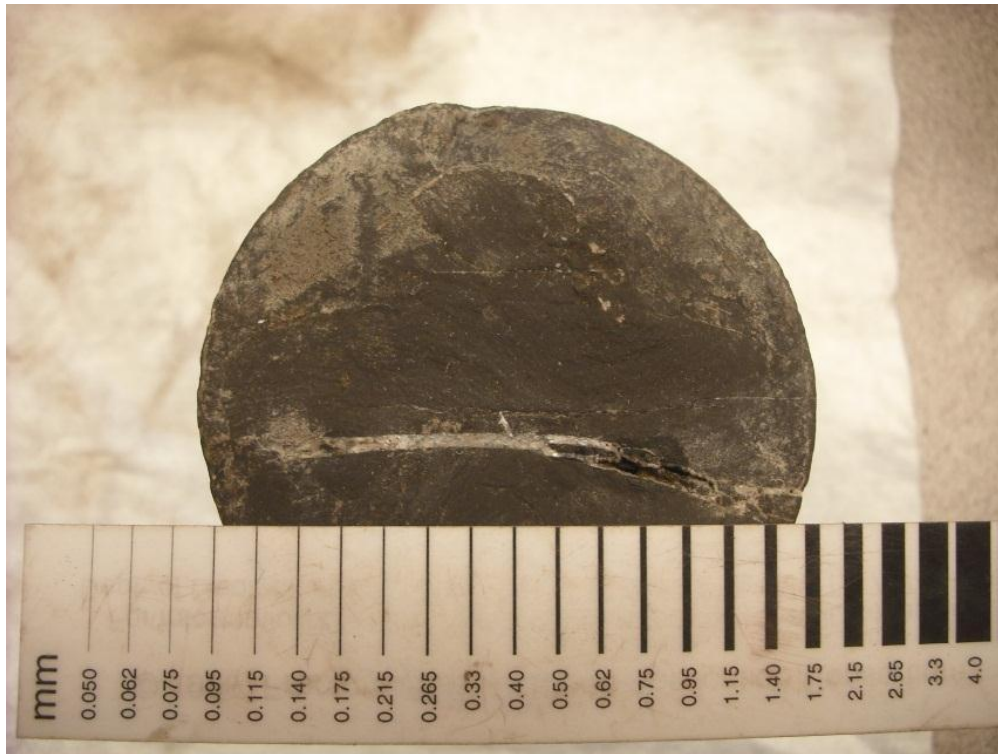


# Effective Aperture

- Kinematic aperture
  - Cubic-law could be used if:
    - Ideal open fracture
    - No asperities, cement bridges, etc.
    - Laminar flow of a Newtonian fluid
- Fracture roughness
  - Joint Roughness Coefficient
- Percent Contact Area
- Percent mineralization
  - Mineralization threshold values

Large uncertainties

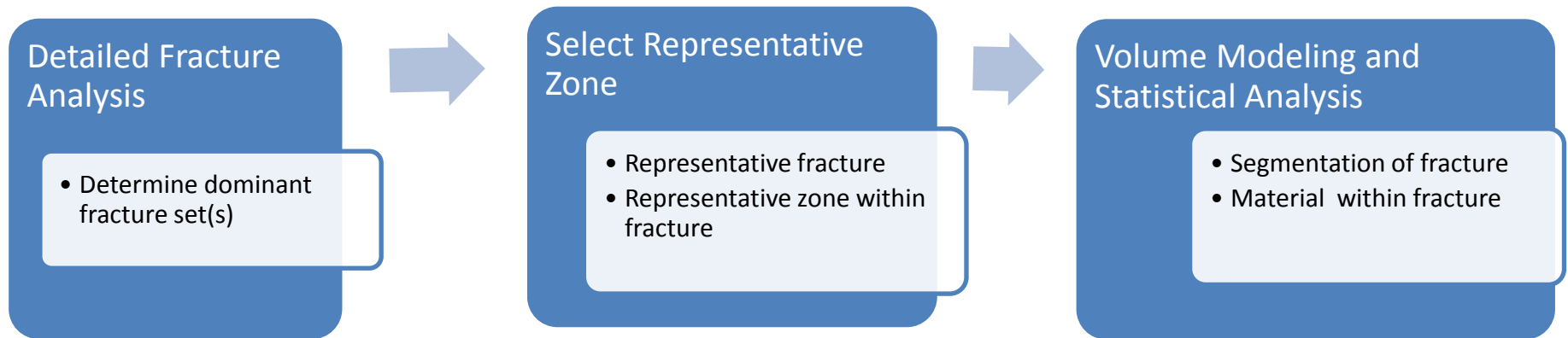
# Helical CT Scanning





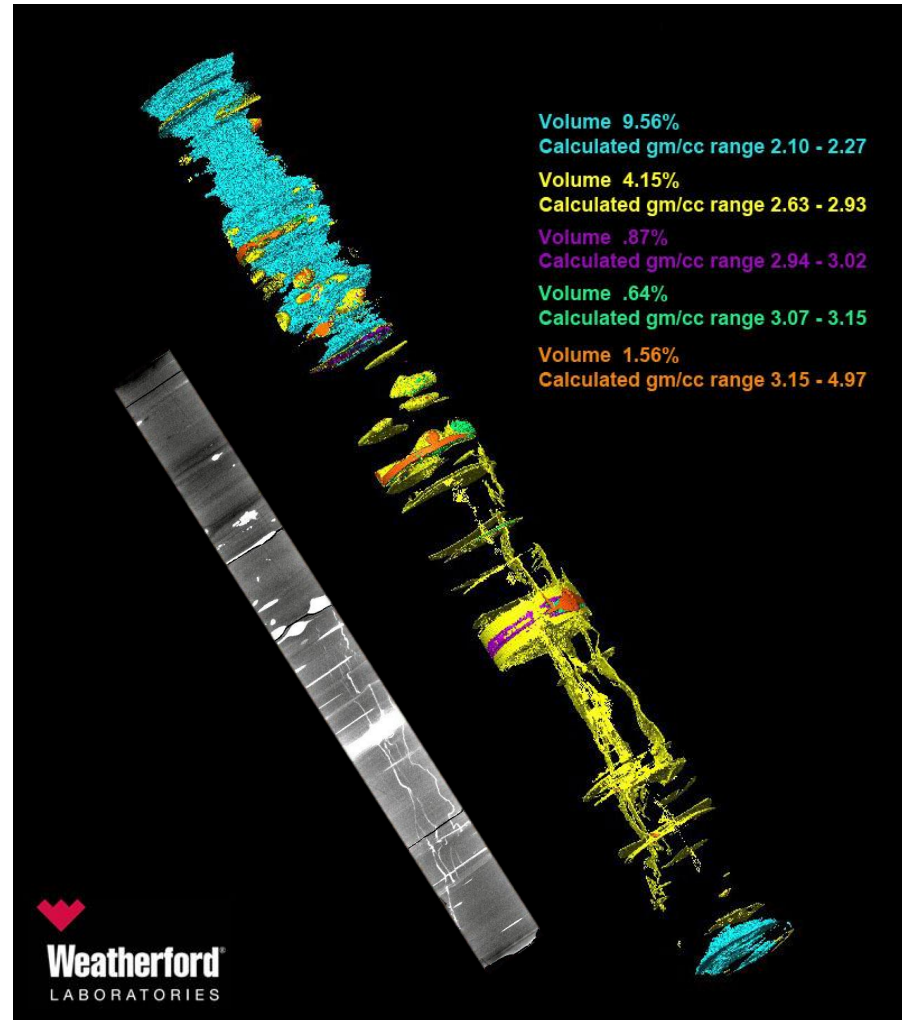
# Fracture Volume Modeling

- Volume modeling can help to determine:
  - Volume of pore space
  - Volume of mineralization
  - Connectivity of porosity



# 64 Slice Helical CT Scanner

- Converted medical scanner
- 0.3 mm voxel resolution
- Approx. 3200 data points per 3ft.
- CT Number and Calculated Density
- Avizo Fire<sup>®</sup> Software for volume modeling



# Avizo® Fire Volume Modeling

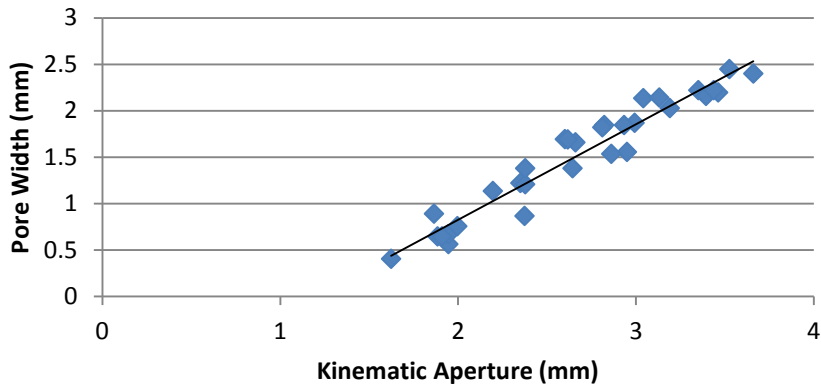
The screenshot displays the Avizo software interface for fire volume modeling. The main window is titled "Avizo - Fire Edition - 11542\_Joint\_Fill\_Pore\_Volume.hx". The interface is divided into several panels:

- Top Panel:** Contains the menu bar (File, Edit, Project, Create, View, Window, Segmentation, Selection, Help) and a toolbar with icons for file operations, view toggling, and help.
- Main Panel:** The central workspace showing a 3D visualization of a fire volume model. The model is a complex, branching structure with a green and yellow color scheme, overlaid on a circular cross-section. The coordinates are shown as "# 116/190 [XY]".
- Right Panel (Main Panel):** Contains the "Project View" and "Materials" sections. The "Project View" shows the current project name "11541.00-2.modif" and the "Label field" "11541.00-2.labels". The "Materials" section lists three materials: "Exterior" (blue), "FractureFill" (purple), and "FracturePorosity" (yellow), each with a "select" button and visibility icons for 3D and 2D views.
- Bottom Panel:** Contains four 2D slice views of the 3D model. The top-left slice is labeled "# 135/272 [XZ]" and the top-right slice is labeled "# 138/278 [YZ]". The bottom-left and bottom-right slices are unlabeled but show similar cross-sections. The "Zoom and Data Window" is visible above the slices, showing a zoom level of "1:1" and a value of "1658.77".
- Bottom-Right Panel:** Contains the "Selection" and "Tools" sections. The "Selection" section includes a "3D Lasso" tool and options for "Volume", "Current slice", and "Show in 3D". The "Tools" section includes a "Magic Wand" tool with a threshold value of "70.747" and a "Draw limit line" checkbox. The "Contrast threshold" is set to "1430.5".

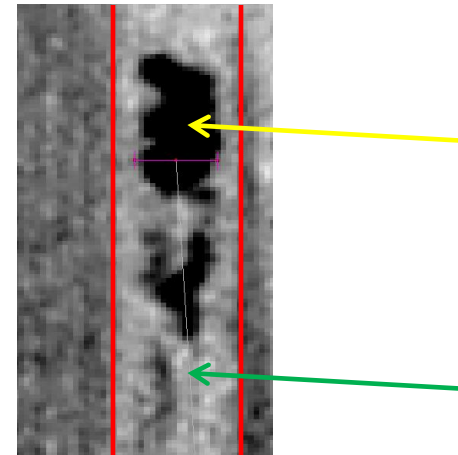
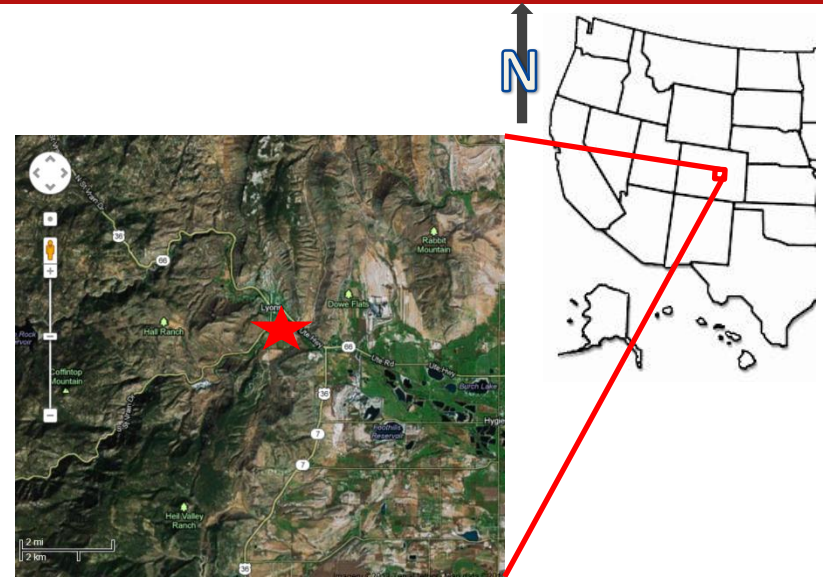
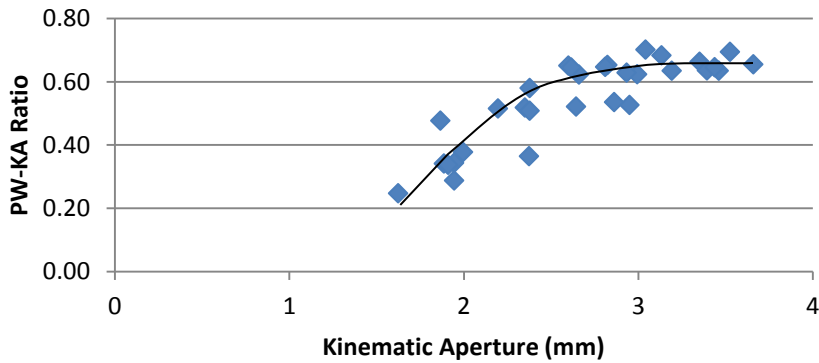
The Avizo logo and the Visualization Sciences Group (VSG) logo are visible in the bottom-left corner of the main panel.

# Width Measurements

## Kinematic Aperture vs. Pore Width



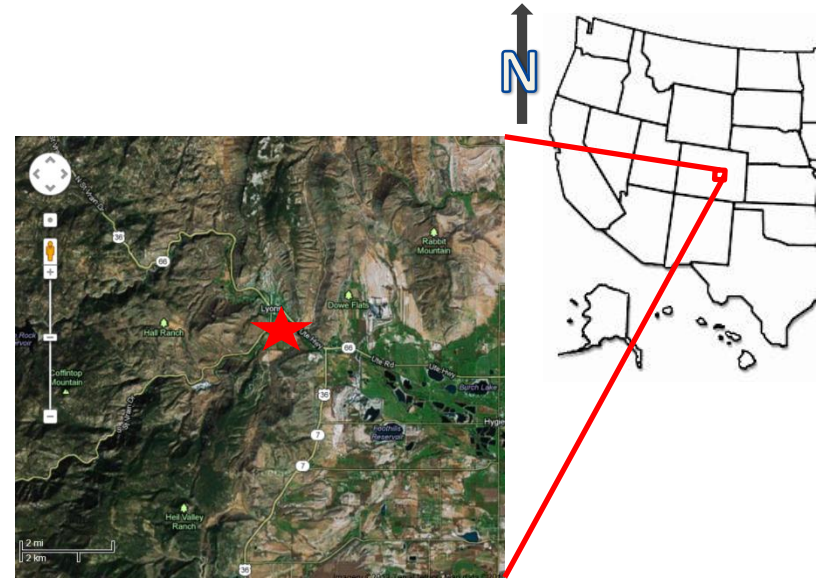
## Pore Width-Kinematic Aperture Ratio



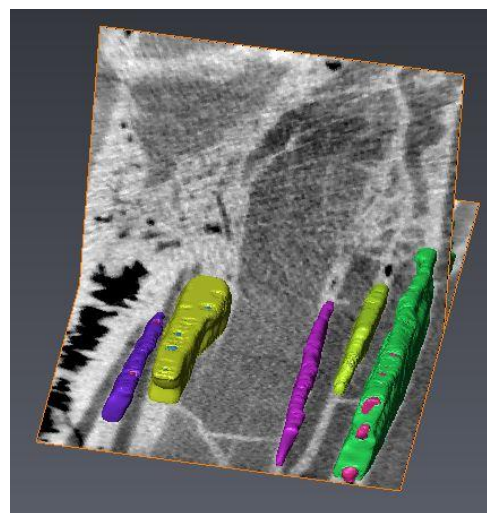
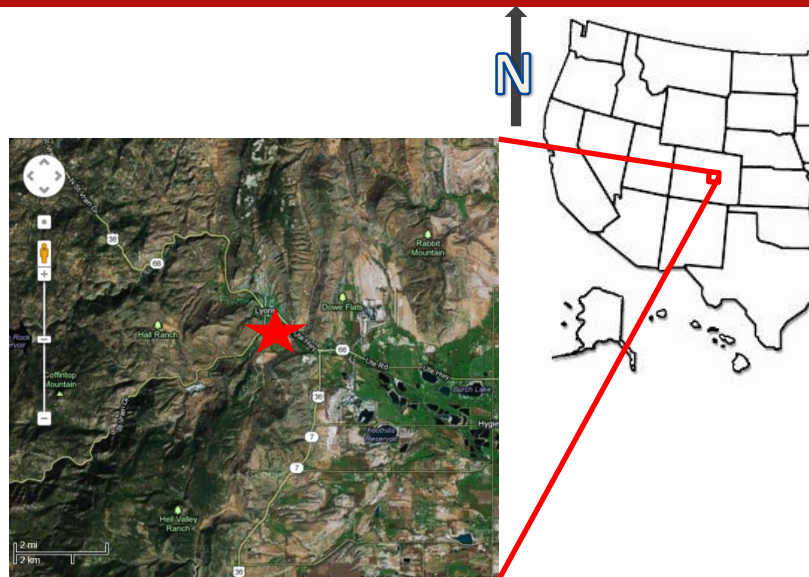
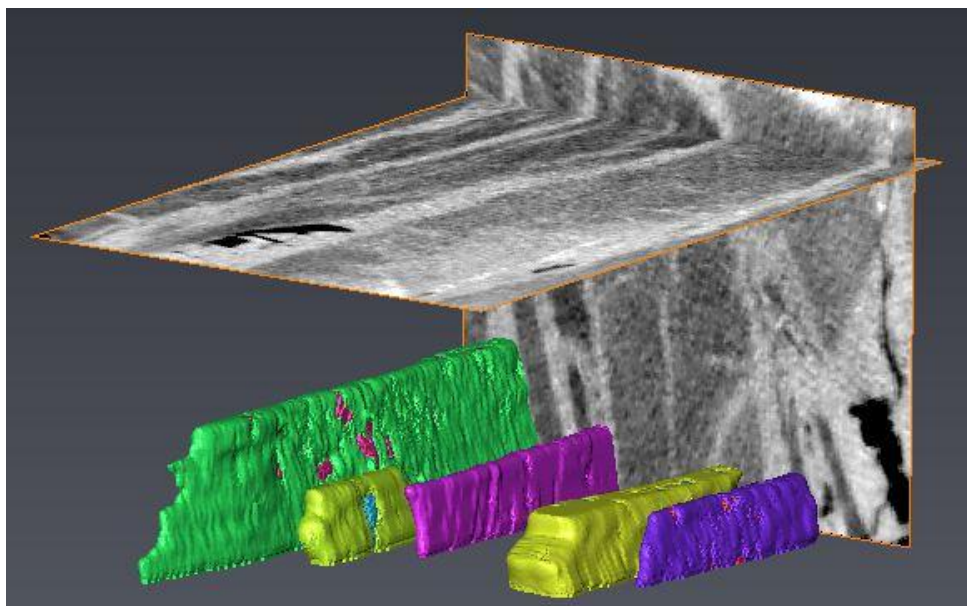


# CEMEX Quarry

- Cretaceous Niobrara Formation
- CEMEX Quarry
- Calcite-filled

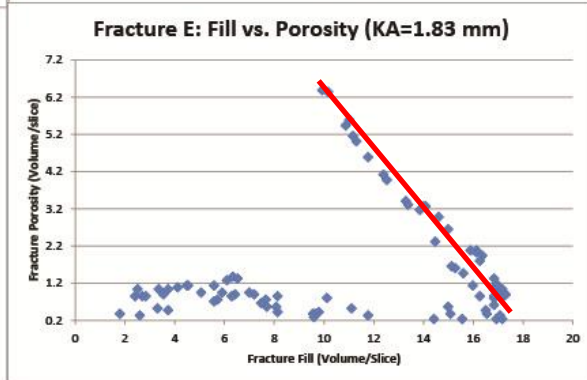
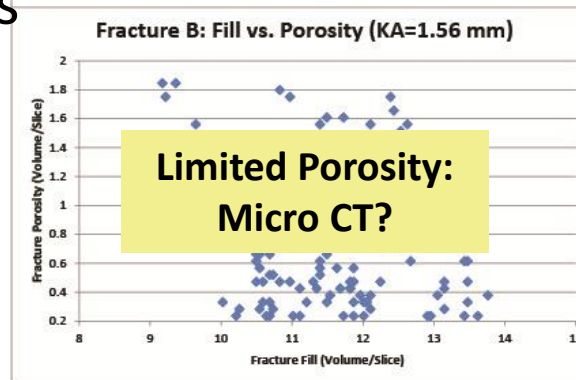
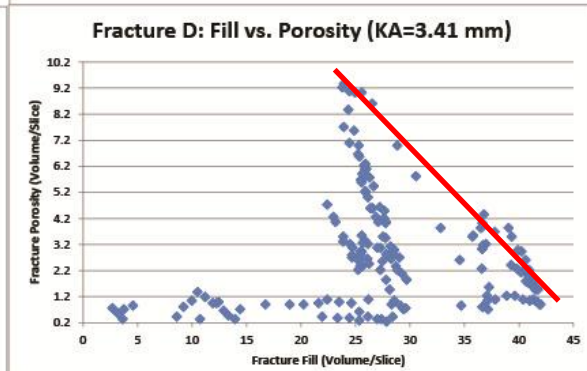
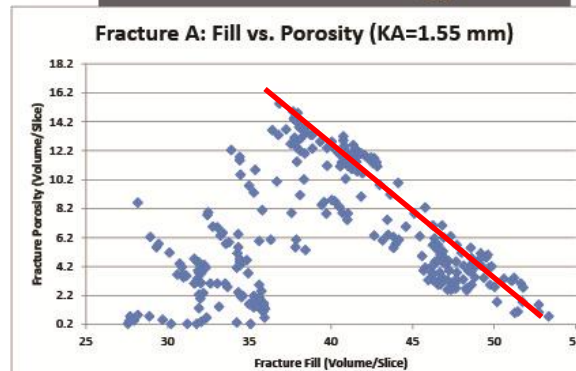
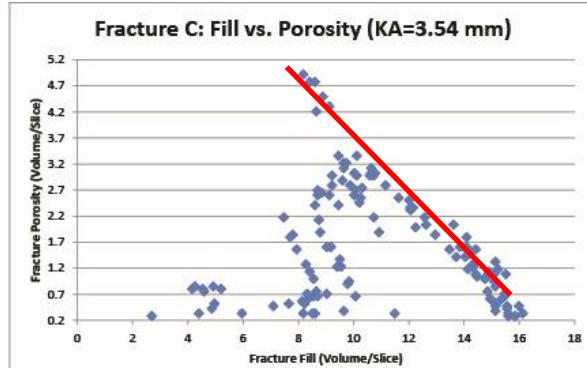
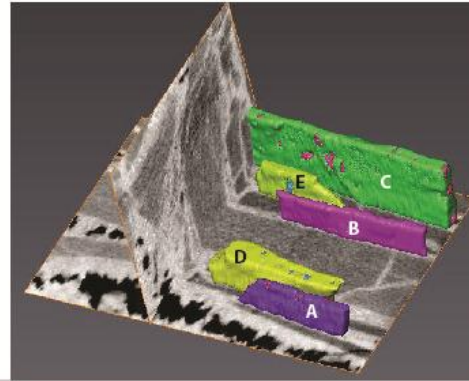


# CEMEX Quarry



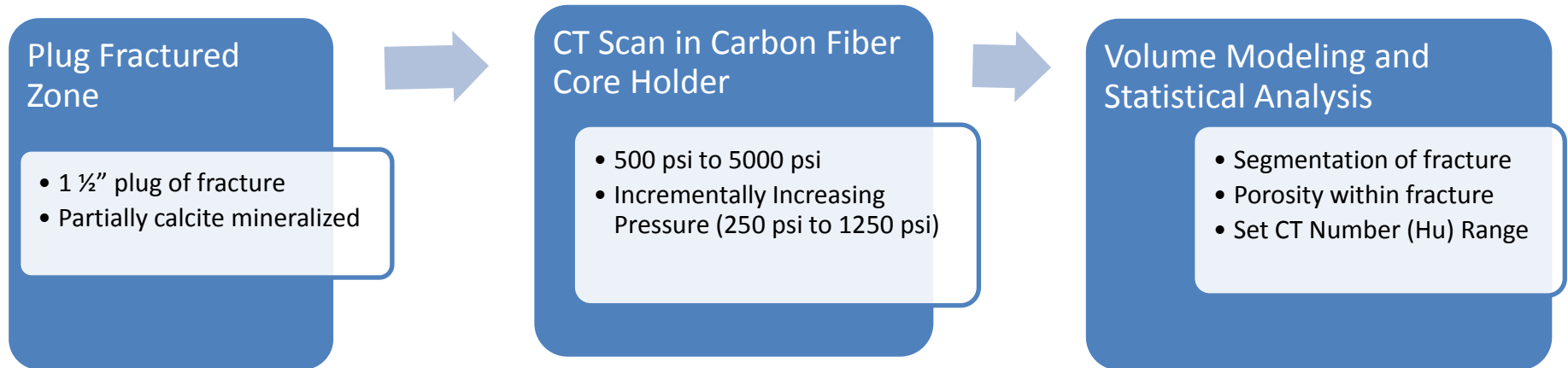
# Volume Modeling

- Multiple threshold peaks where porosity is preserved
- Peak in porosity in variable aperture fractures (A, C, and D)
- Final decline in porosity where cement bridges exist holding the fractures open (red lines)



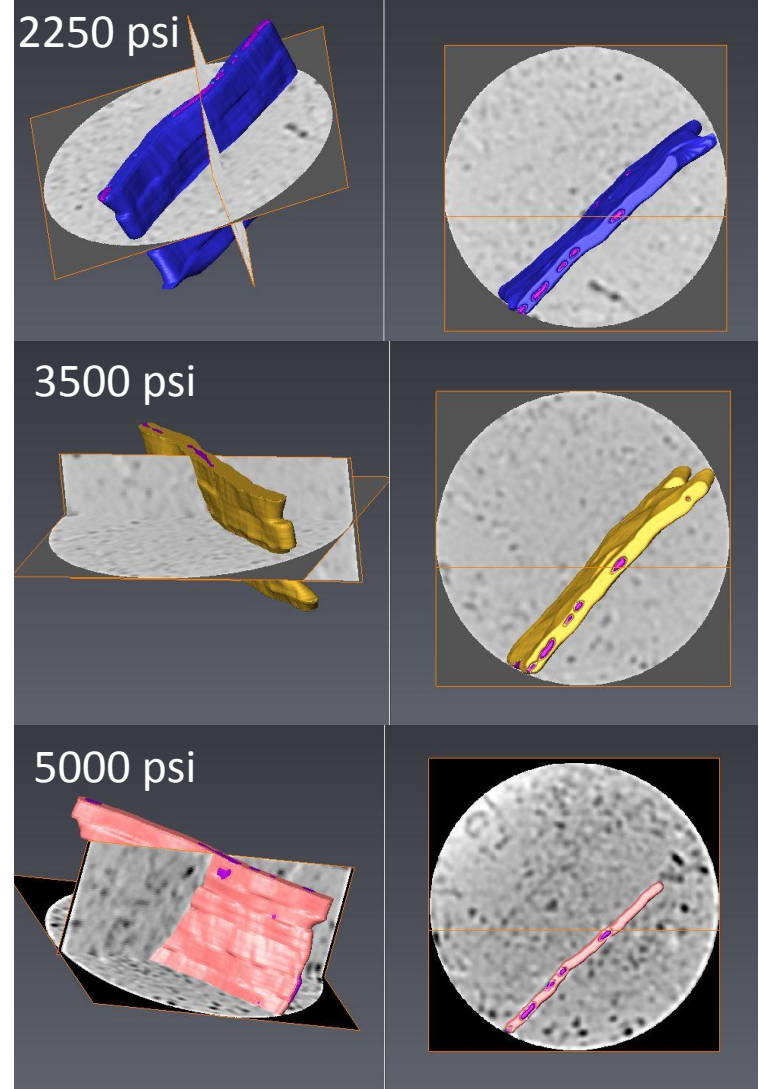
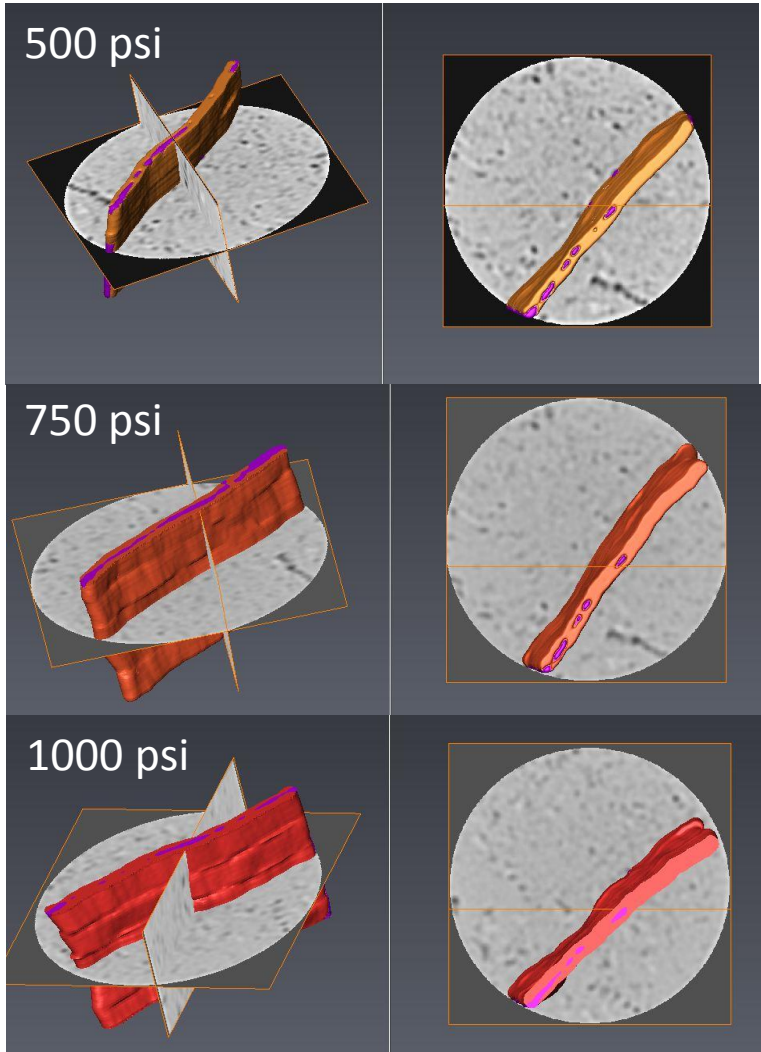
# Confining Pressure Test

- Core is not at reservoir conditions
- Porosity and permeability are maximum values
- Get to subsurface conditions for more realistic values



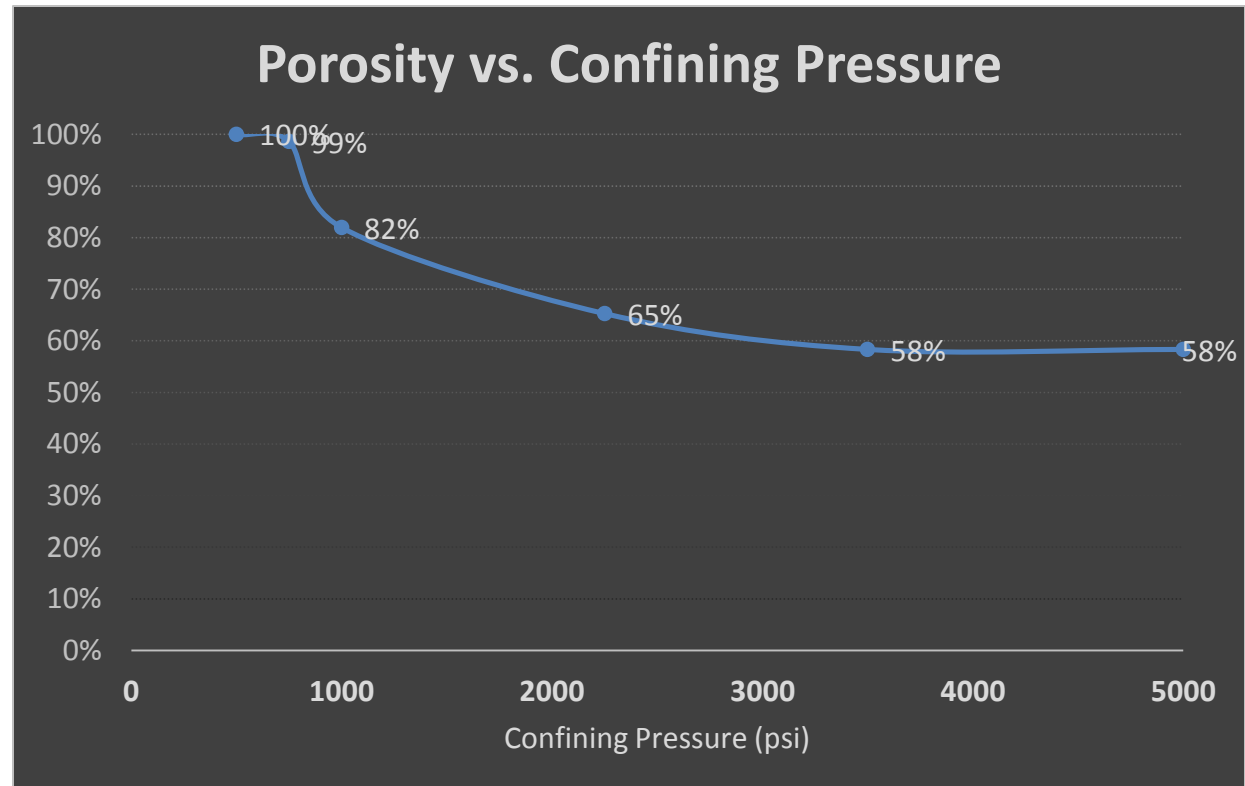


# Fracture Volume Modeling (BEG)



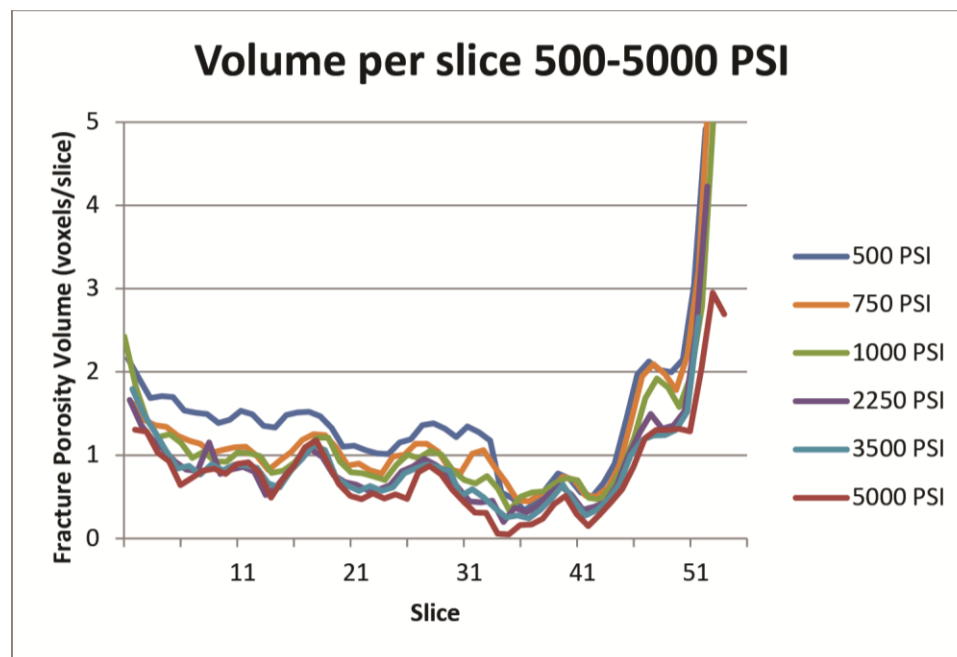
# Confining Pressure Intervals

- Rapid drop in porosity at ~800 psi
- Little change in porosity after ~2500 psi
- Fracture “closes” after confining pressure is applied, but 58% of porosity remains



# Confining Pressure Intervals

- Margins reflect anomalously high porosity from coring
- Rapid decrease in porosity with at ~800 psi
- Appears relatively steady from 2250 psi to 5000 psi
- Variable across the fracture



# Conclusion

- Kinematic aperture is not sufficient data
- Core must be pressurized for accurate porosity calculations
- With advances in CT scanning and software we can:
  - Visualize 3D volumes of materials within fractures
  - Quantify fracture porosity
  - Bring core closer to reservoir conditions by pressurizing samples
  - Find the porosity volume preserved in a partially cemented fracture
  - Distinguish between kinematic and effective aperture in the subsurface
- Are all fractures closed under stress??? -Not really



# Challenges

- Including pore pressure
- Pore connectivity must be applied
- Resolution does not allow imaging of hairline fractures
  - Common in core

## Future Analyses

- Include pore pressure
- Map pore connectivity to fractures “closed” under stress
- Porosity/matrix connectivity
- Anisotropic stress
- Micro-CT for hairline fractures



# Thank You

## Questions?