

# **Rock Physics Constraints on Seismic Signatures of Fractures**

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# Objective

Relate seismic attributes to fractures,

... by *quantitatively* integrating

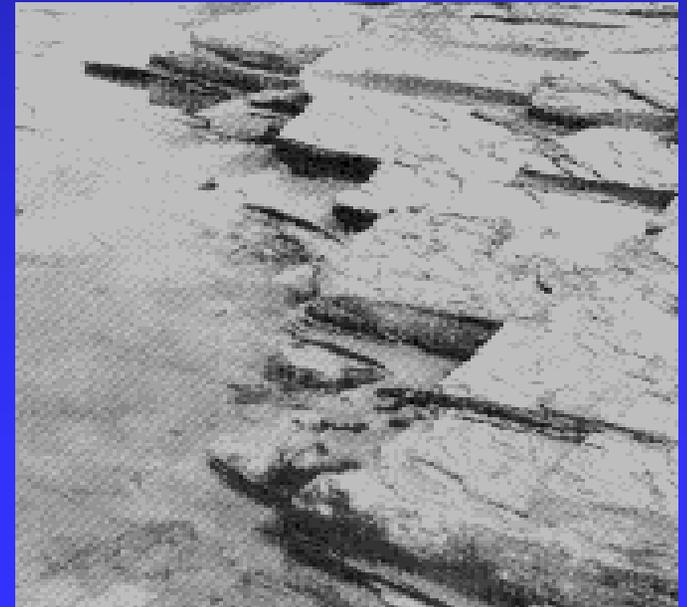
- Multi-attribute seismic
- Well logs
- Geology

... using Rock Physics

# Why Worry About Fractures?

They dominate permeability:

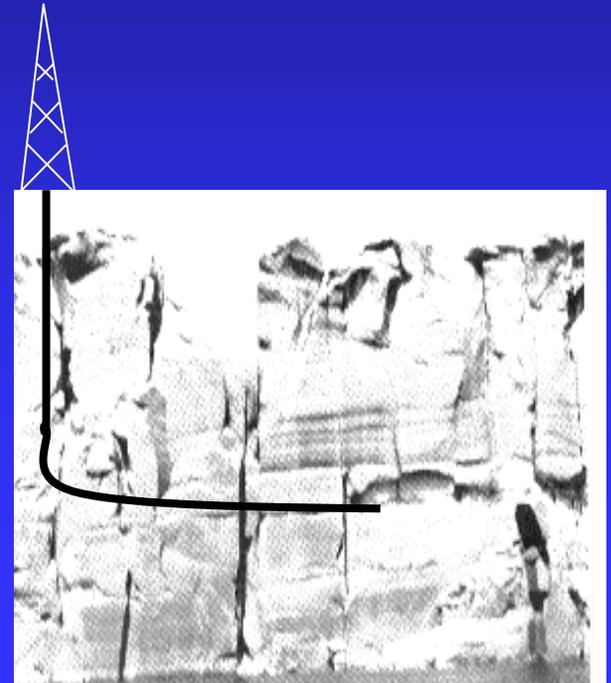
- Can make tight gas economical



# What do we need to know?

Where to find “Sweet Spots” for drilling

- Fracture location
- Fracture intensity
- Fracture orientation
- Gas, oil, or water?
- Permeability



# Rock Physics

Discover, understand relations between

- **Seismic Attributes:**

- Velocity, Impedance
- AVO, Reflectivity
- Attenuation

- **Rock and Fluid Properties:**

- *Fractures*
- *Gas vs. Oil vs. Water*
- Rock type, porosity, mineralogy
- Stress, Pore, Pressure, Temperature

# Fractures Can Have Many Seismic Attributes

- Low P- and S-wave velocities
- Anomalous reflectivity (Impedance)
- Low Q (high seismic attenuation)
- Low Poisson's Ratio ( $V_p/V_s$  ratio)
- Anomalous AVO
- Azimuthal variation in velocity, AVO

... the optimum choice will vary from site to site

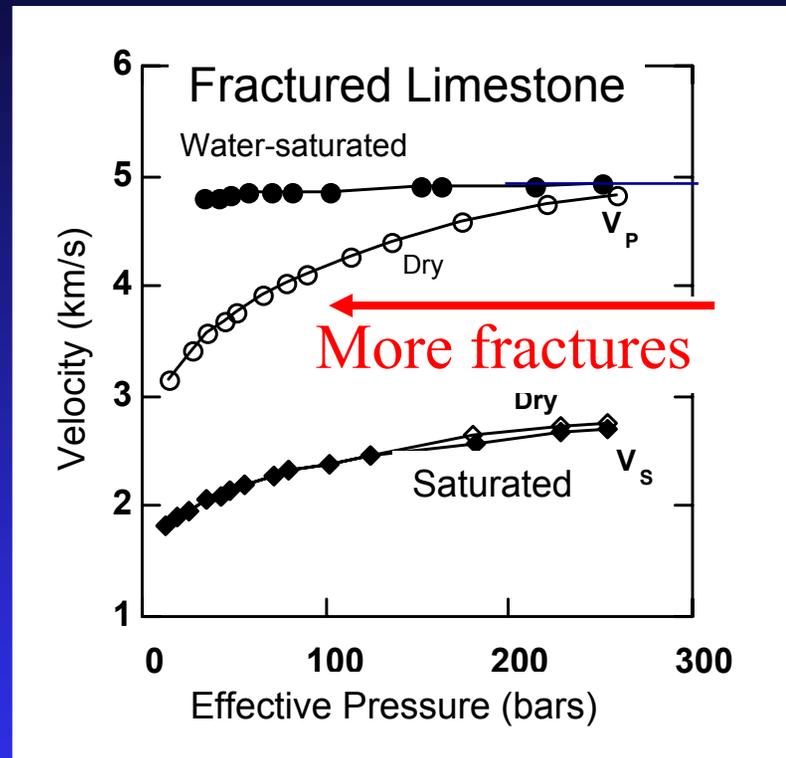
Site-to-site variations result from:

- Rock type
- Fracture geometries
- Fluids
- Acquisition geometries
- Business objective/constraints

... there is no “silver bullet” that works everywhere.

# Seismic Velocity

# Velocity Indicator of Fractures



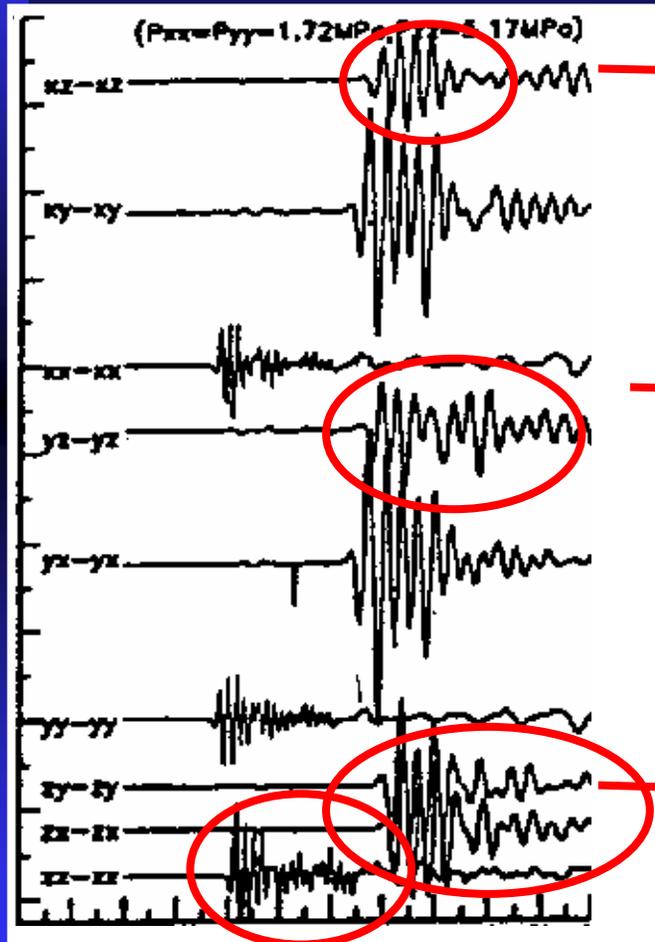
Adding Fractures:

- Lowers Seismic Velocities
- Change Seismic V<sub>p</sub>/V<sub>s</sub> ratio

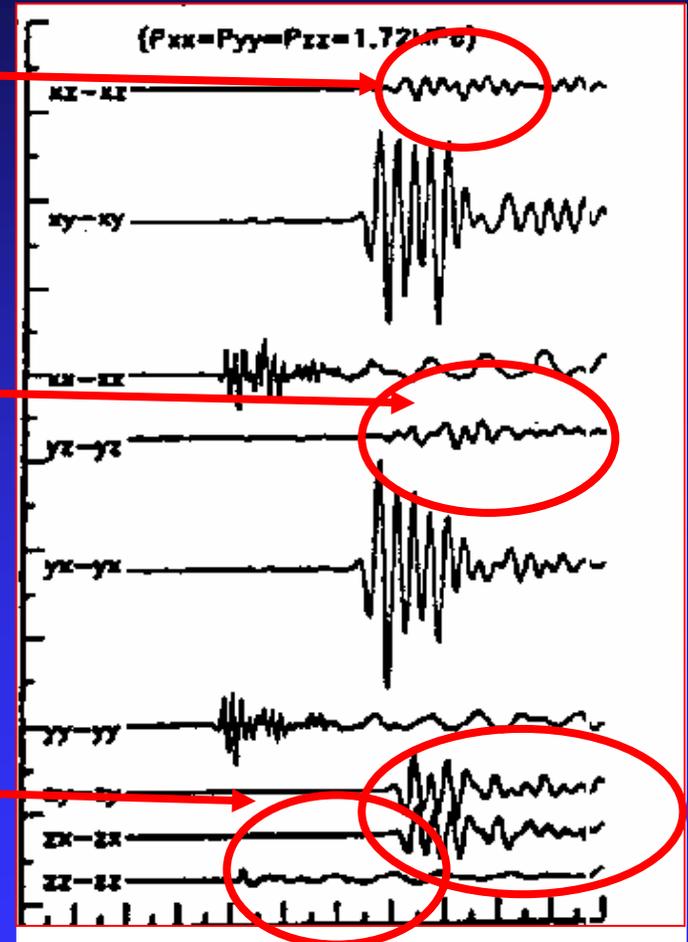
# Seismic Attenuation

# Attenuation Indicator of Fractures

Unfractured



Fractured

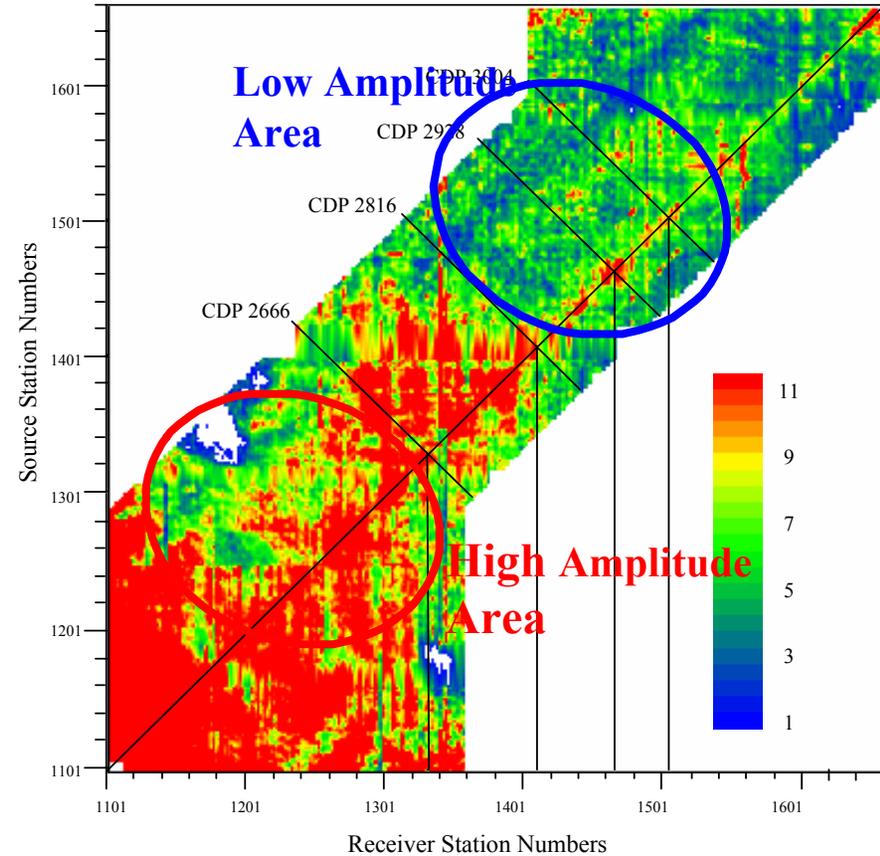
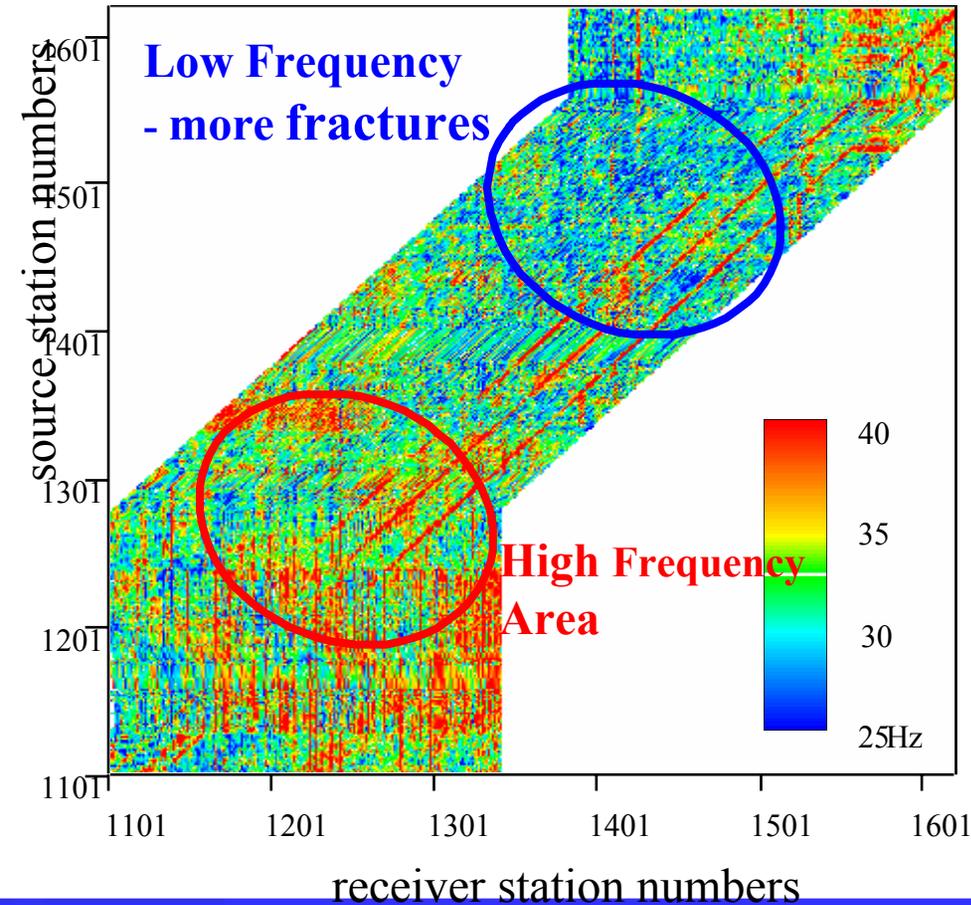


Adding Fractures: changes amplitude & frequency

# Frequency/Amplitude

## Tight Sands - Powder River Basin

Line 2: Surface-consistent RMS Amplitude (event at 2.5 seconds)

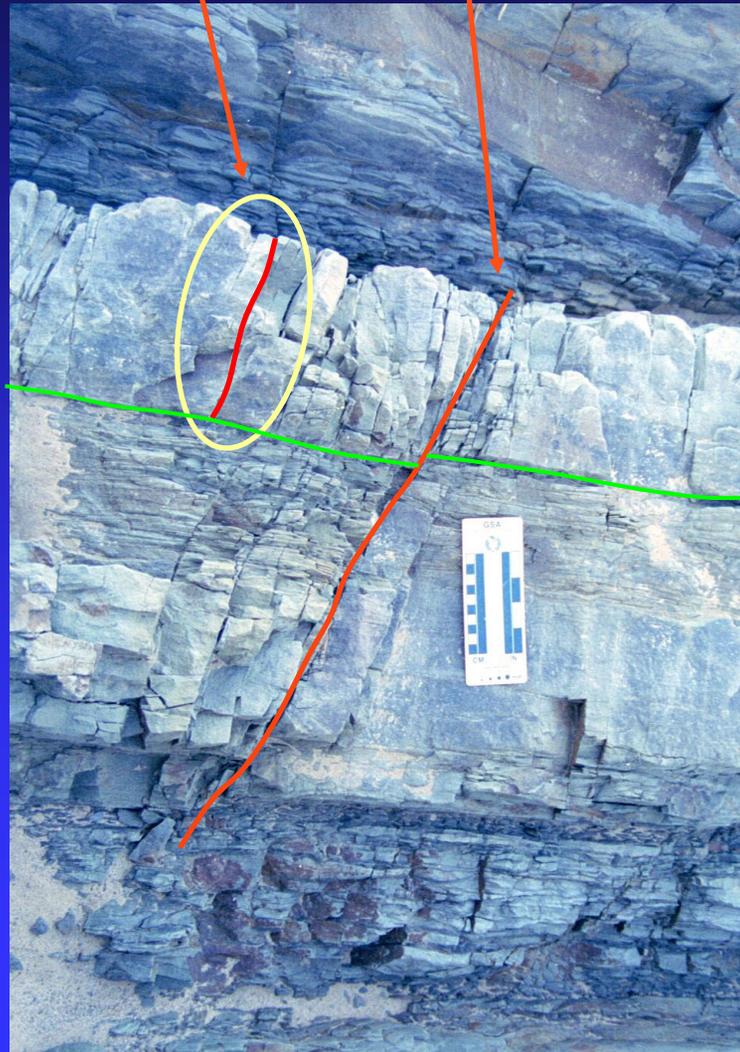


# Seismic Facies

# Fractures Often Prefer Certain Lithofacies

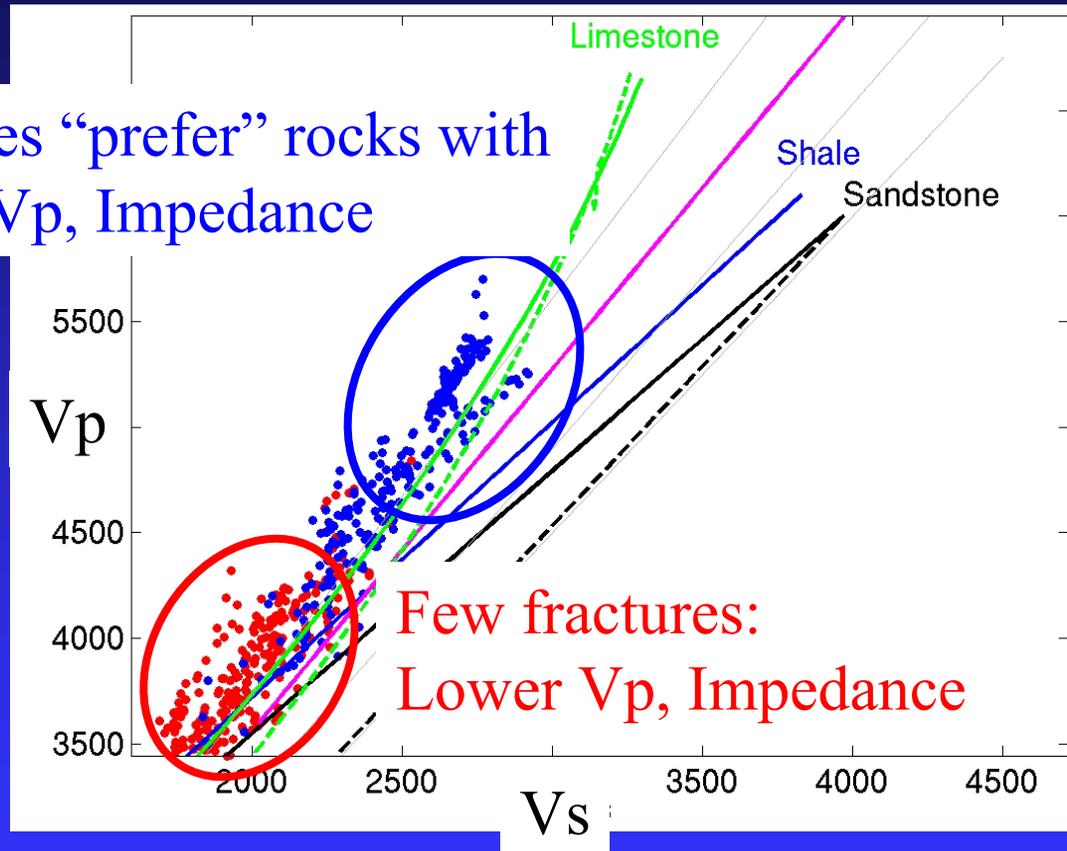
Joint

Sheared Joint



# Seismic Indicator of Fracture-Preferred Lithofacies

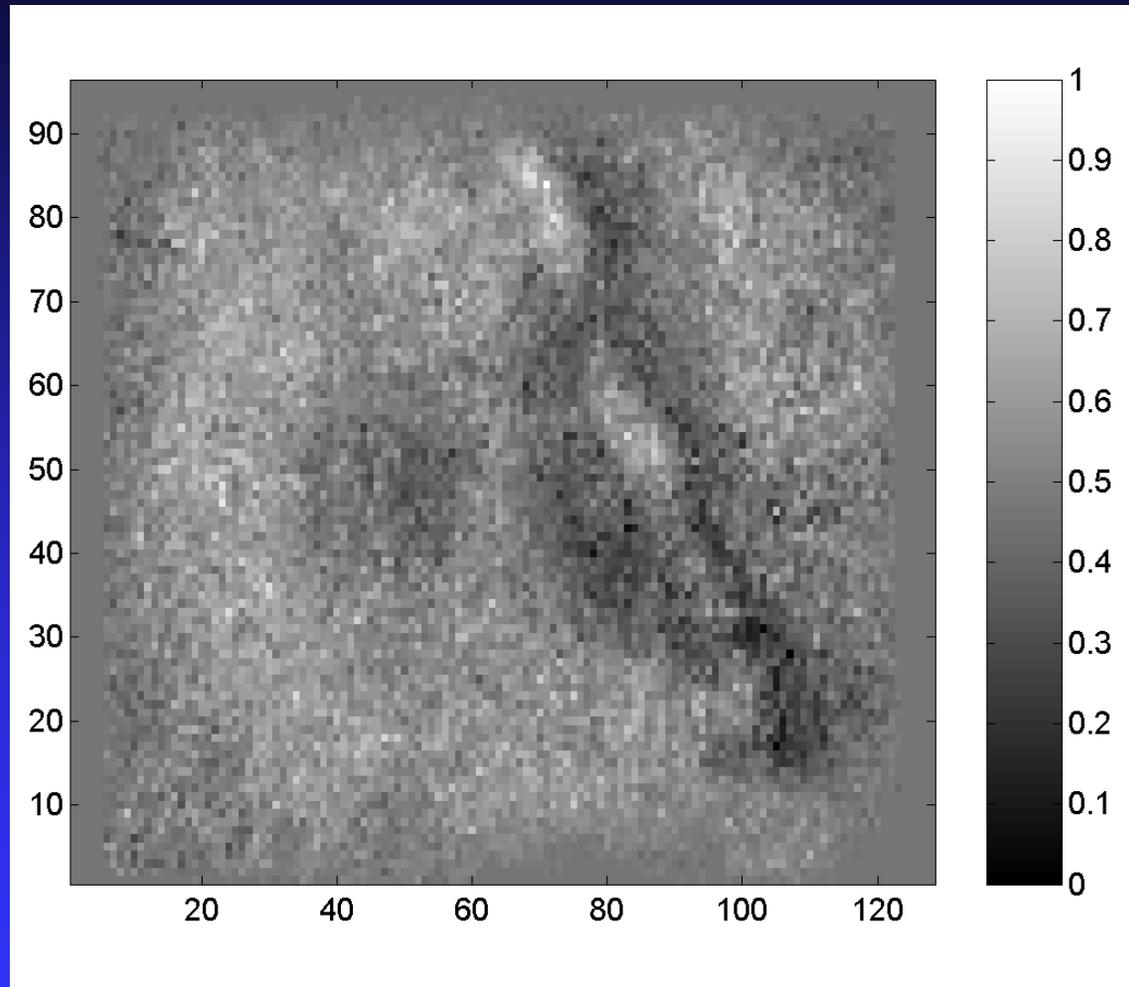
Fractures “prefer” rocks with higher  $V_p$ , Impedance



... and we might detect the facies more easily than the fractures

# Seismic Amplitude

# Amplitude Indicator of Fractures

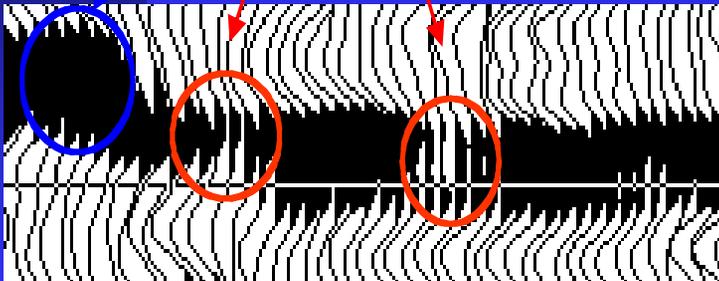
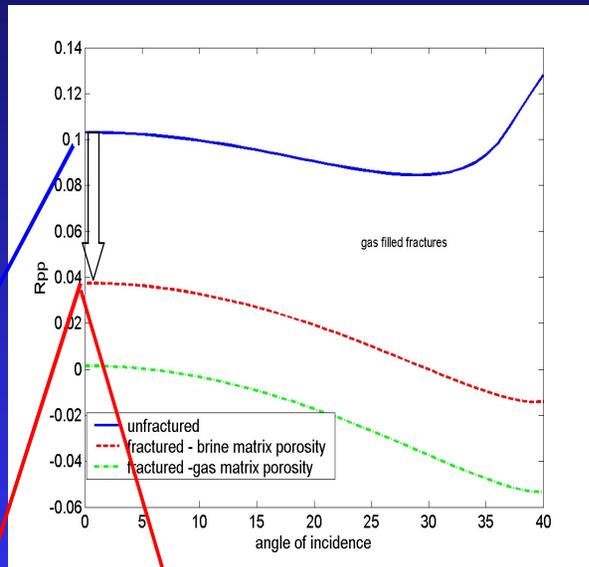


Fractures elastically soften the rock, changing the elastic impedance, and lowering reflectivity.

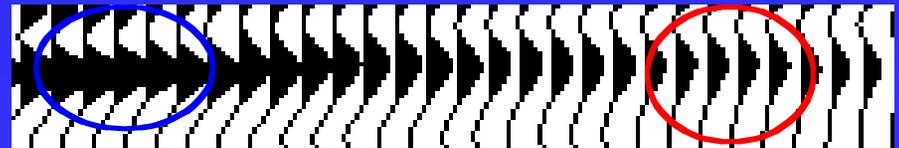
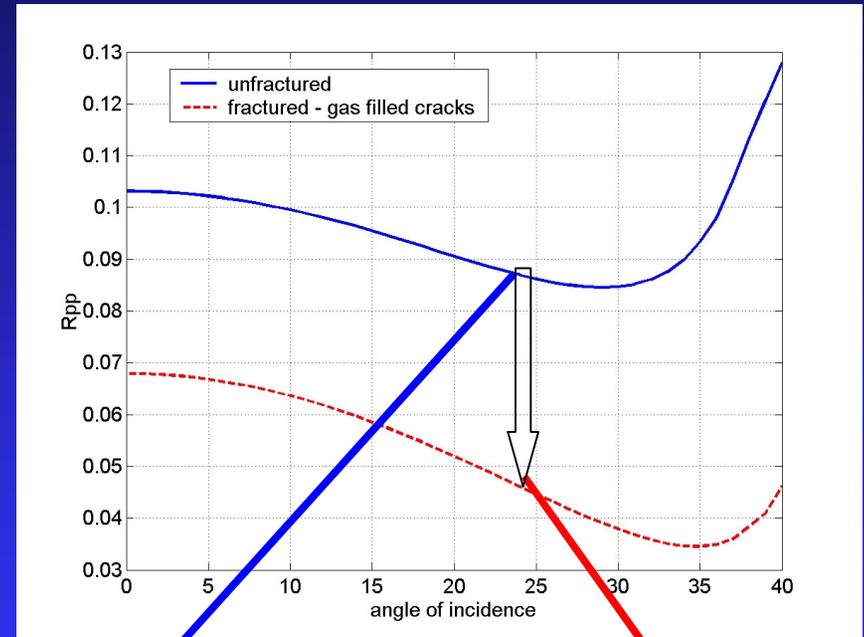
# Tight Limestone

## Anomalous Stack Amplitude at Fracture clusters

3D Seismic



VSP

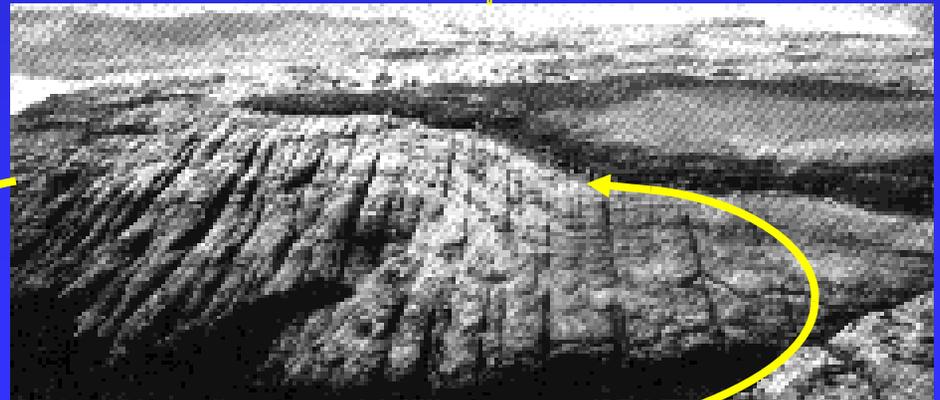
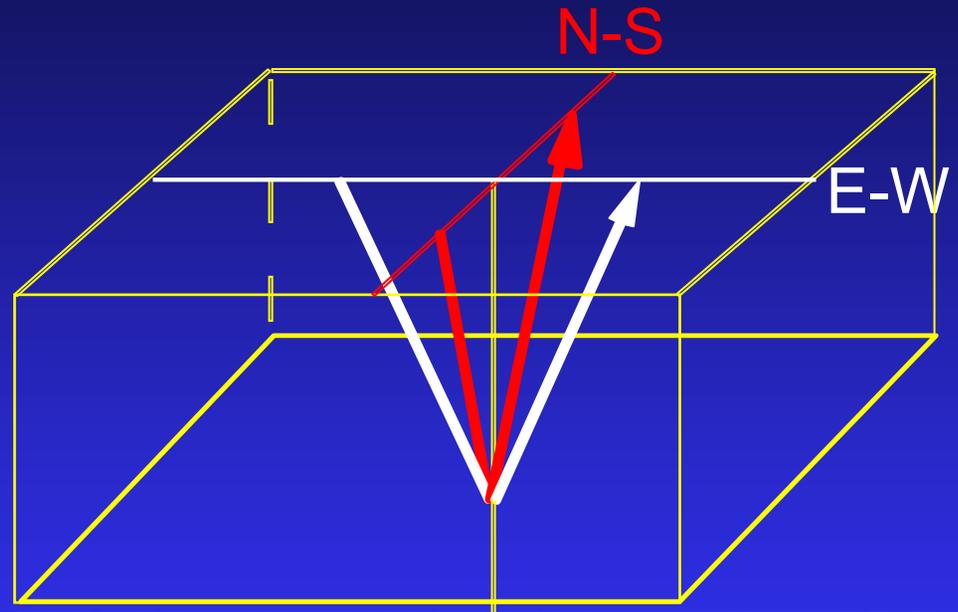


# ***Azimuthal Attributes***

# Azimuthal Seismic Attributes

3D Surveys yield azimuthal variations in:

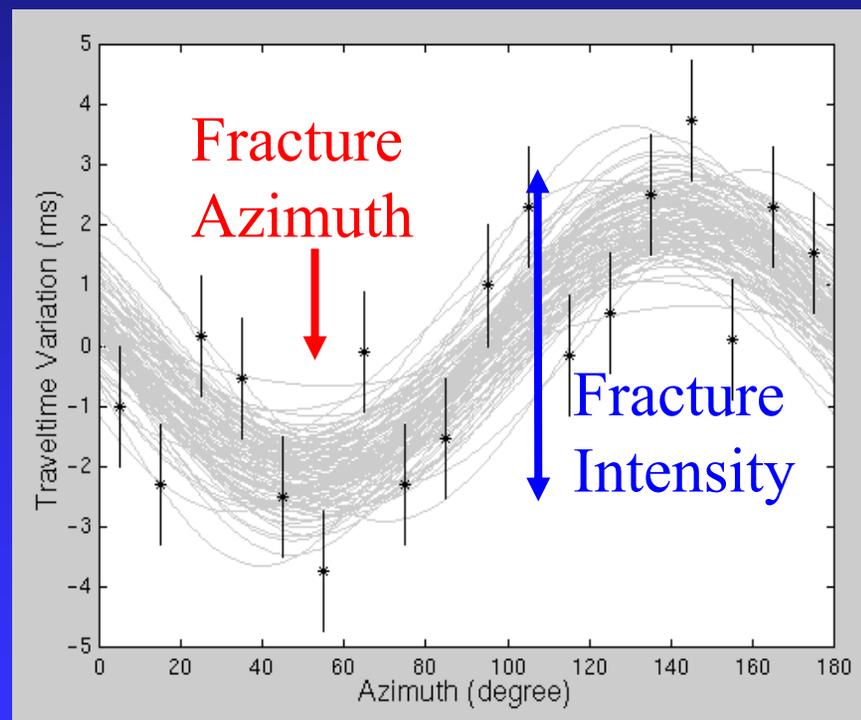
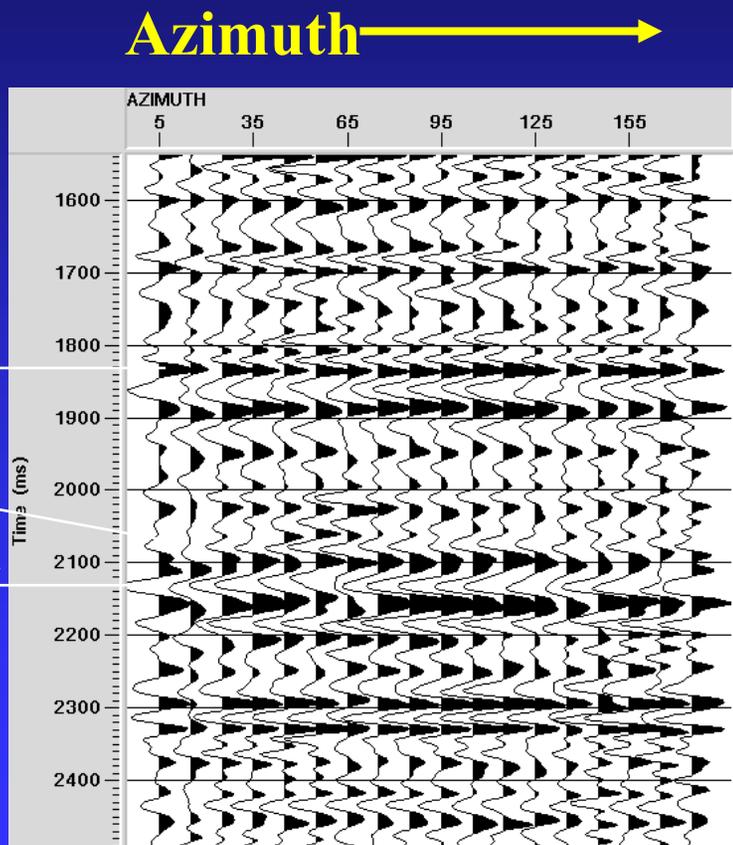
- NMO
- Amplitude
- Frequency/Q



# Tight Gas - Powder River Basin

## Azimuthal variations at a CMP Superbin

### Far offset azimuthal P- Traveltime variation



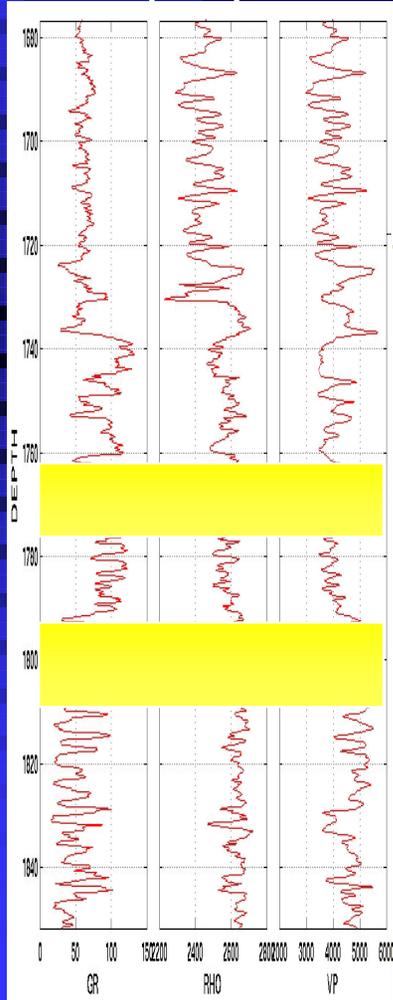
Far Offset (25-30°) P-wave

$\Delta t$  between top Sussex and  
bottom first Frontier sands

# Rock Physics Workflows

# Rock Physics Workflow

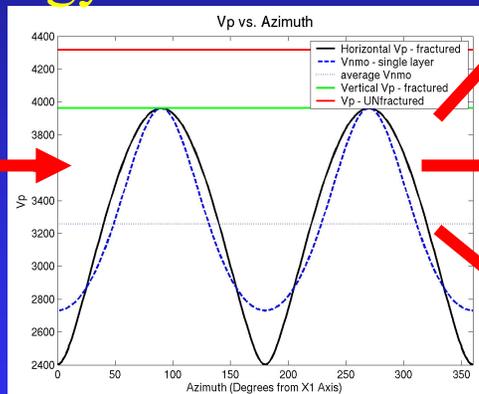
Logs:  
Site-specific  
Rock properties



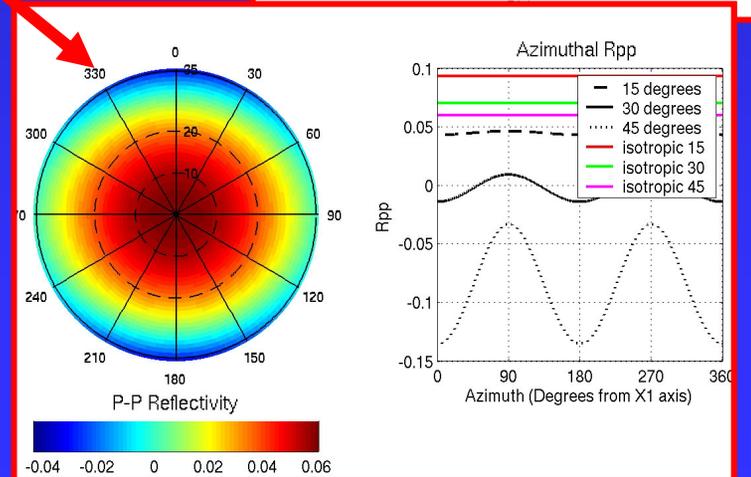
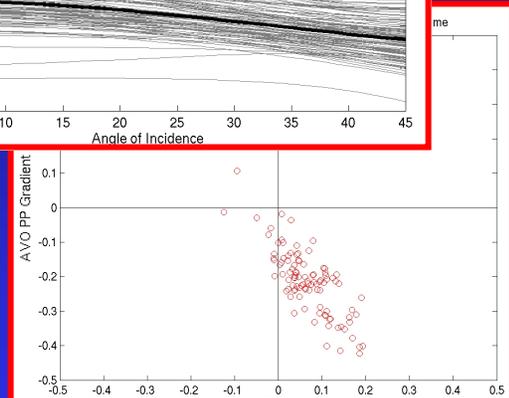
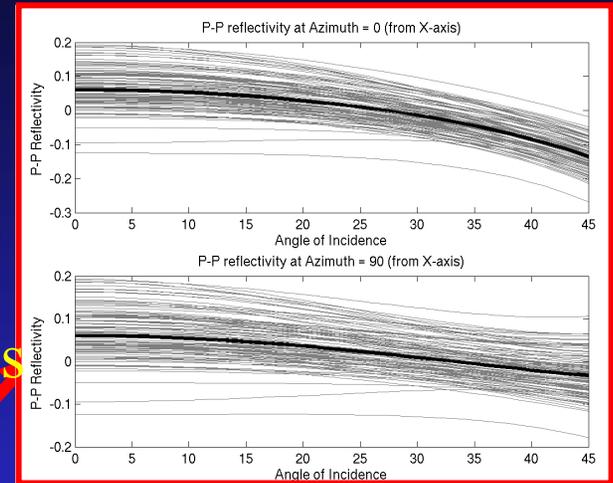
Specify

- Fractures
- Fluids
- Lithology

Compute  
seismic  
signatures

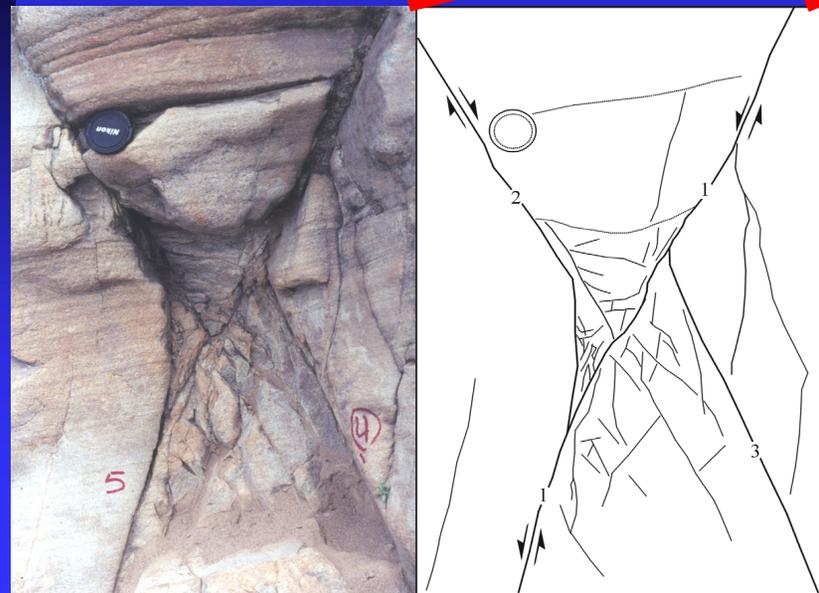
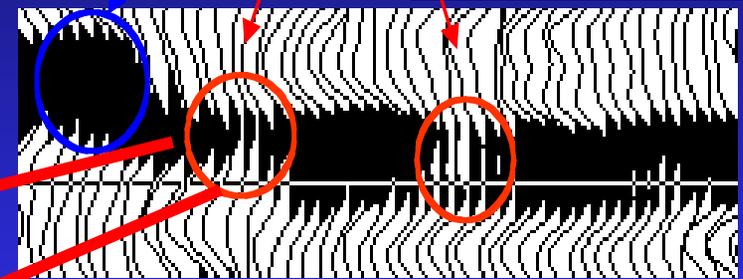
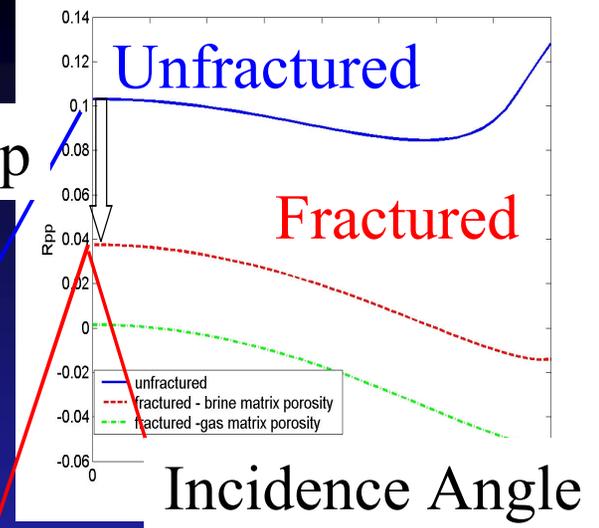


Fractured Interval  
Properties



# Fracture Details below Seismic Resolution

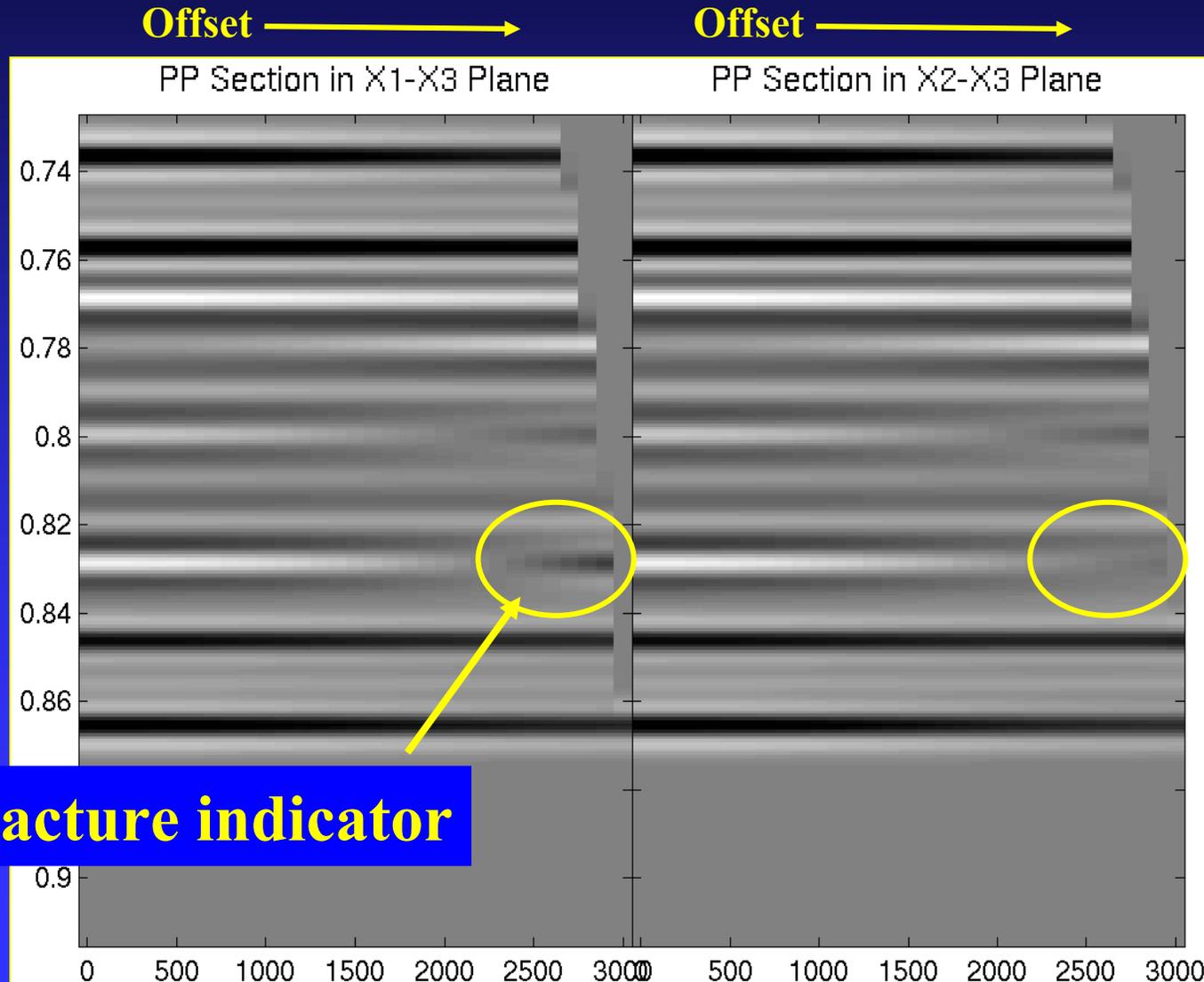
$R_{pp}$



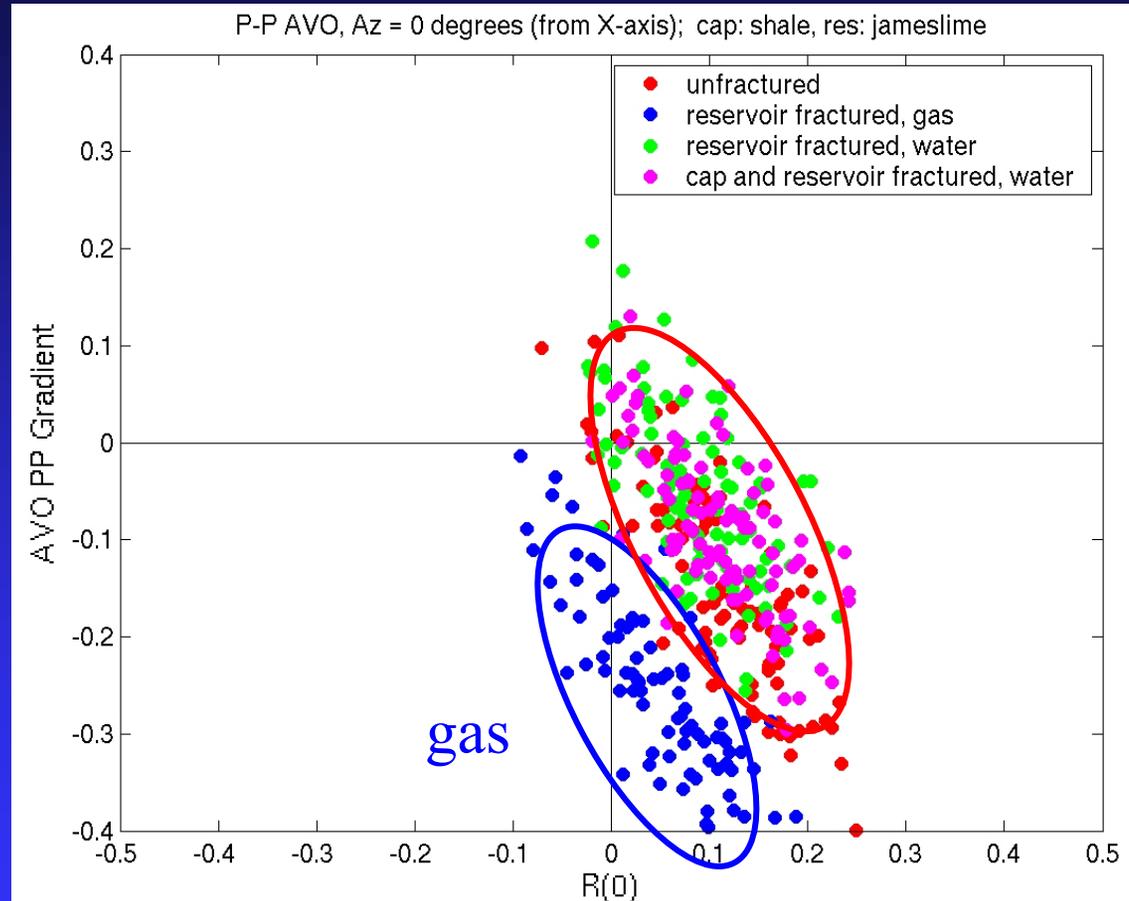
Anomalous Amplitude  
at Fracture clusters

# AVO

## Computed Anomaly: Gas-filled Fractures

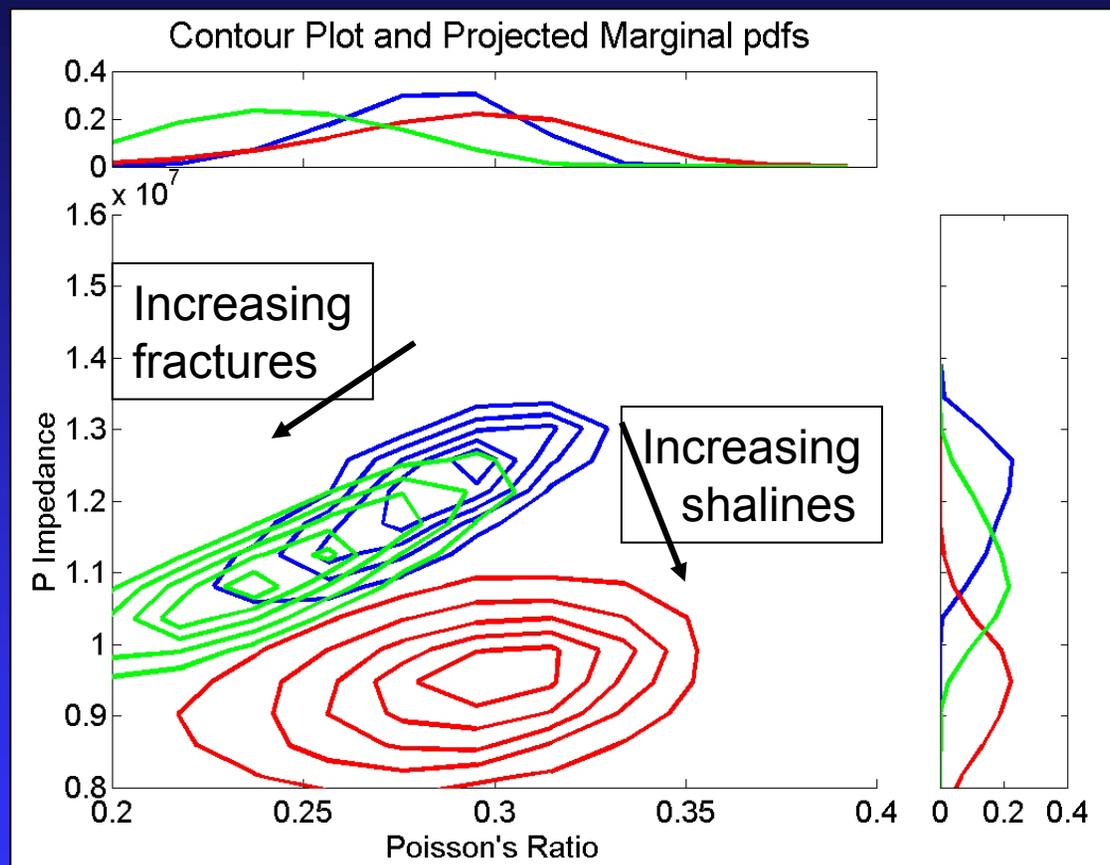


# Will We See the Fractures?



*...at this site, AVO can distinguish gas-filled fractures, but not water-filled.*

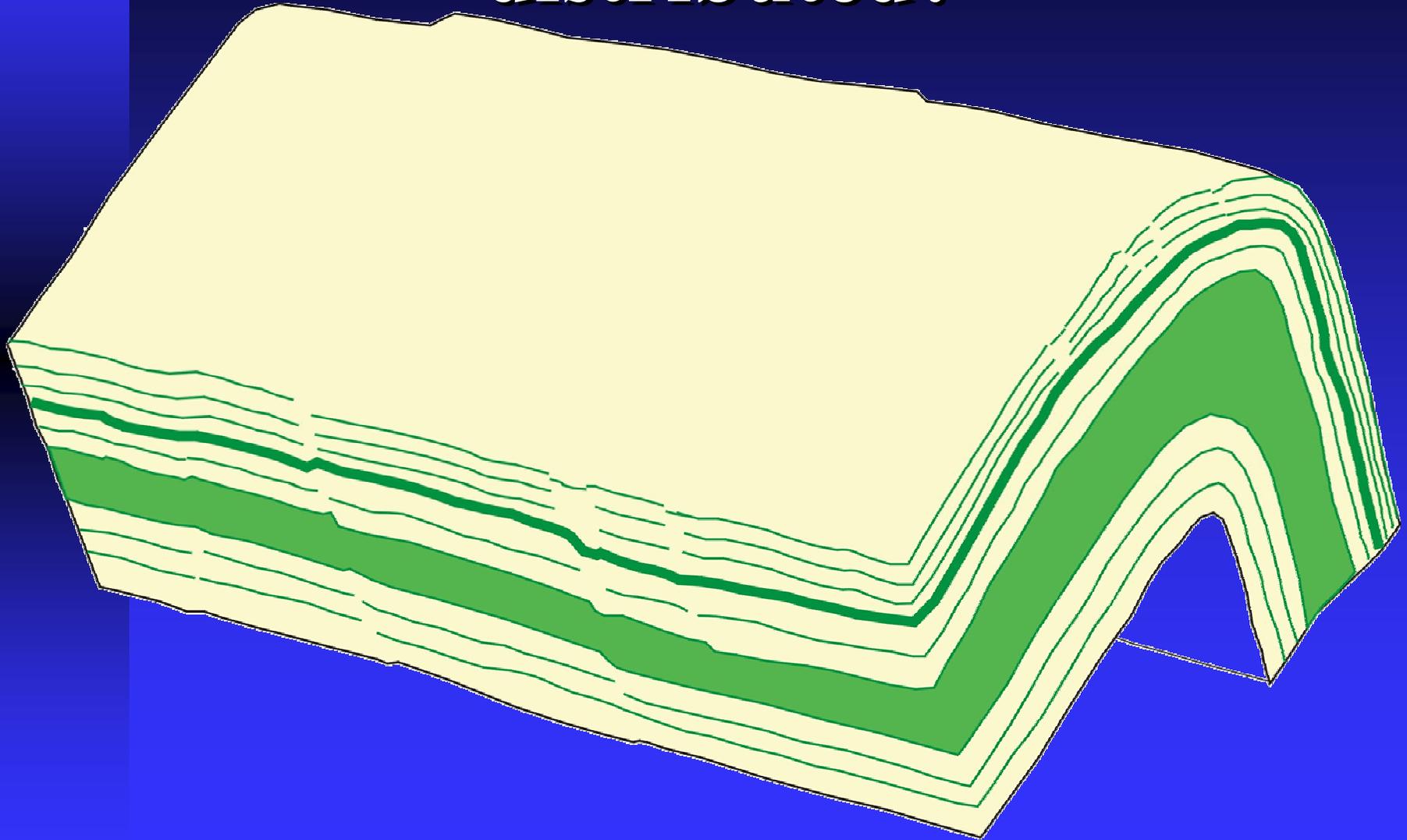
# Can We Distinguish Fractures from Shale?

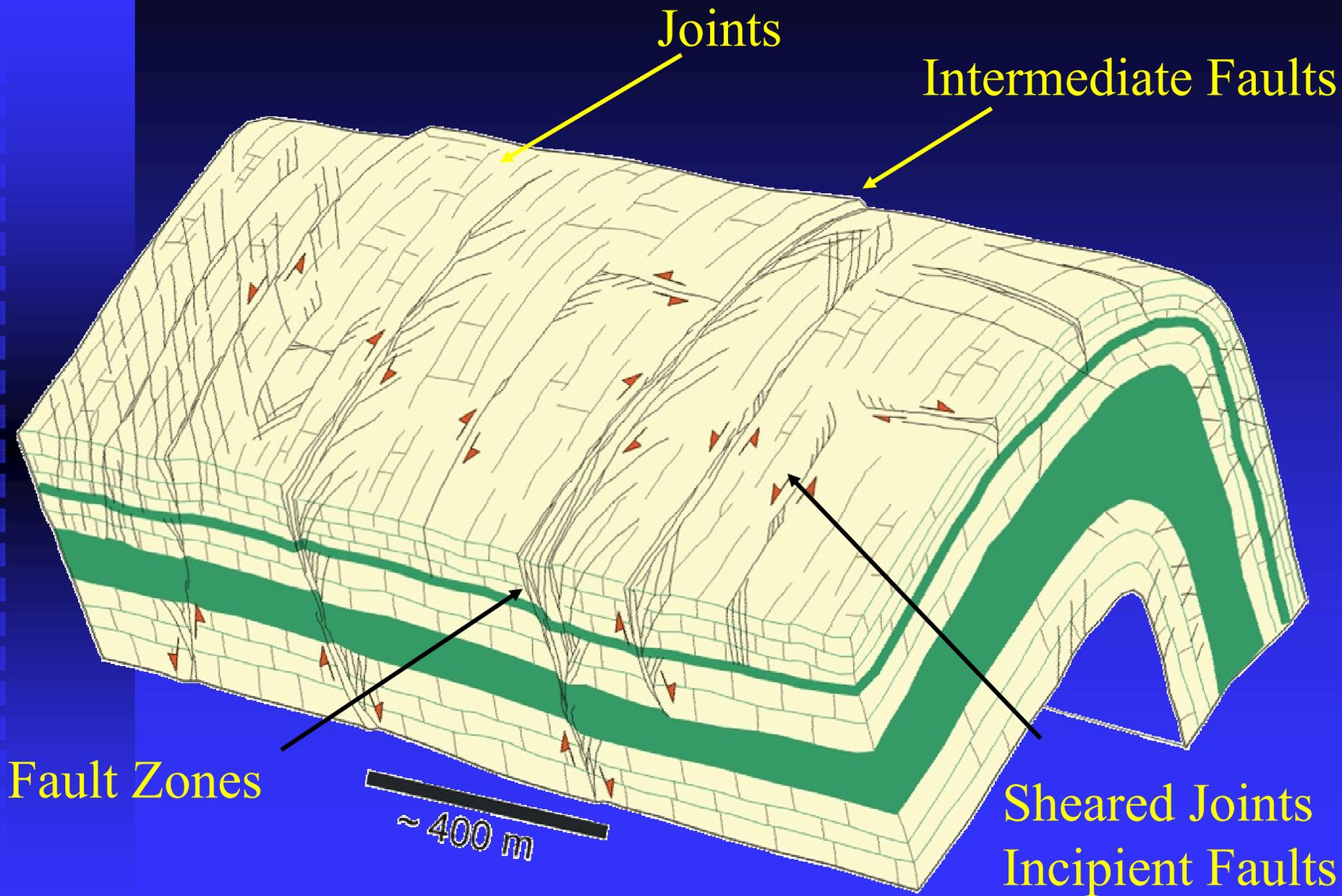


*...at this site, AVO can distinguish gas-filled fractures from unfractured shale*

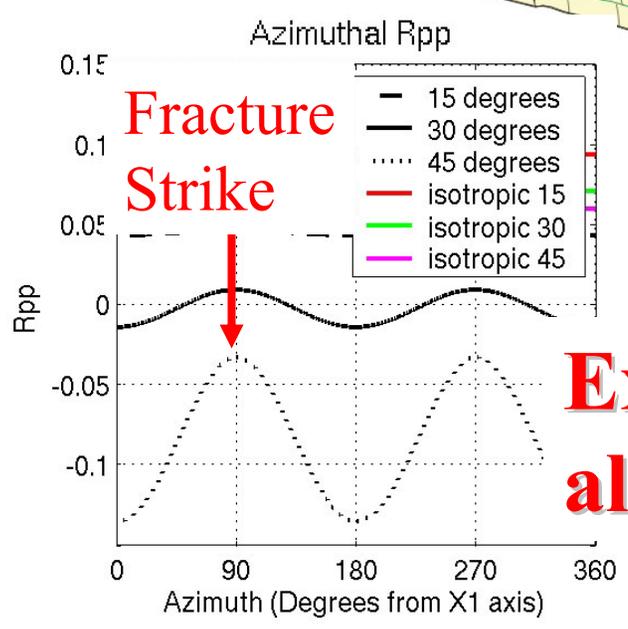
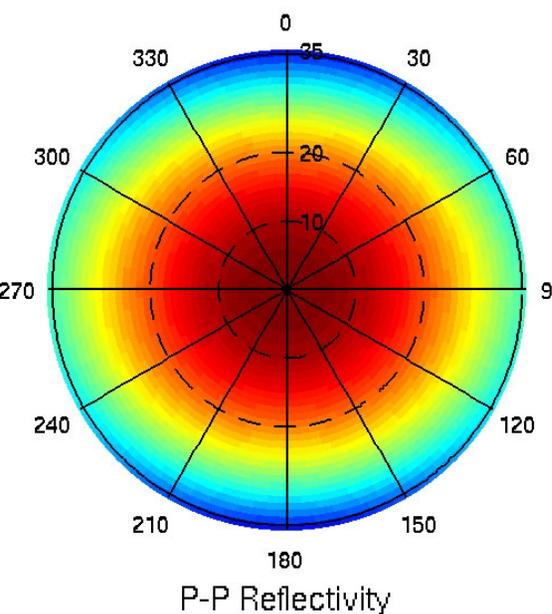
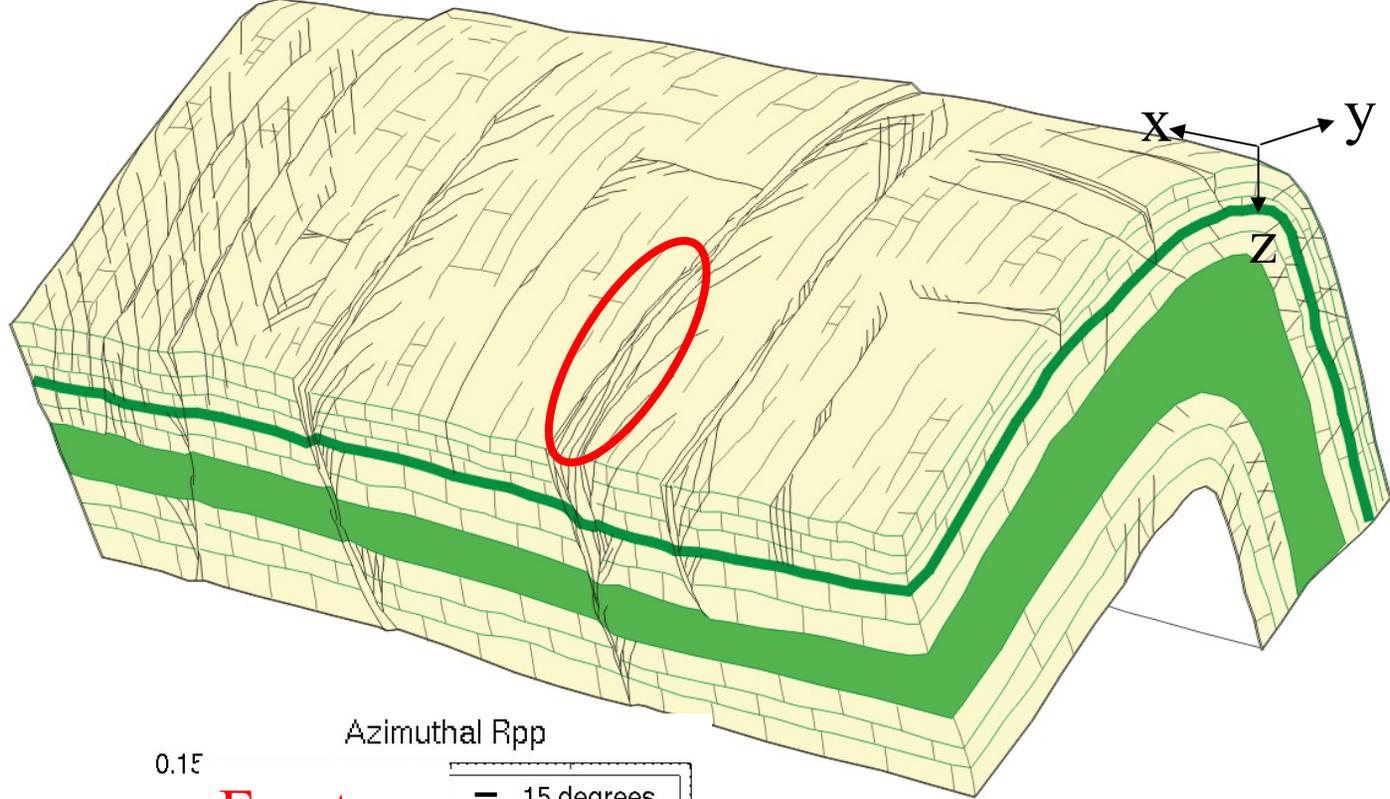
# **A Few Interpretation Pitfalls**

# How are Faults and Fractures distributed?



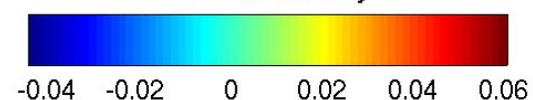


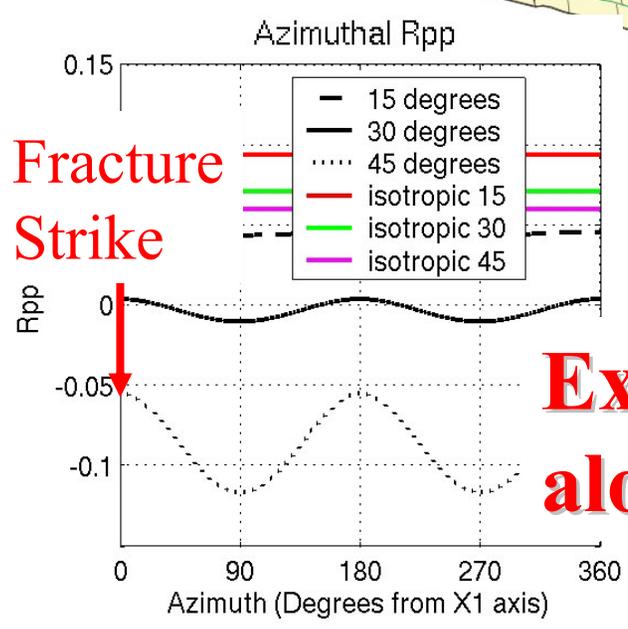
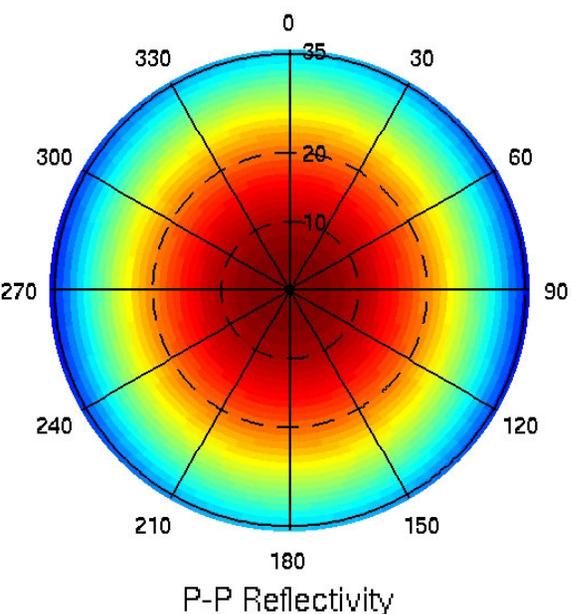
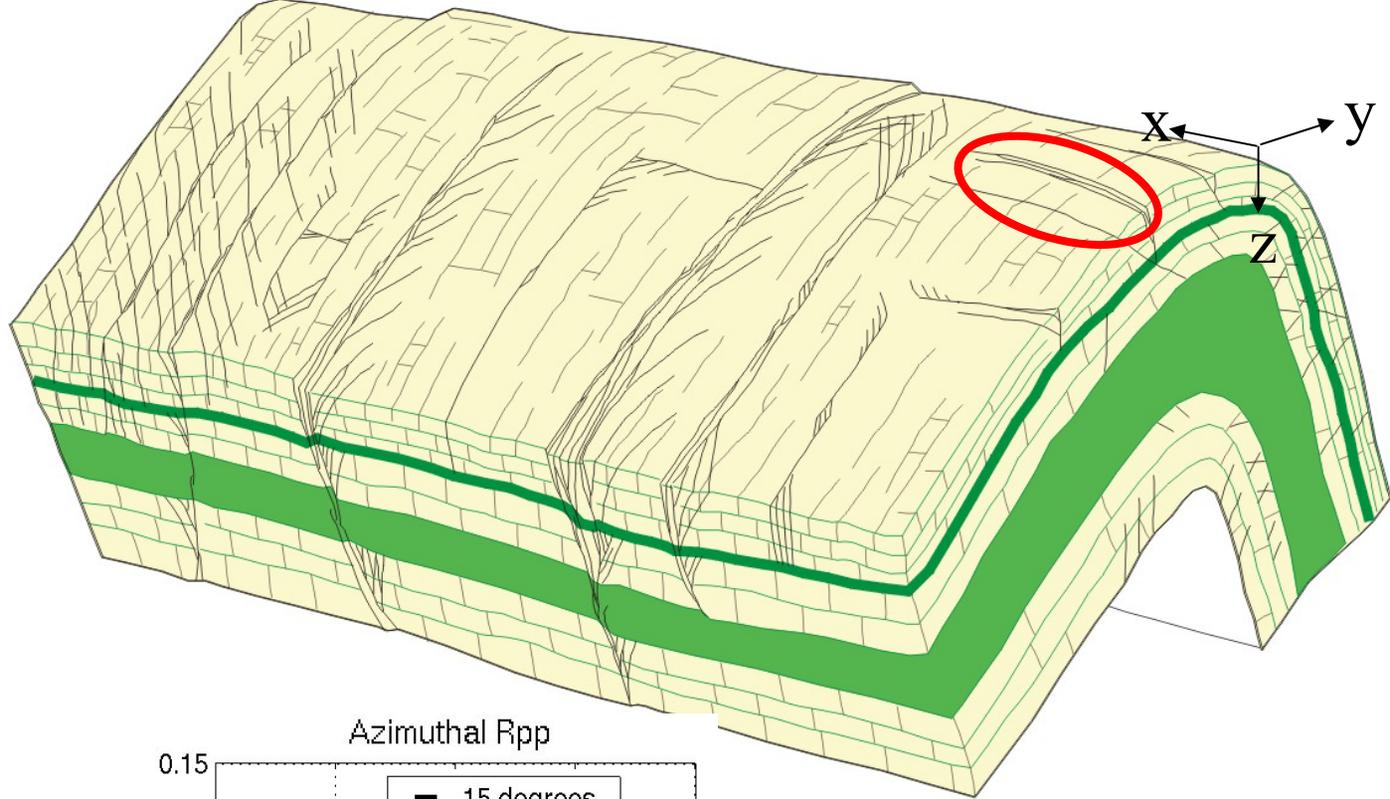
Courtesy, Juan-Mauricio Florez-Nino



**Excellent Fractures along dip. Gas**

cdx = .1  
cdy = 0  
gas

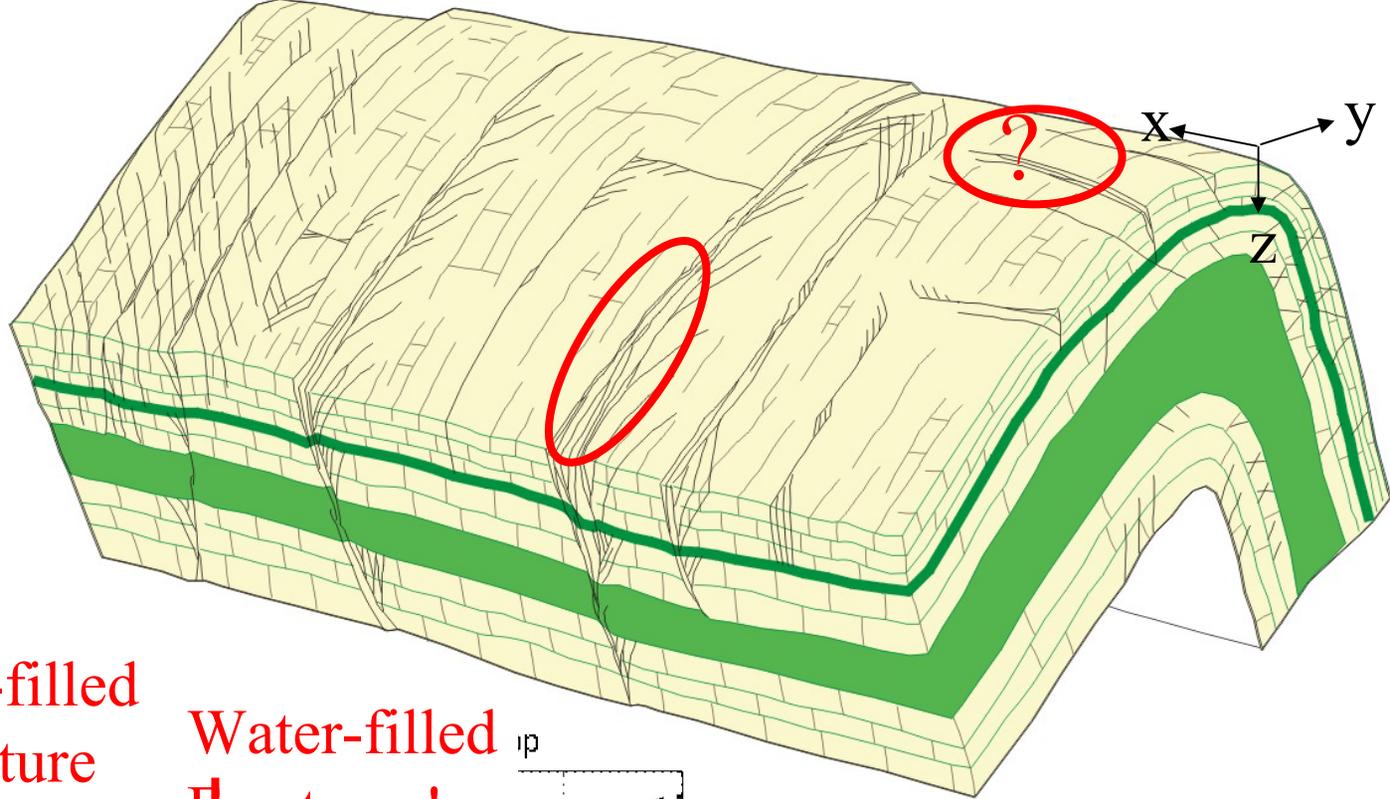




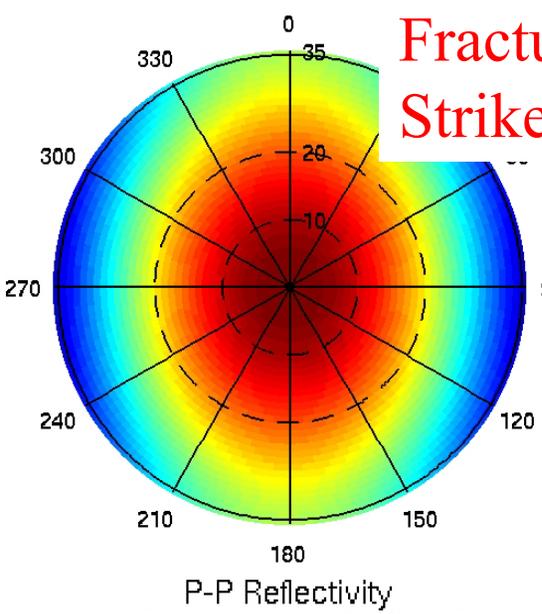
Fracture  
Strike

**Excellent Fractures  
along strike. Gas**

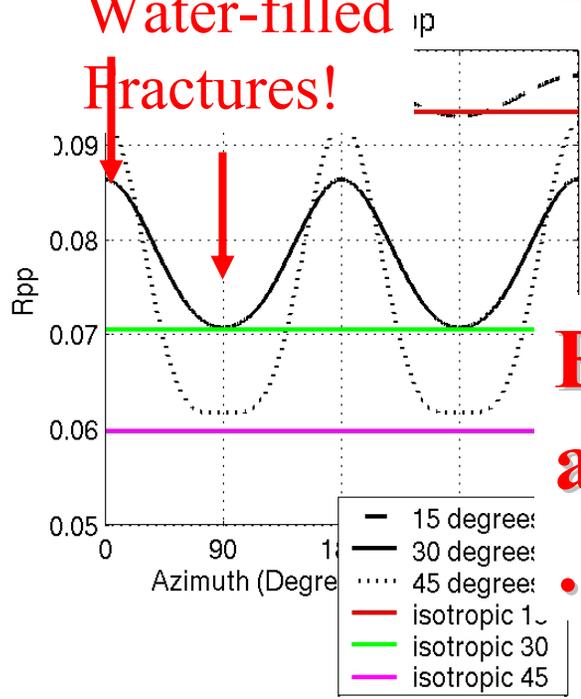
cdx = .02  
cdy = .08  
gas



**Gas-filled  
Fracture  
Strike?**

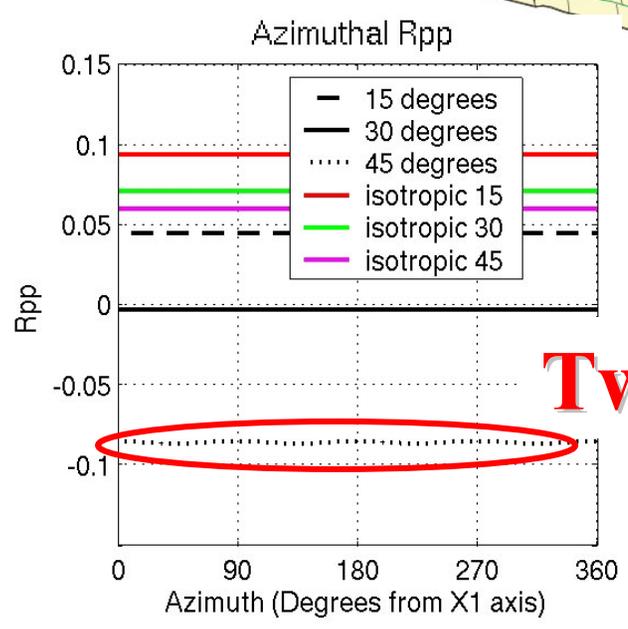
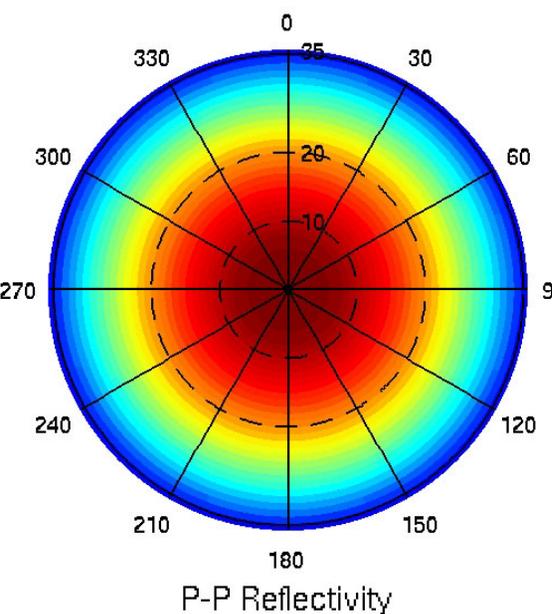
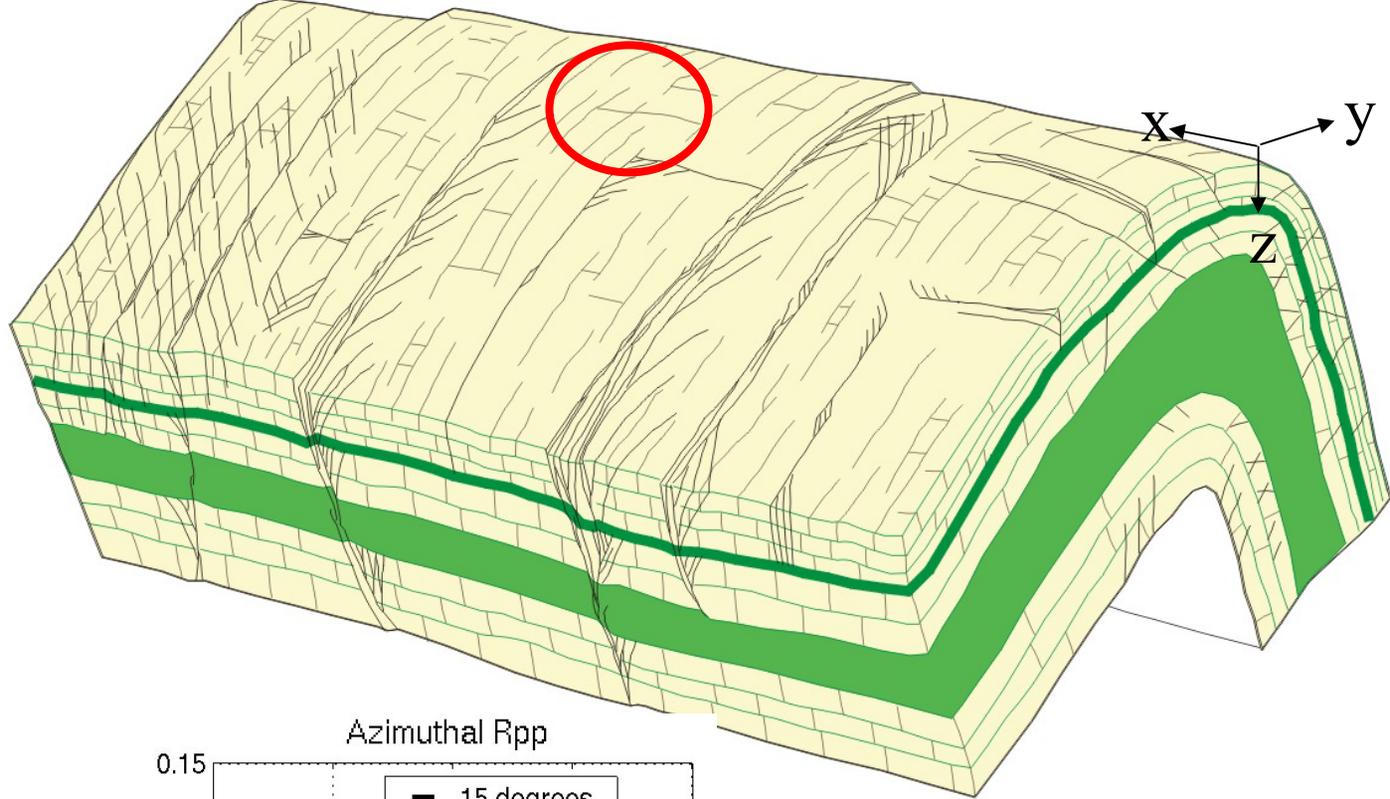


**Water-filled  
Fractures!**



**Excellent Fractures  
along dip,  
... but, with Water!**

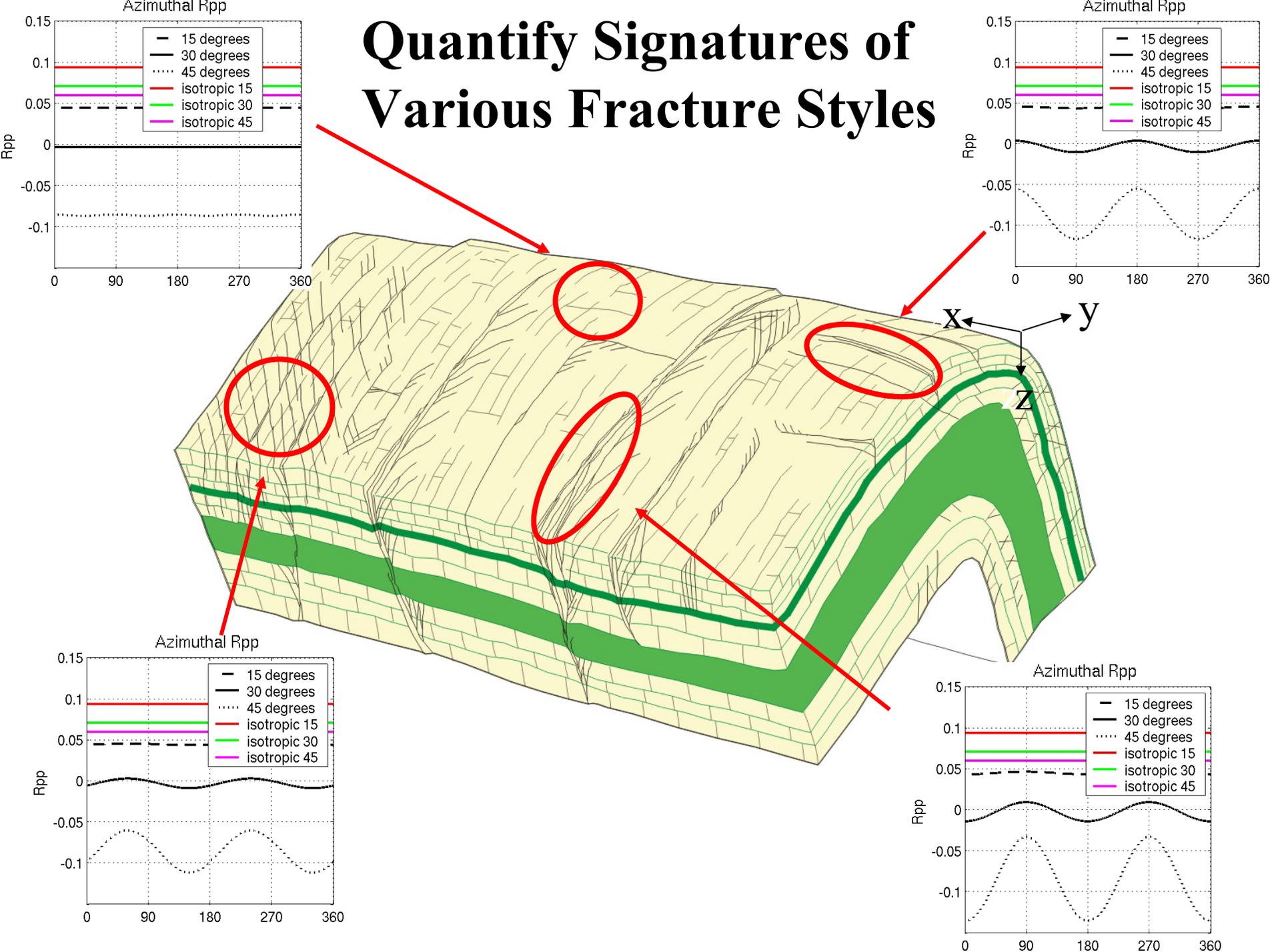
$c_{45} = u$   
gas



**No Anisotropy**  
**No Fractures?**  
**Two Fracture sets!**

cdx = .05  
 cdy = .05  
 gas

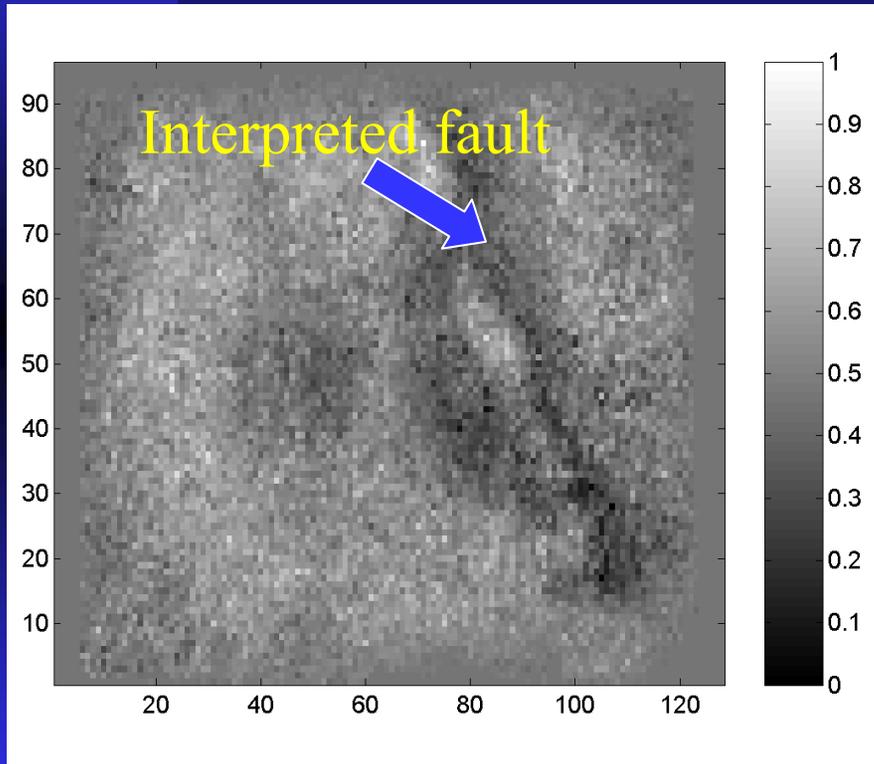
# Quantify Signatures of Various Fracture Styles



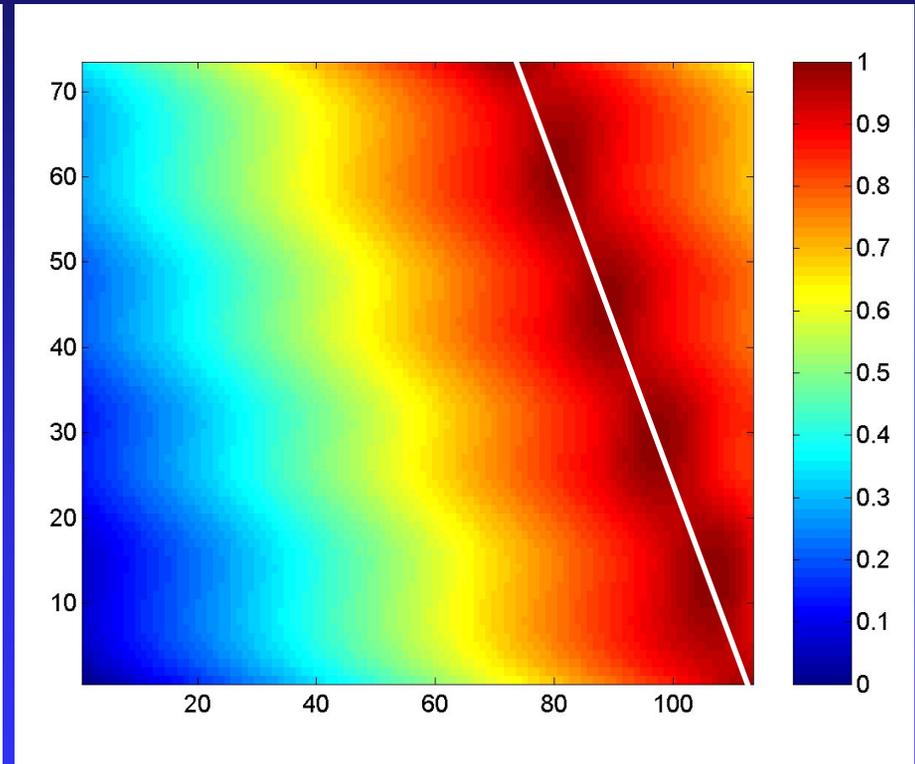
# **Integration Methodology**

# Independent Constraints

Seismic amplitude

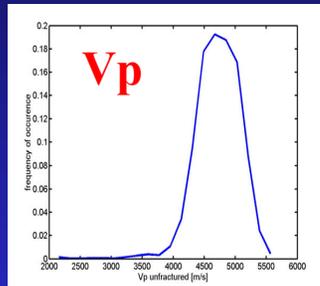


Geologic rule

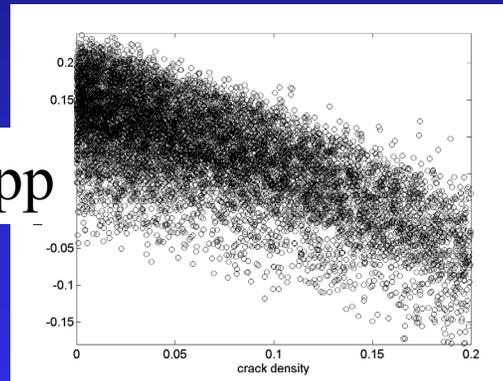


# Integration Methodology

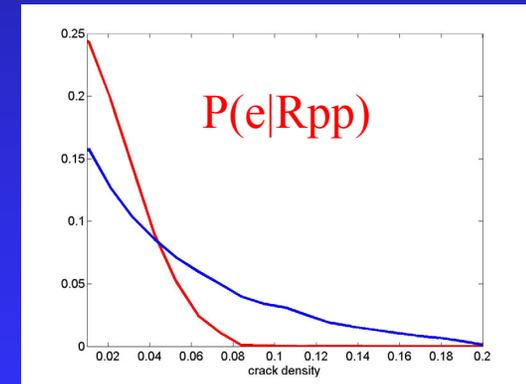
Well Log



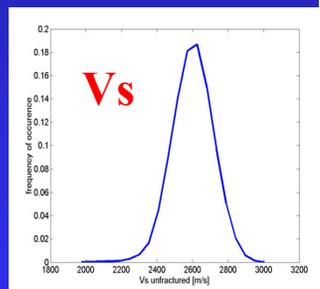
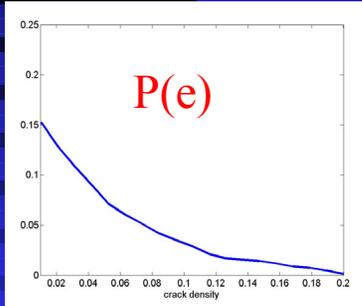
Fracture modeling & Stochastic simulations



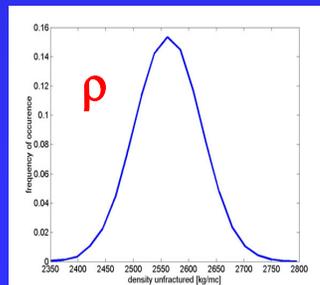
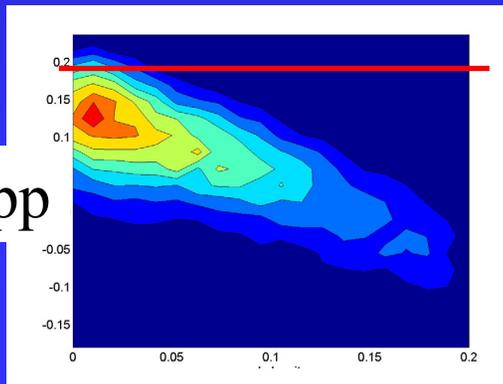
Condition on PP reflectivity from seismic data



Prior Geological Info



$R_{pp}$



$R_{pp}$

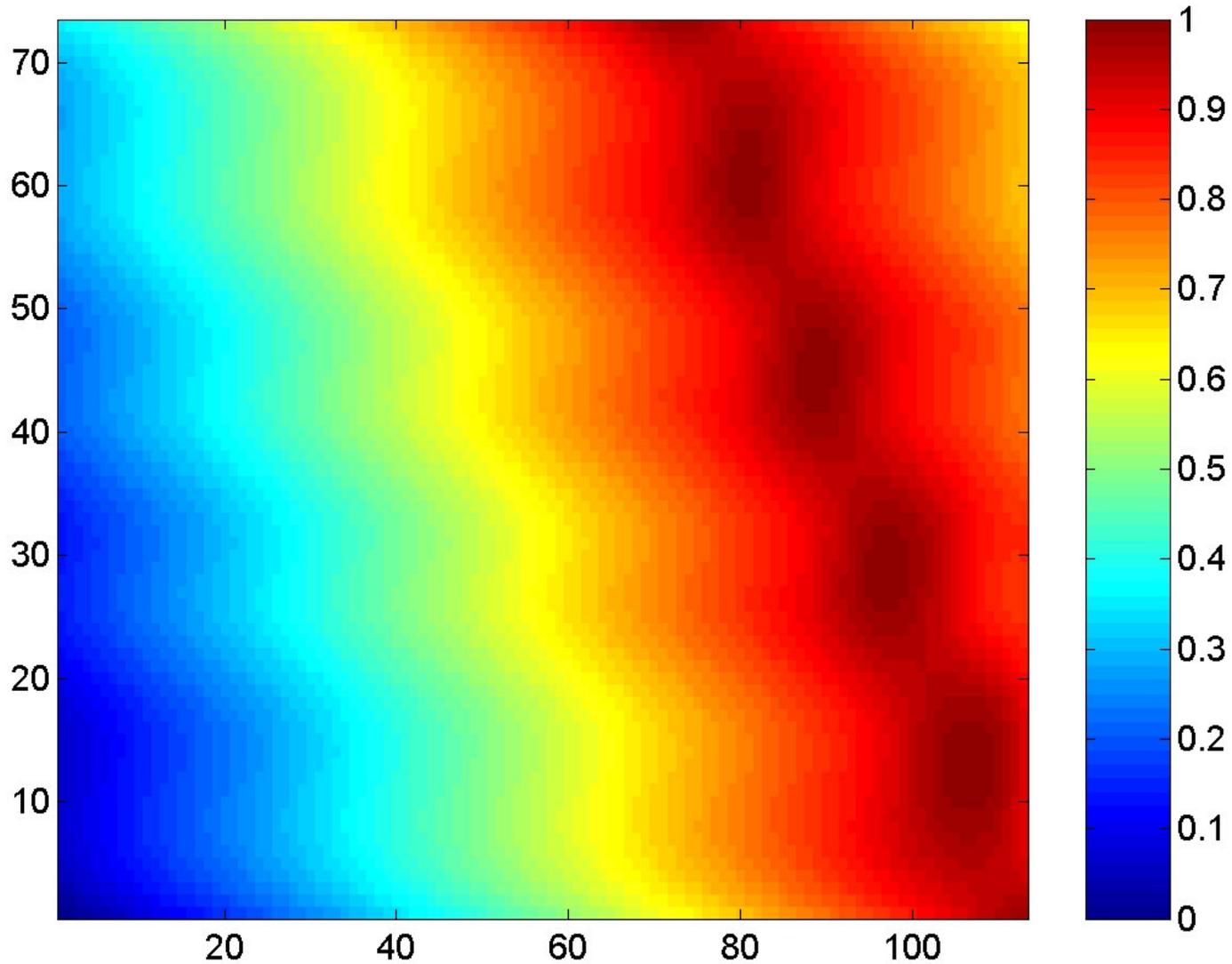
Crack Density

$$E [P(e|R_{pp})] = 0.02$$

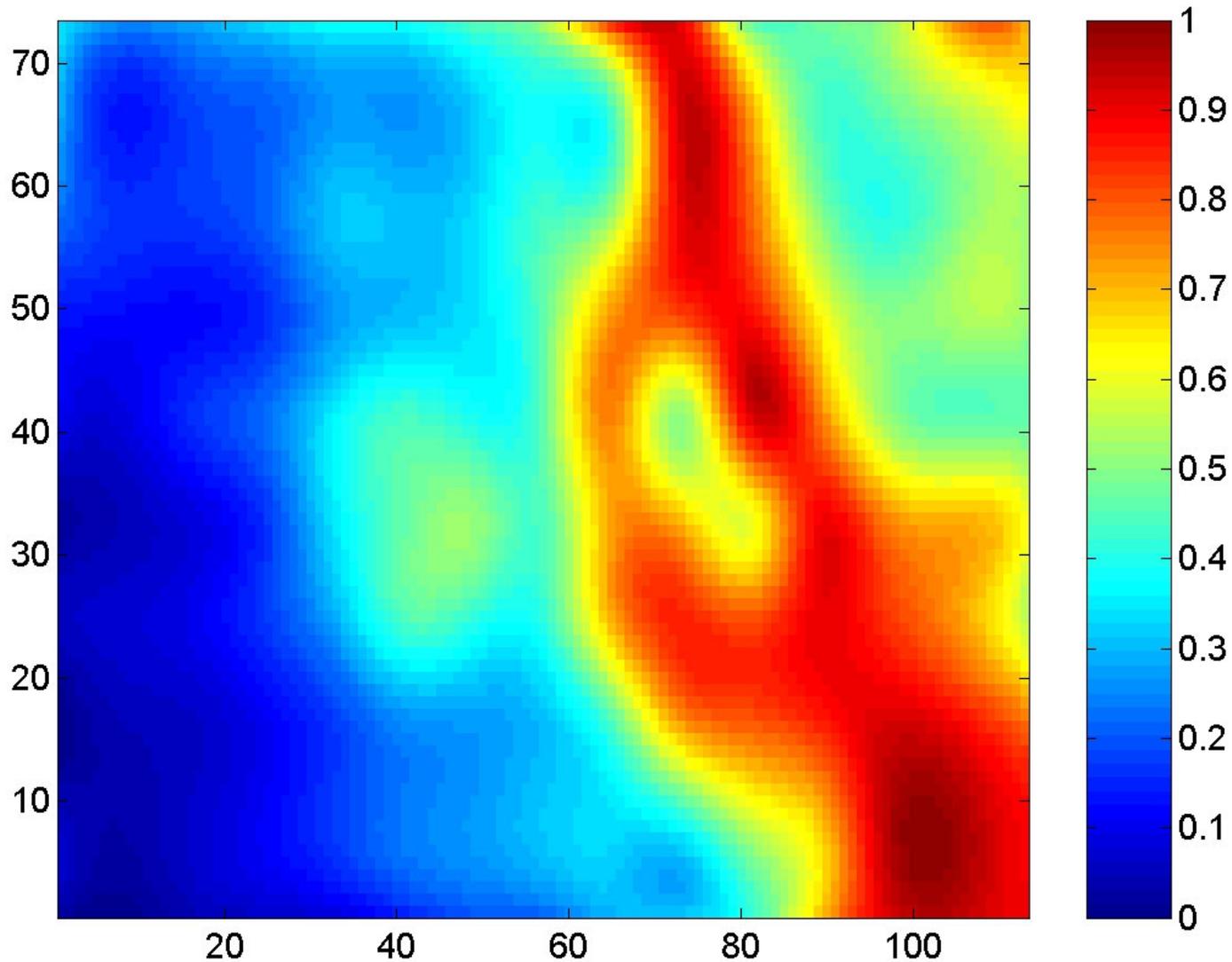
$$E [P(e)] = 0.05$$

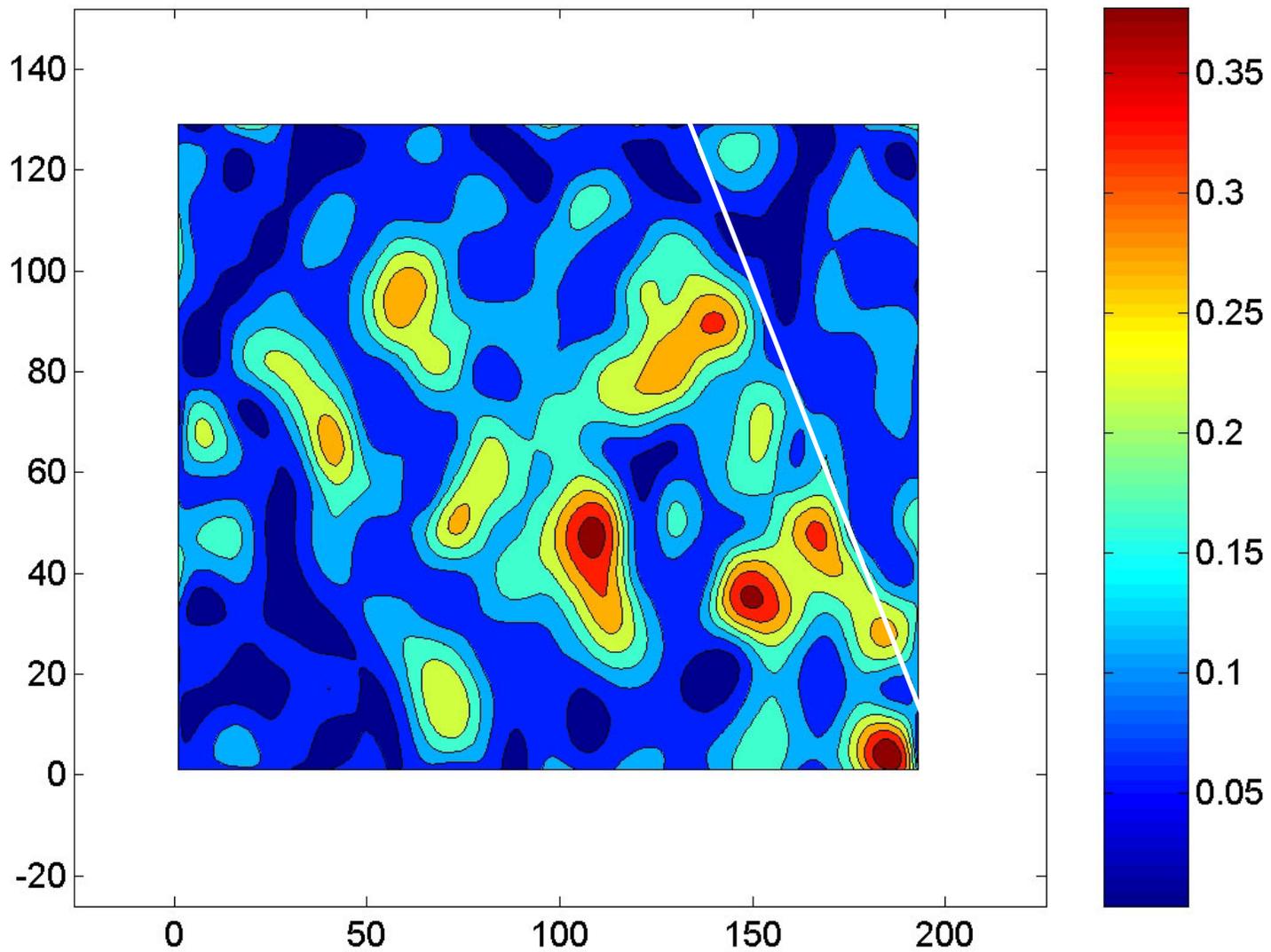
e: fracture density

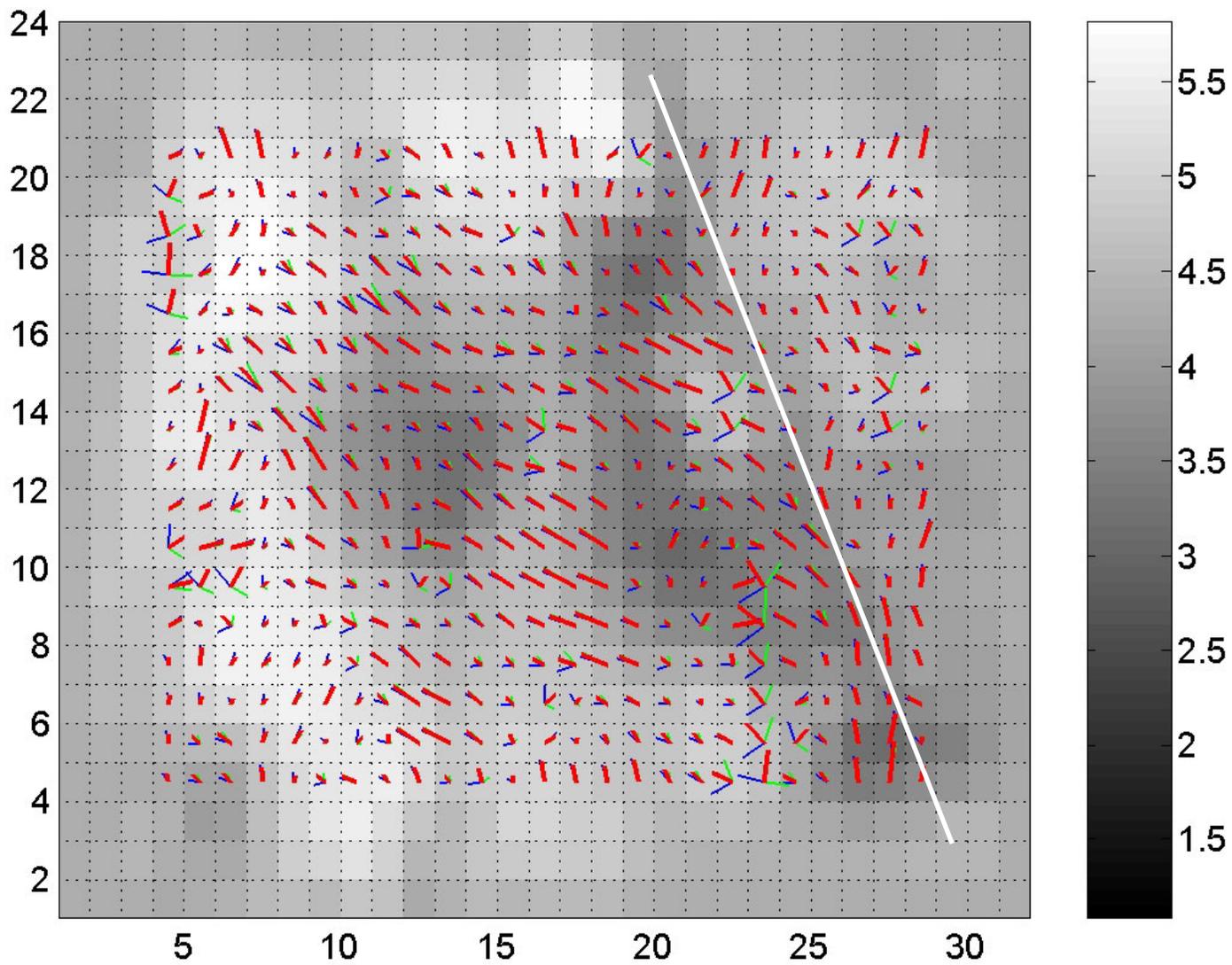
# Prior crack density distribution



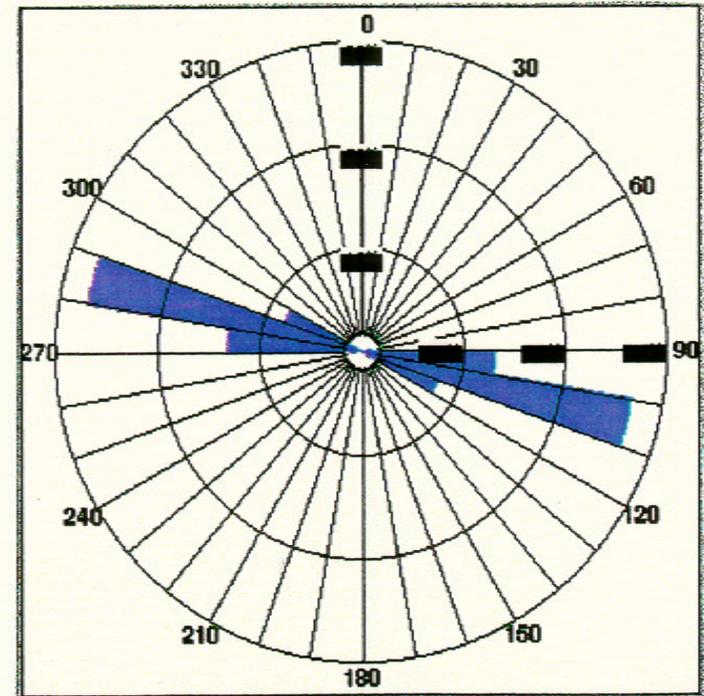
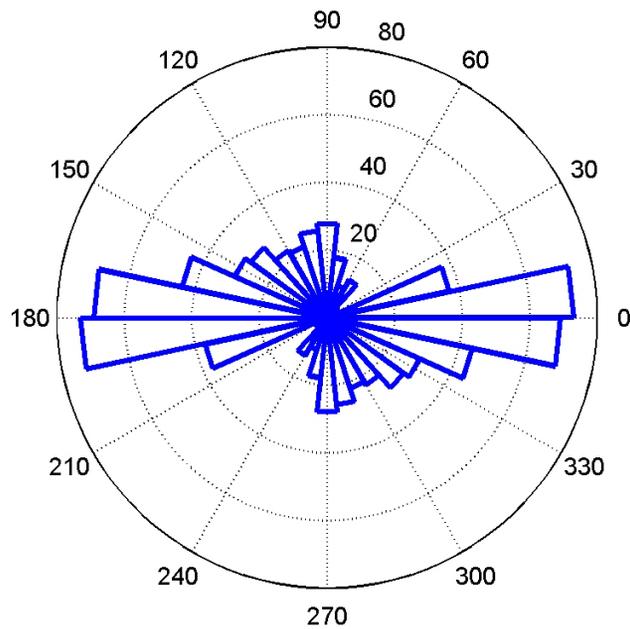
# Updated crack density distribution







# Comparison with FMI data



# Conclusions

- No “Silver Bullet” for fracture detection; Anisotropy alone might not be the answer
- Fracture mapping has many pitfalls
- Rock physics can help reduce risk, by:
  - Quantifying signatures of fracture scenarios
  - Exploring effects of rock types, fluids
  - Integrating well log and seismic constraints
  - Finding optimum attributes