

# Developments in Wellbore Geophysical Data to Evaluate Open Natural Fractures

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# Fracture Evaluation Techniques

## Wellbore Scale

### - High Resolution

Borehole images

### - Medium Resolution

Classical open hole logs (laterologs)

Stoneley attenuation and reflections

Stoneley mobility

Shear anisotropy

Borehole Acoustic Reflectivity (BARS)

Mud losses

Cores

Well test and production

## Reservoir Scale

### - Large Scale

Surface seismic

VSP

Micro-seismicity

Outcrop studies

### - Integration

Fractured reservoir modeling

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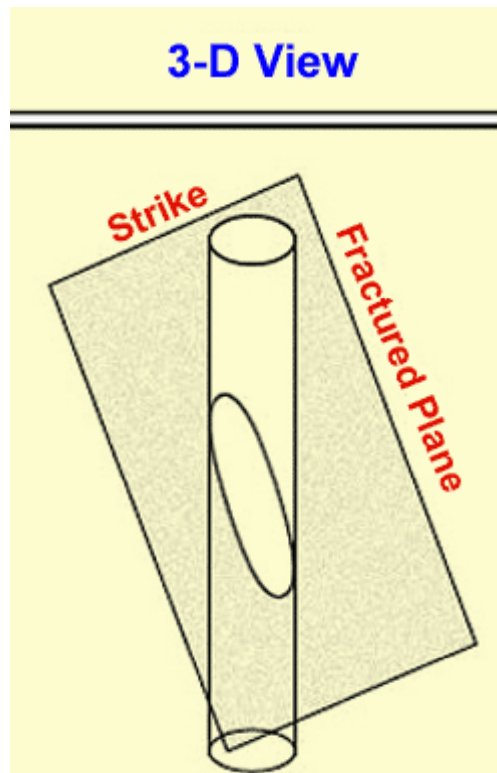
Borehole Acoustic Reflectivity (BARS)

# Borehole imaging tools can distinguish:

- Features not perfectly continuous or interrupted by other features, such as fractures crossing bed boundaries or laminations
- Small apparent angle between the plane and the borehole axis; and highly deviated boreholes

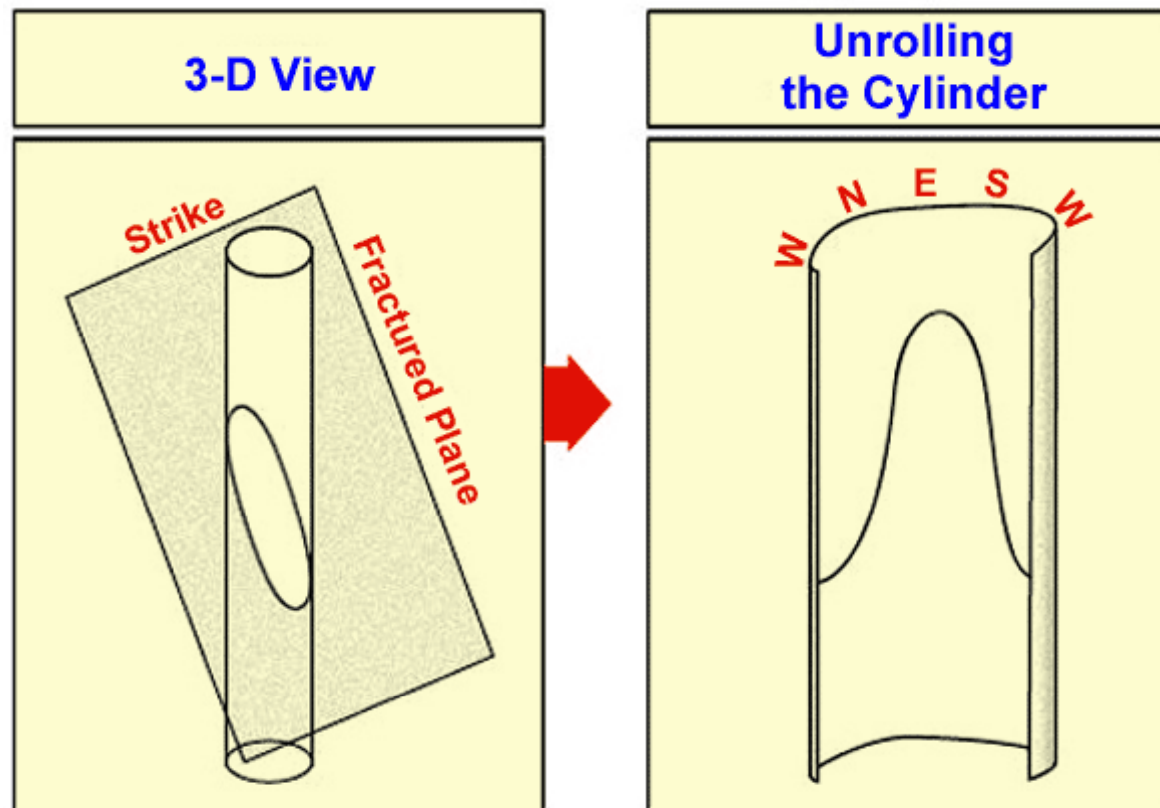
# Borehole imaging tools can distinguish:

- Any plane not perpendicular to the borehole axis intersects the cylindrical borehole surface along an ellipse



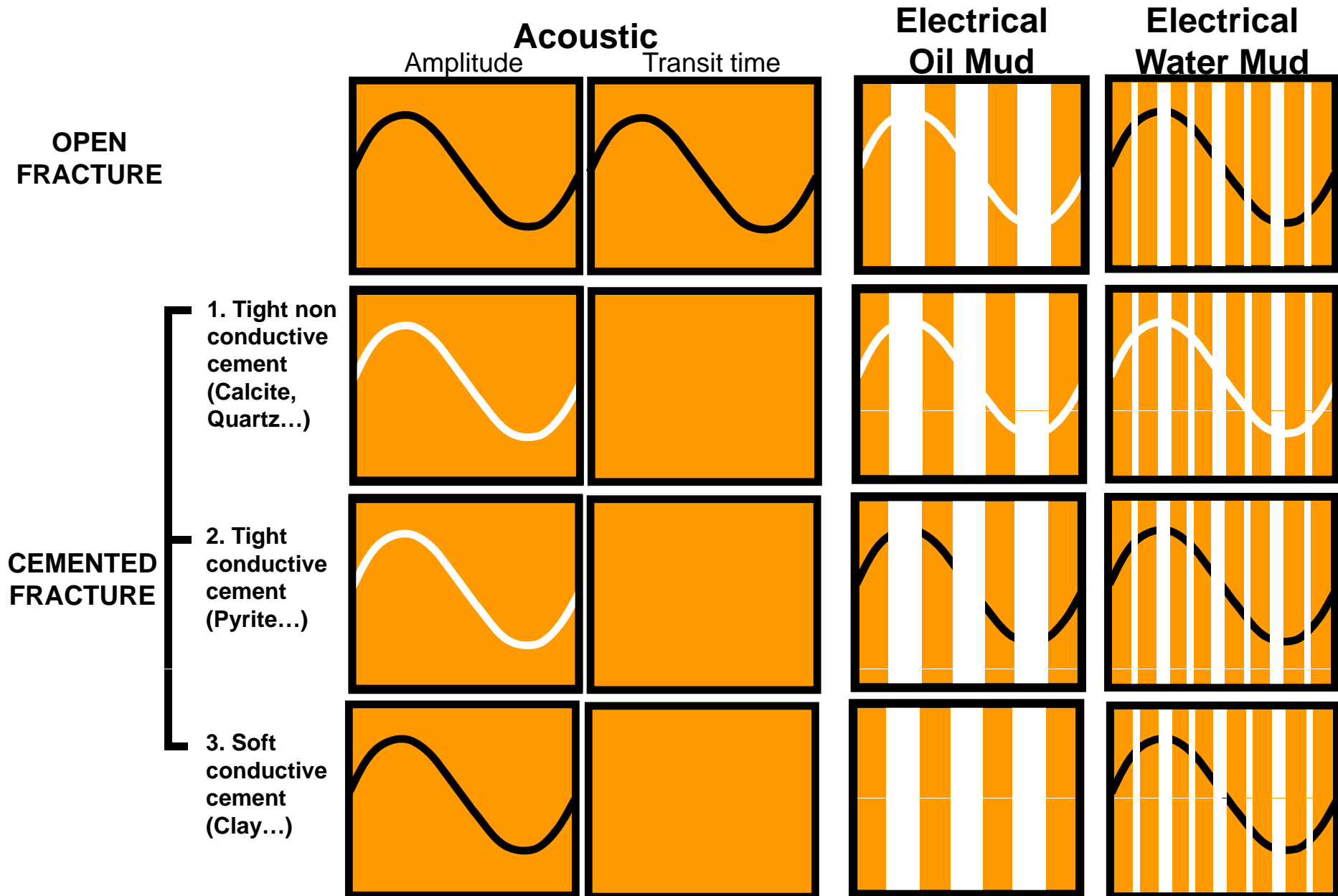
# Borehole imaging tools can distinguish:

- When cut and unrolled onto a flat log presentation, the ellipse is represented by a sine wave



After Serra, 1989

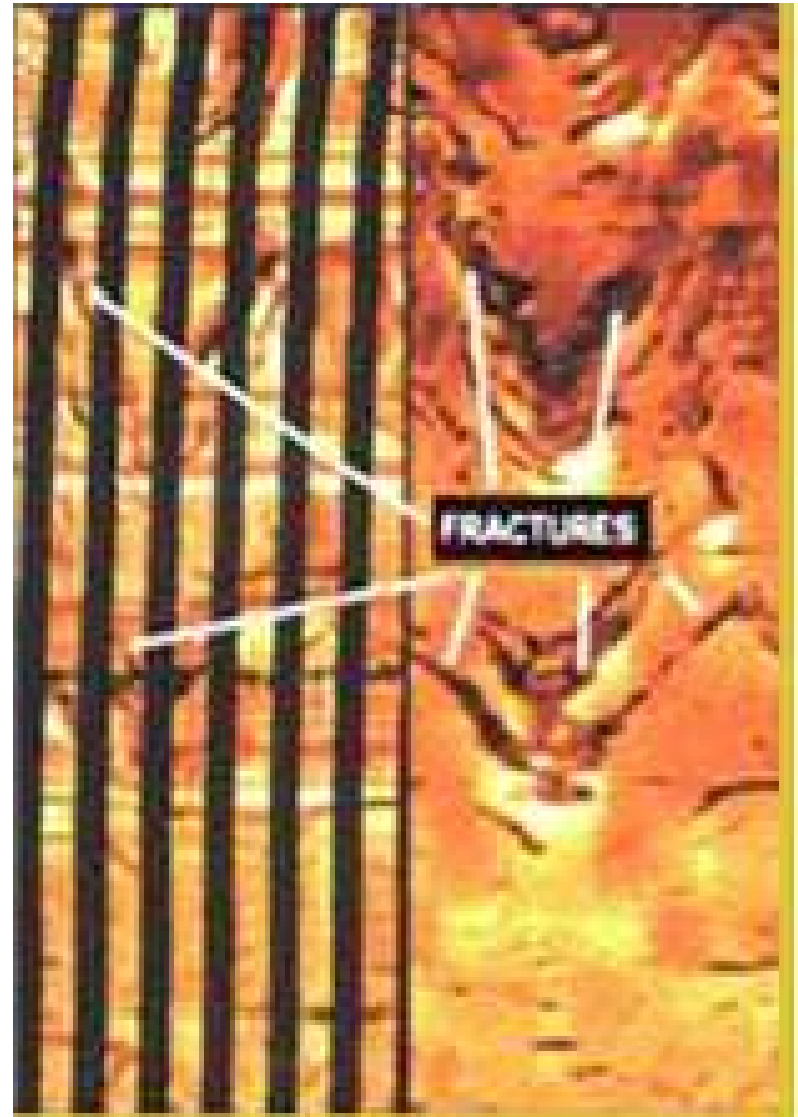
# Natural fractures from Borehole Images





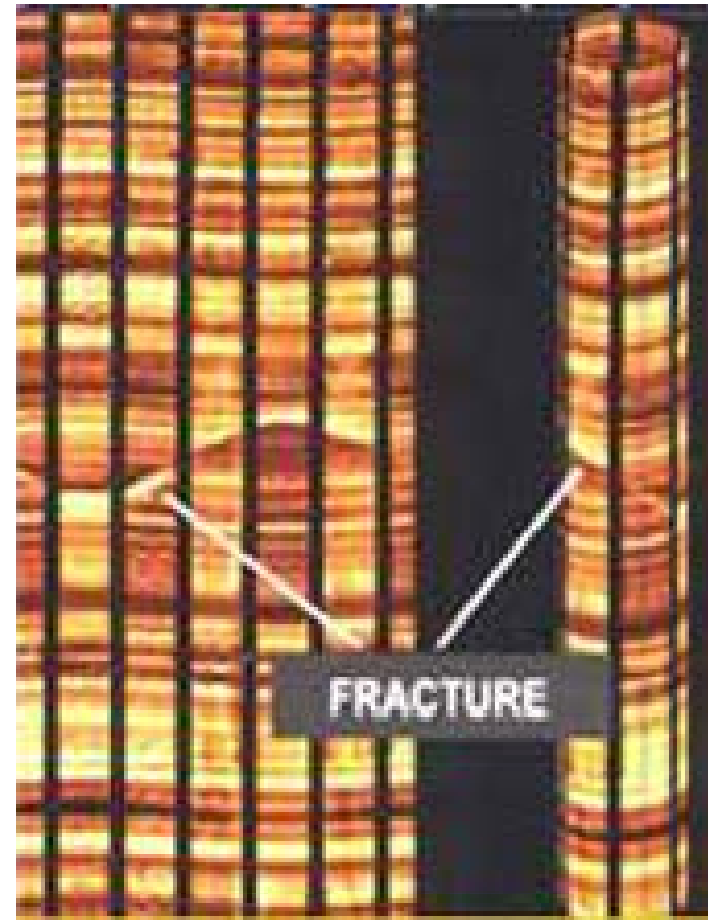
# Natural fractures from Borehole Images

- Fractures are not perfectly planar surfaces
- Appear as vertical or inclined features that are seldom straight
- Often seen over relatively long interval



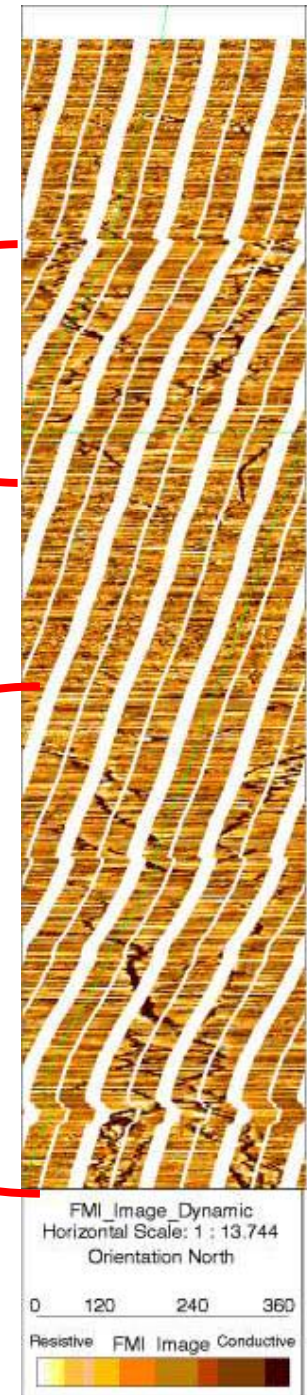
# Natural fractures from Borehole Images

- Fractures healed by cementation produce images characterized by fine, vertical or oblique features
- These fractures are resistive, and are lighter in color than the surrounding medium
- The minimum detected fracture width is controlled by the width of the electrode, the order of a few millimeters
- Pattern recognition techniques may be used to find and measure fractures, and detect vugs, and nodules.



# Natural fractures from Borehole Images

- What is your interpretation?



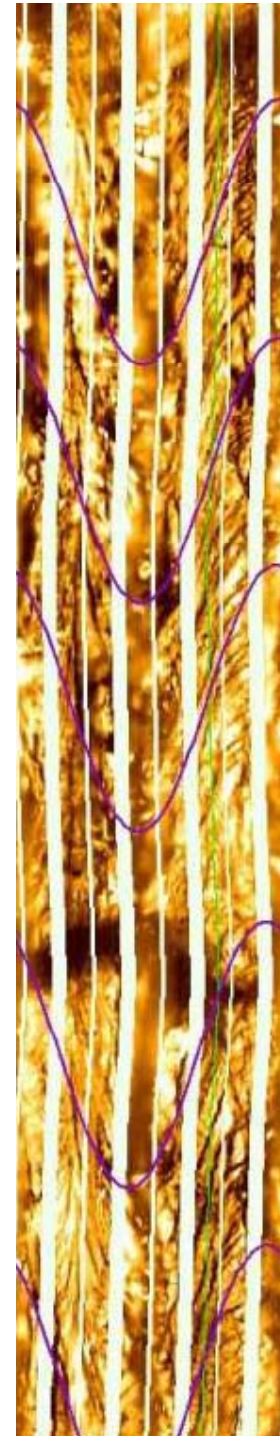
# Natural fractures from Borehole Images

- What is your interpretation?



# Natural fractures from Borehole Images

- What is your interpretation?



# Fracture Evaluation Techniques

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Stoneley attenuation and reflections

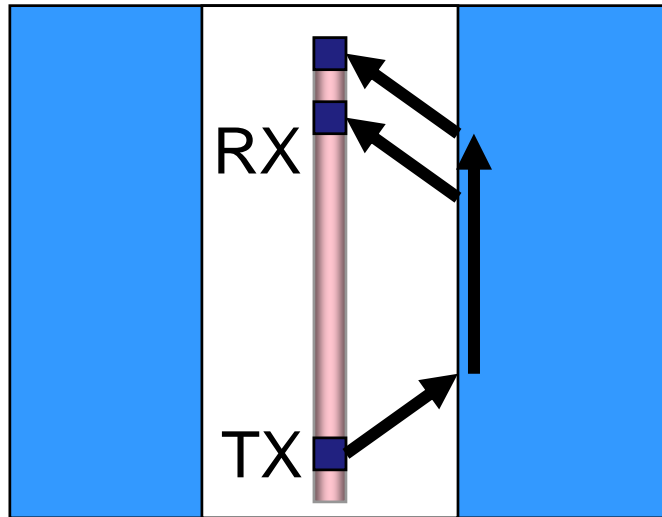
Stoneley mobility

Shear anisotropy

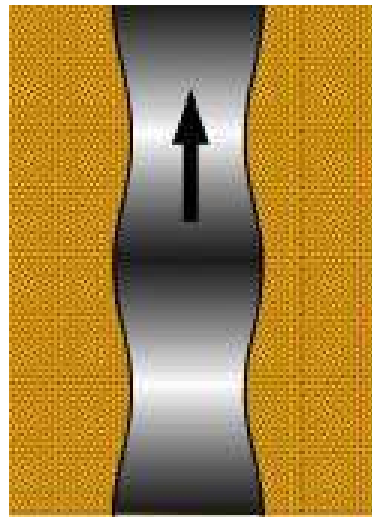
Borehole Acoustic Reflectivity (BARS)

# Borehole Sonic Mode Propagation

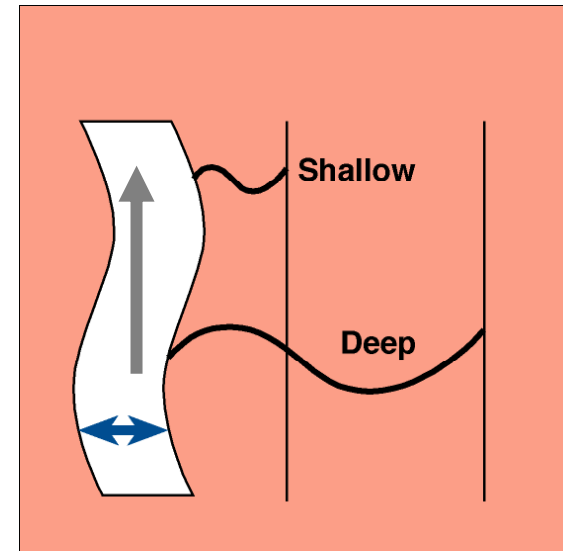
Compressional / Shear  
Headwaves



Stoneley  
Borehole mode



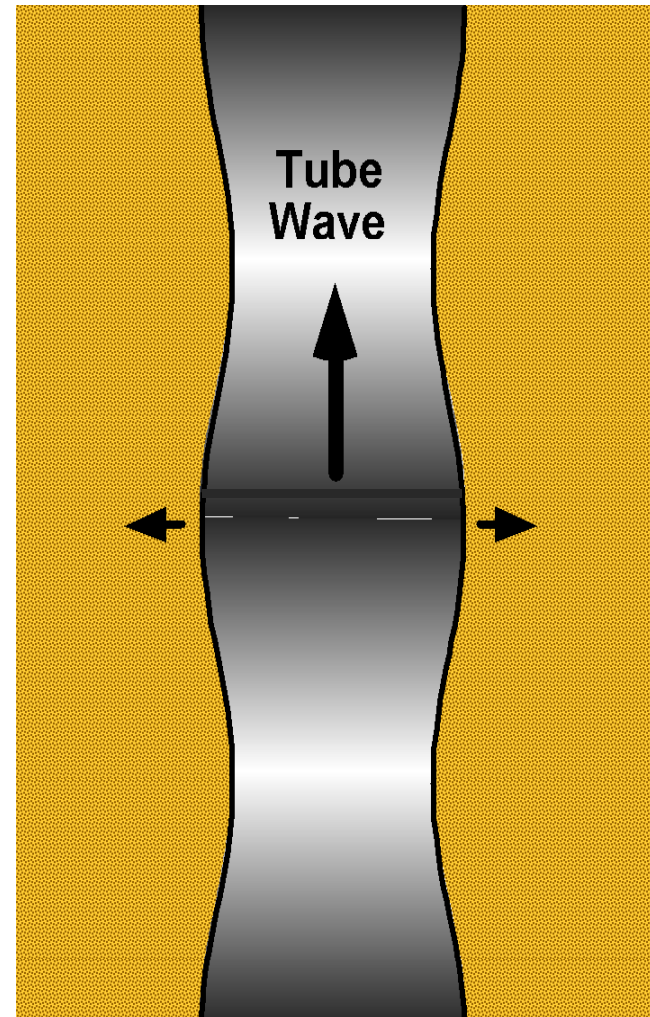
Dipole Shear  
Borehole mode



Dipole

# Stoneley-wave

- Borehole mode
- Excited by low frequency monopole source
- At low frequency
  - Tube wave
- At high frequency
  - Surface wave
- Dispersive wave





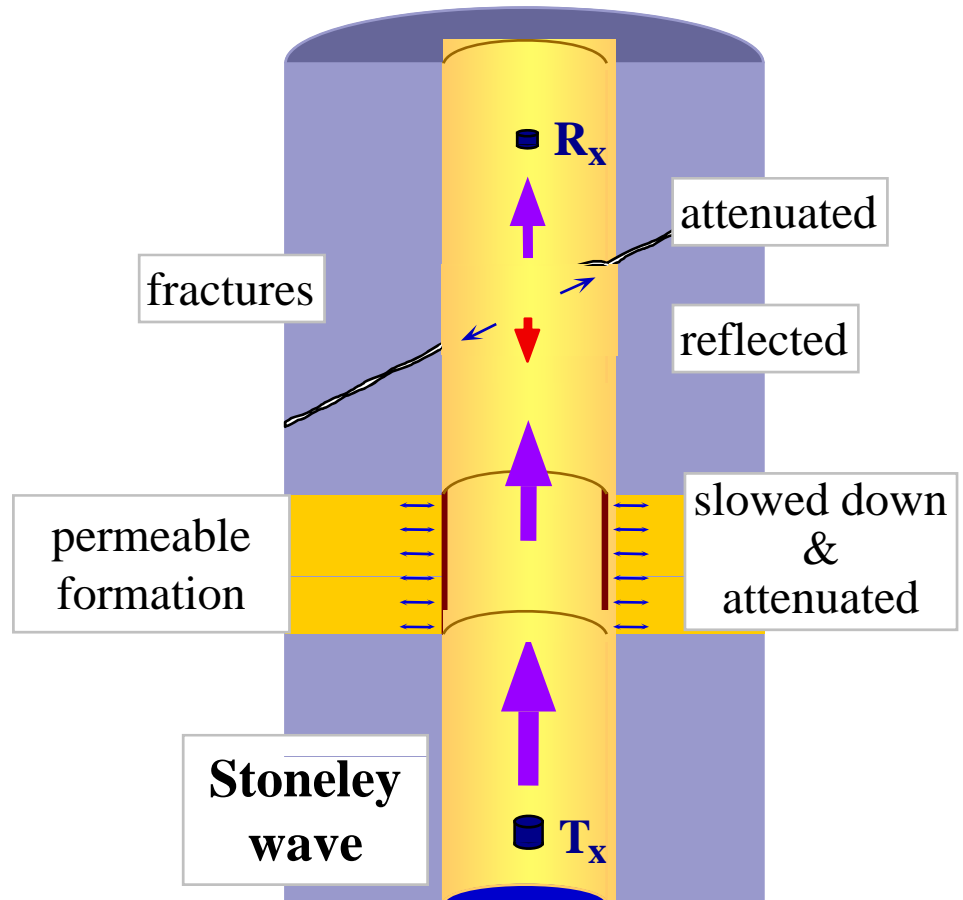
# Stoneley-wave interaction with Formation

- Permeable Formation

- Slowing down
- Attenuation

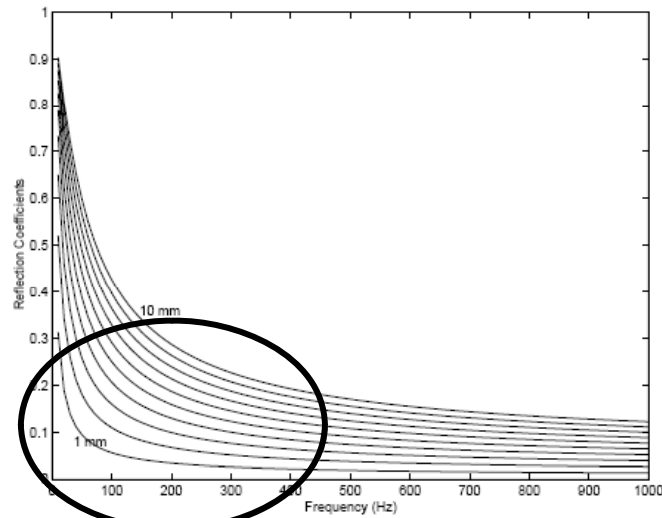
- Open Fractures

- Reflection
- Attenuation

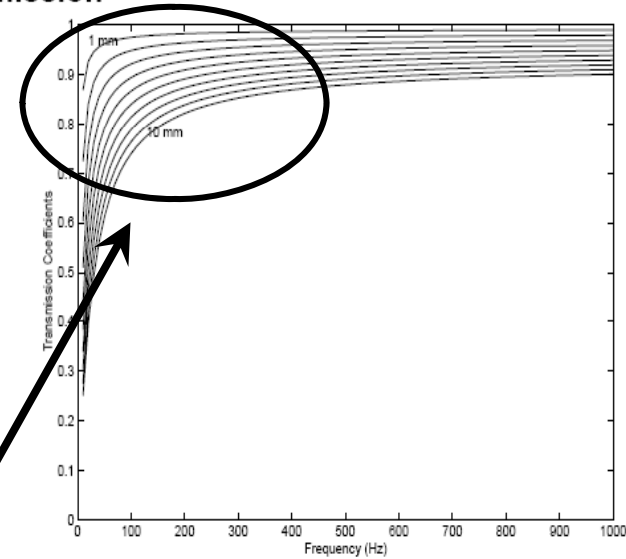


# Effects of Fracture Aperture on Stoneley Reflection and Transmission Coefficients

Reflection

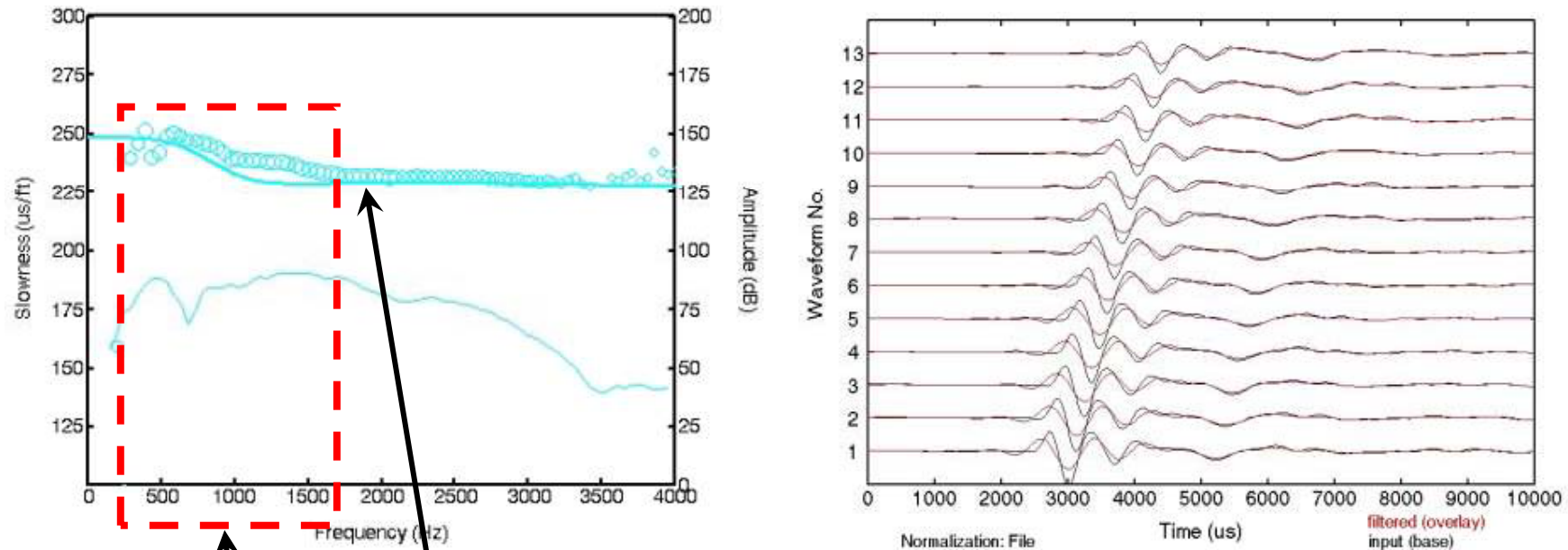


Transmission



Most Sensitive at low frequencies

# Dispersion, Amplitude and Filtering (300 to 1500 Hz)



Solid Line: Homogeneous Isotropic Model, including the presence of the tool in the borehole

Open Dots: Dispersion profile of the raw waveforms

Frequency and Amplitude Window

# Fracture Evaluation Techniques

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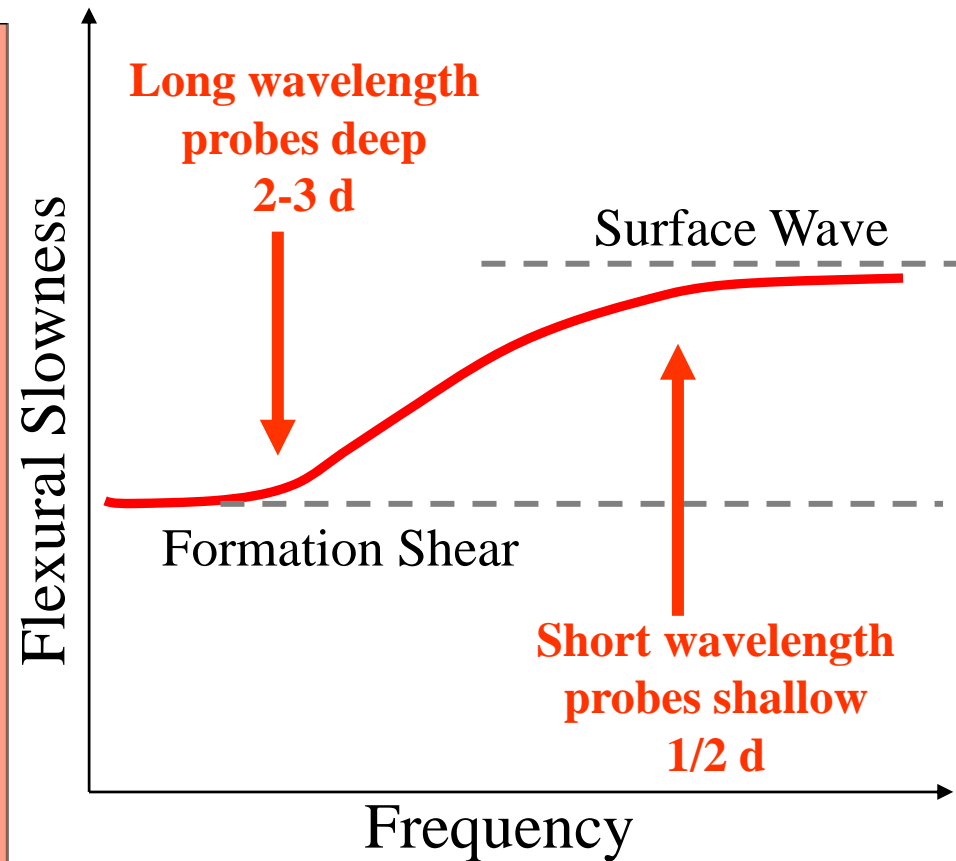
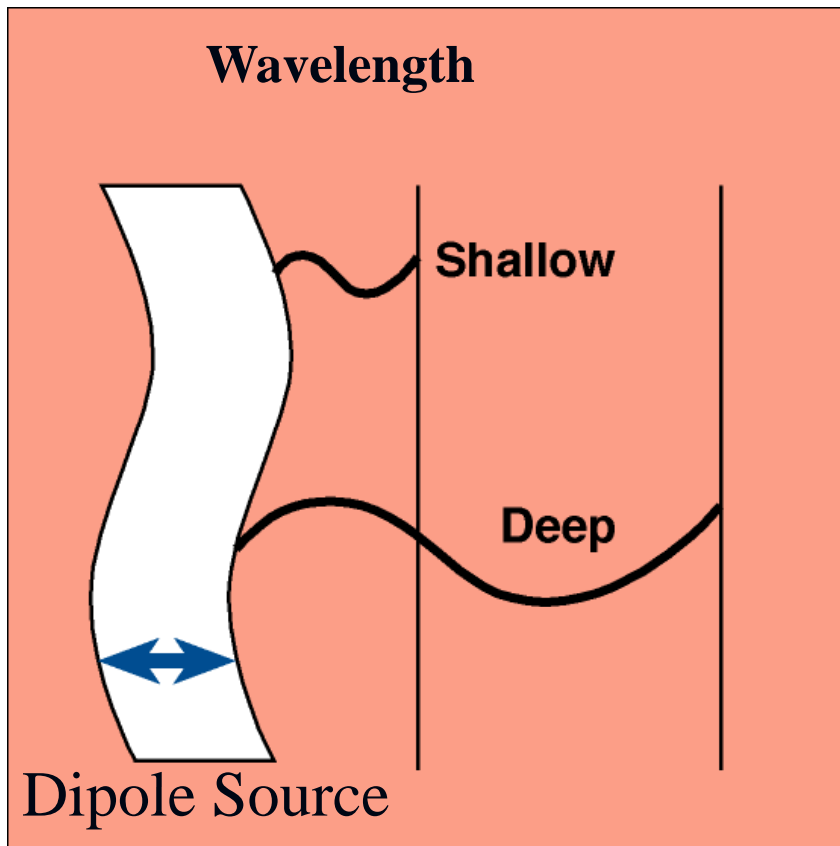
Stoneley attenuation and reflections

Stoneley mobility

Shear anisotropy

Borehole Acoustic Reflectivity (BARS)

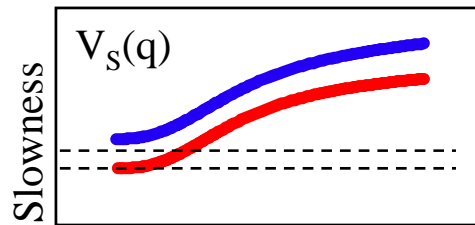
# Flexural Wave generated from Dipole Source



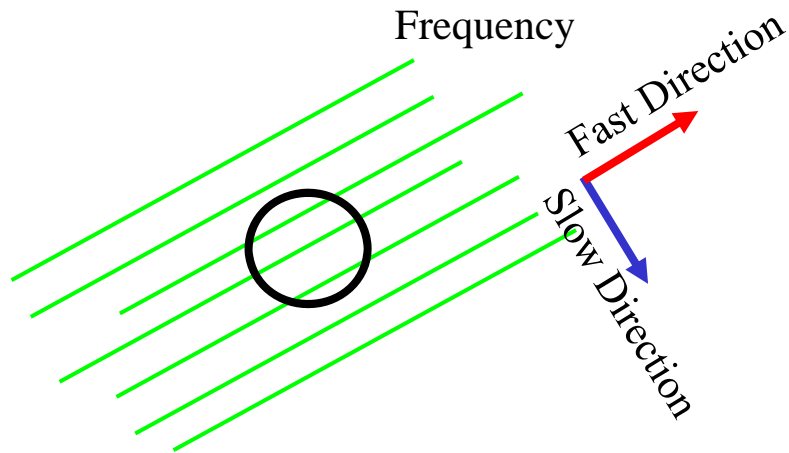
# Dispersion Analysis

Intrinsic:  
Shales,  
fractures

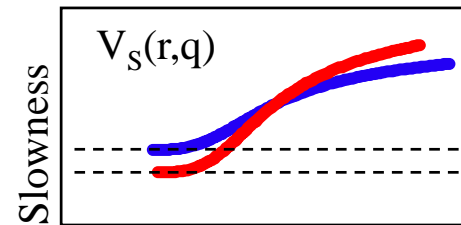
Homogeneous anisotropic



Frequency

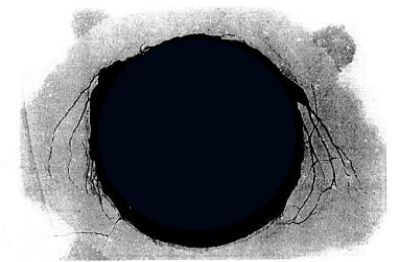
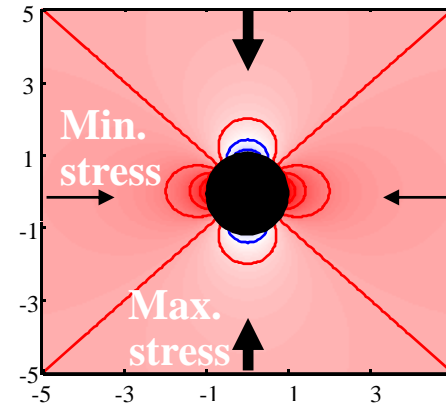


Inhomogeneous anisotropic



Frequency

Stress  
induced



- Fast shear azimuth corresponds to fracture strike

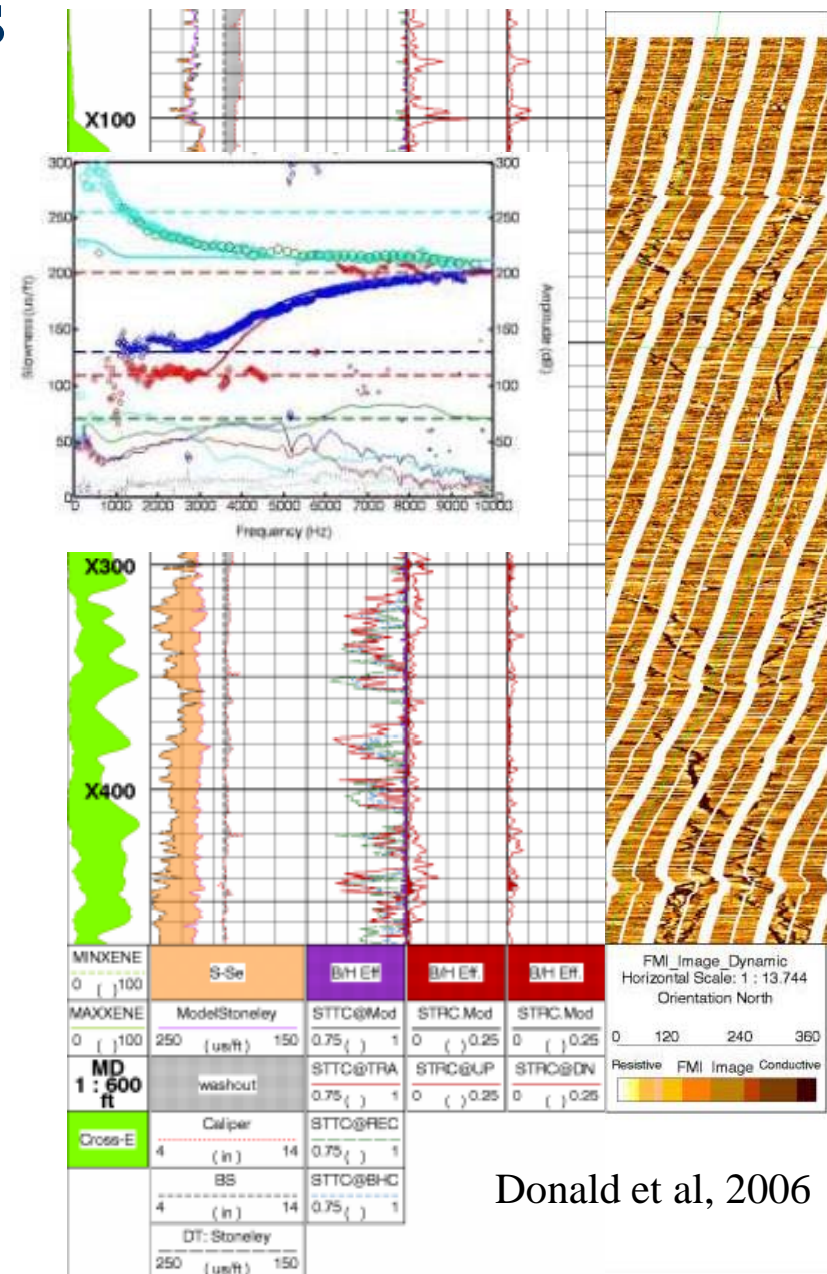
# Stoneley & Image Analysis (Colorado Carbonate)

- Borehole Image analysis suggests drilling induced fractures
- Large acoustic cross energy anisotropy, change in transmission and reflection coefficients
- Integrated interpretation with borehole sonic - fractures are natural and open



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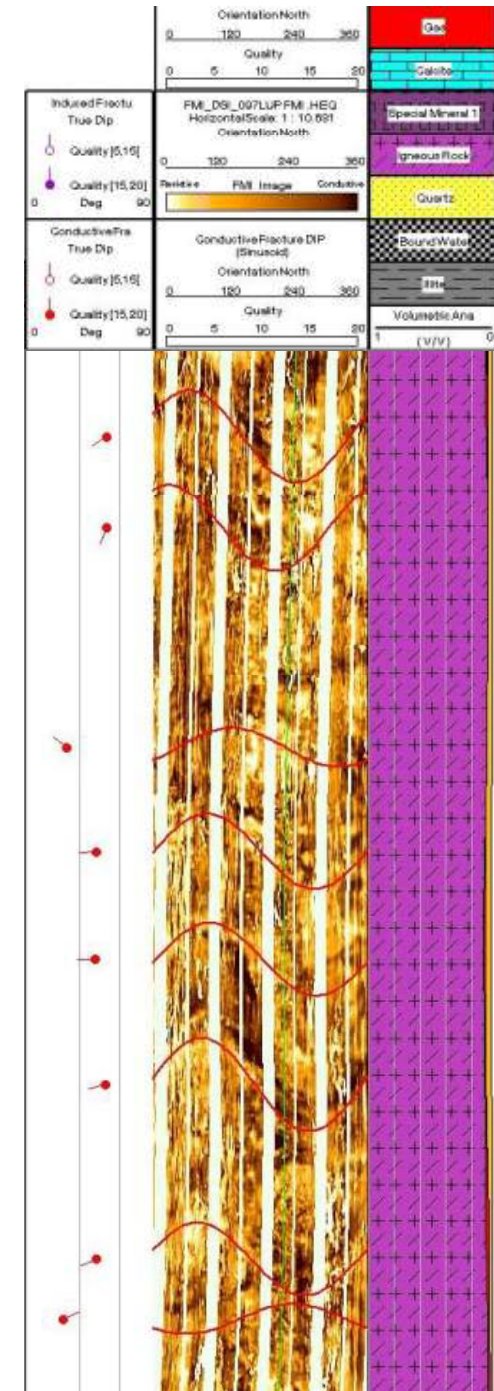


Donald et al, 2006



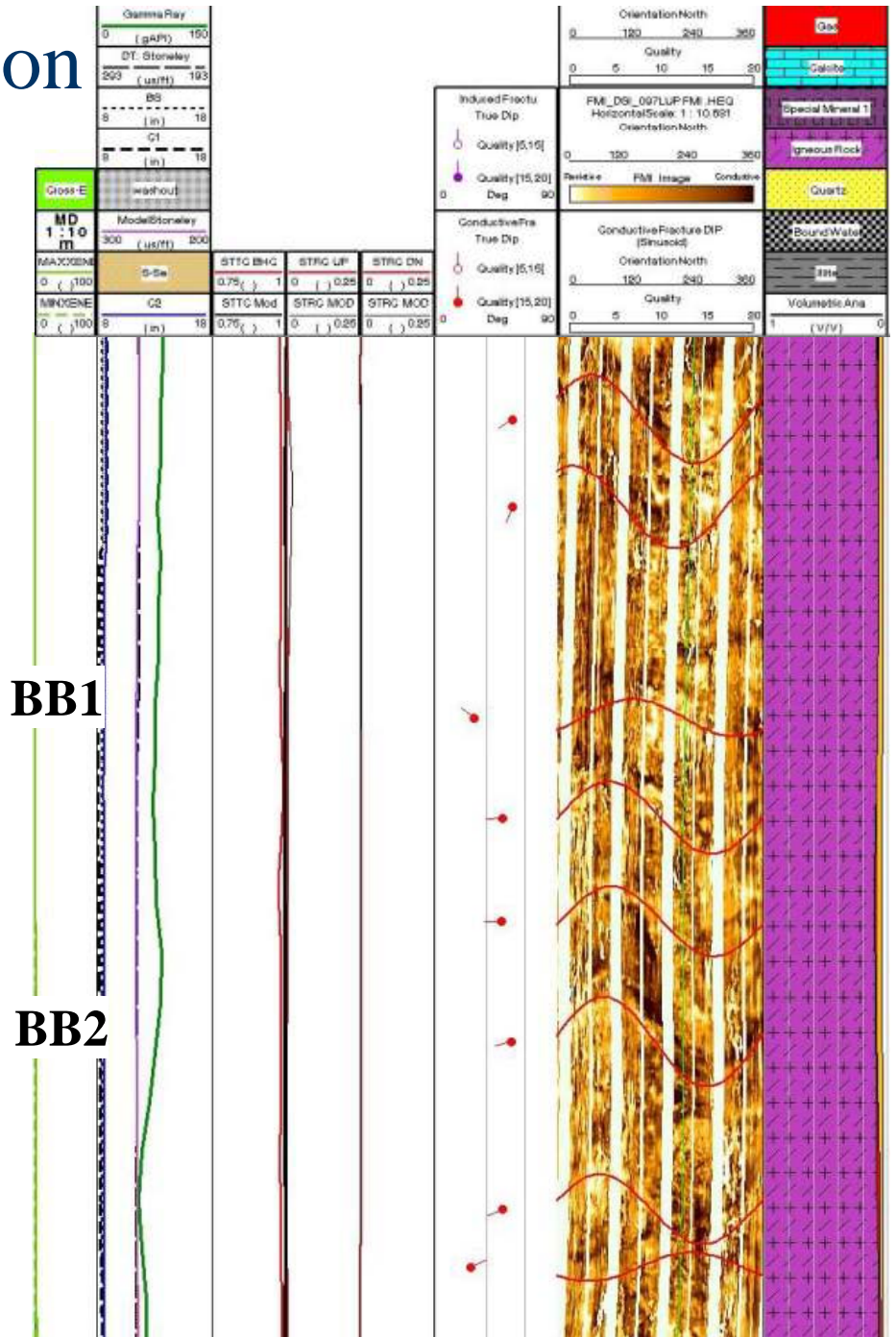
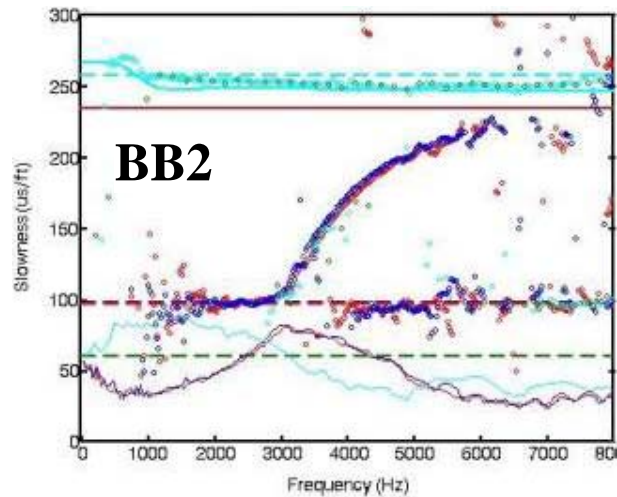
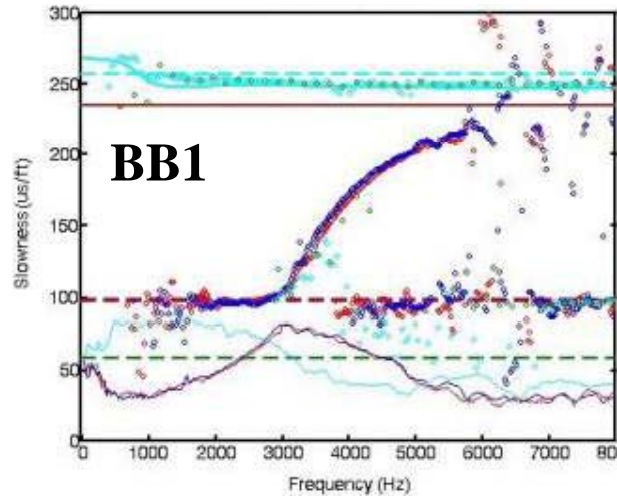
# Integrated Fracture Evaluation (Volcanic Reservoir in China)

- Borehole Image analysis suggests conductive fractures
- No acoustic cross energy anisotropy, no change in transmission and reflection coefficients
- Integrated interpretation with borehole sonic – fractures??



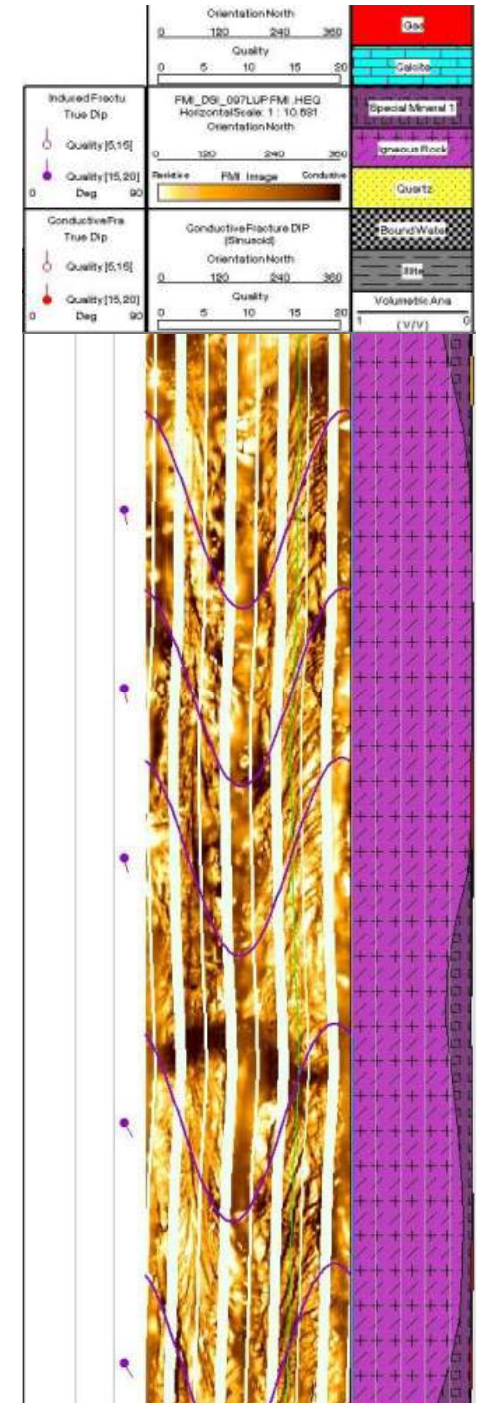
# Integrated Fracture Evaluation (Volcanic Reservoir in China)

Slowness Frequency Dispersion  
Plots show no evidence of Fractures



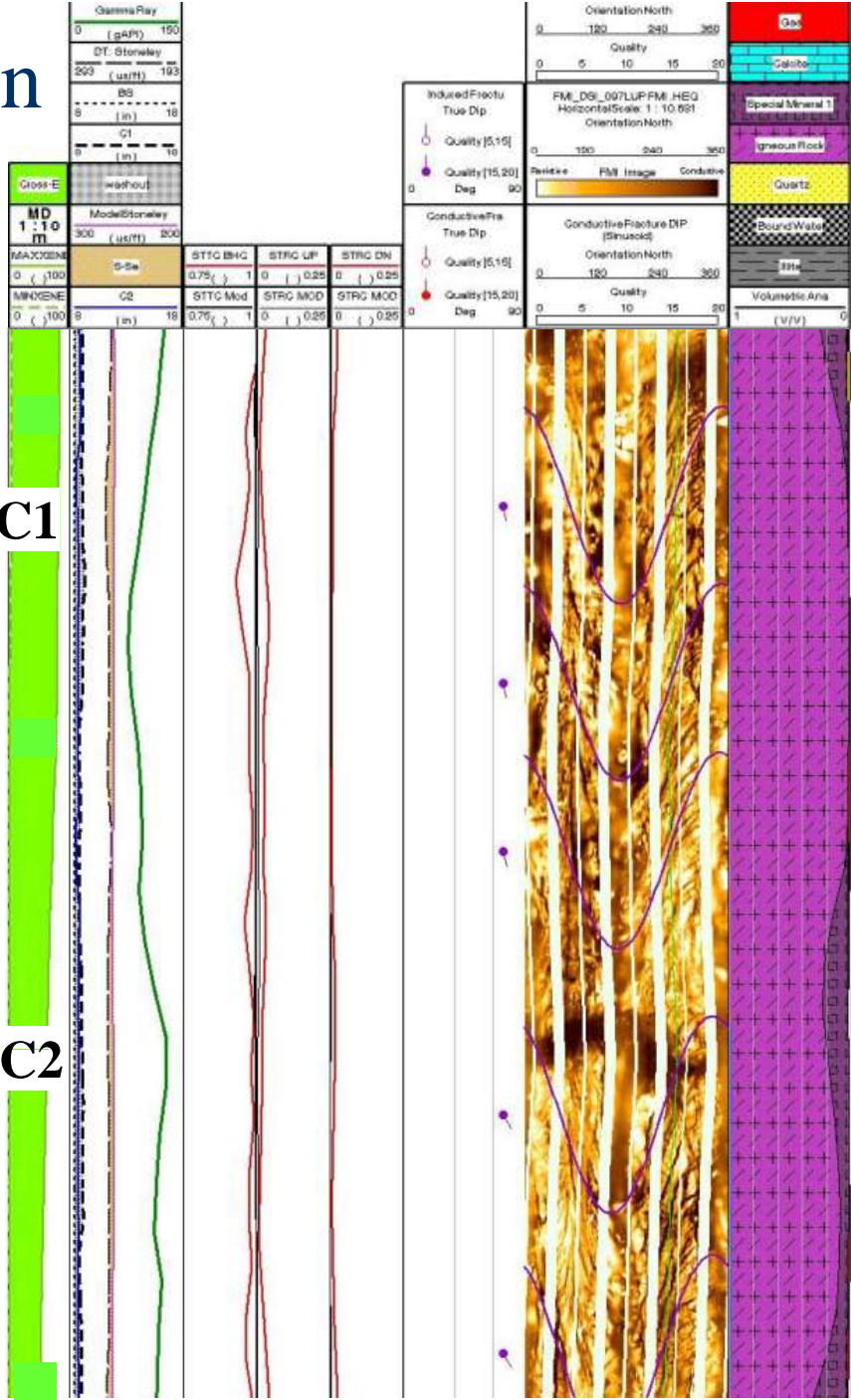
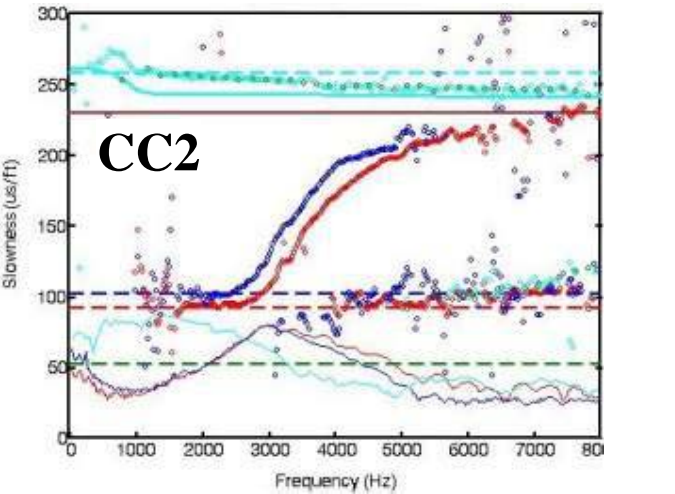
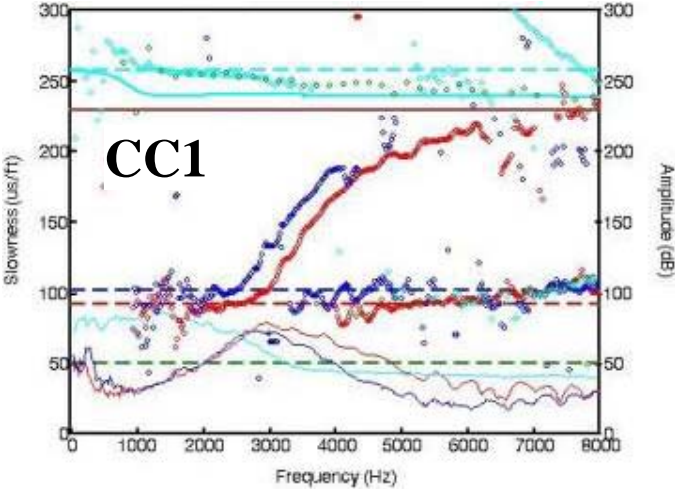
# Integrated Fracture Evaluation (Volcanic Reservoir in China)

- Borehole Image analysis suggests drilling induced fractures
- Large acoustic cross energy anisotropy, change in transmission and reflection coefficients
- Integrated interpretation with borehole sonic – open natural fractures



# Integrated Fracture Evaluation (Volcanic Reservoir in China)

Slowness Frequency Dispersion  
Plots indicate Open Fractures



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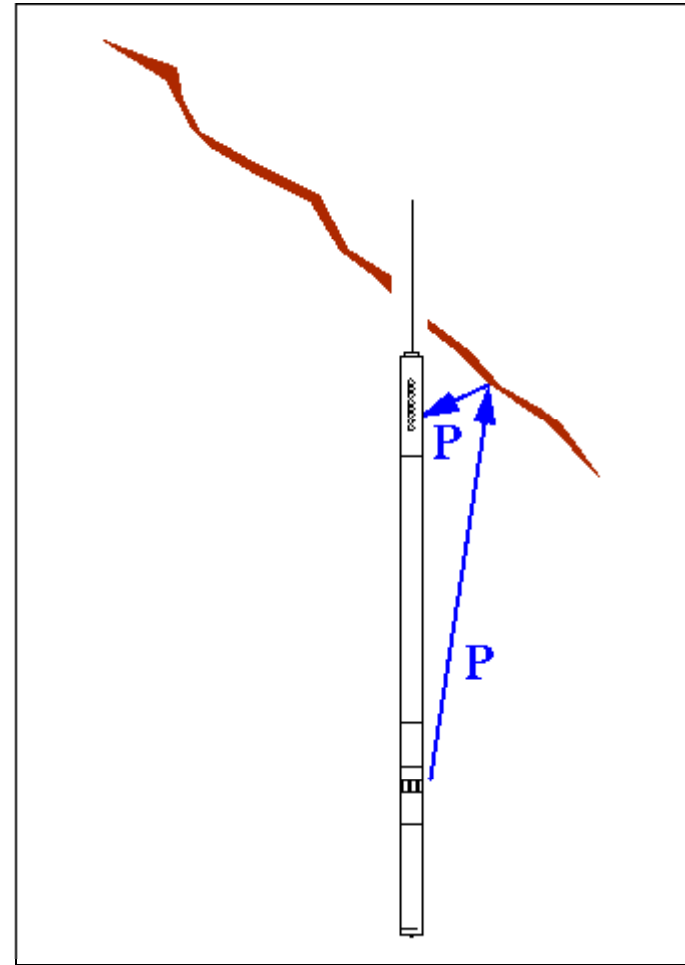
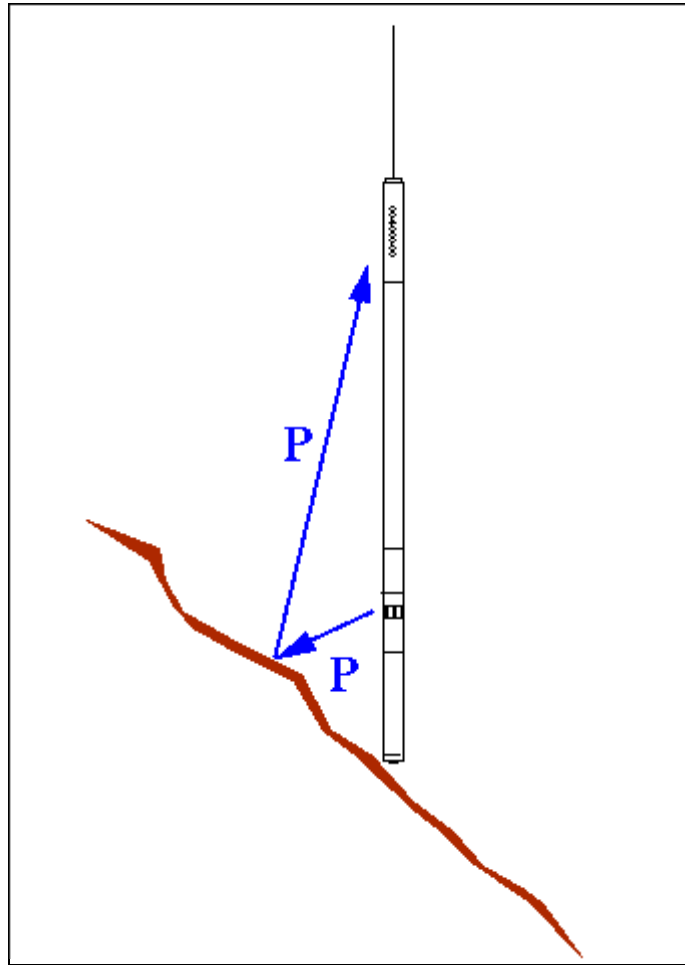
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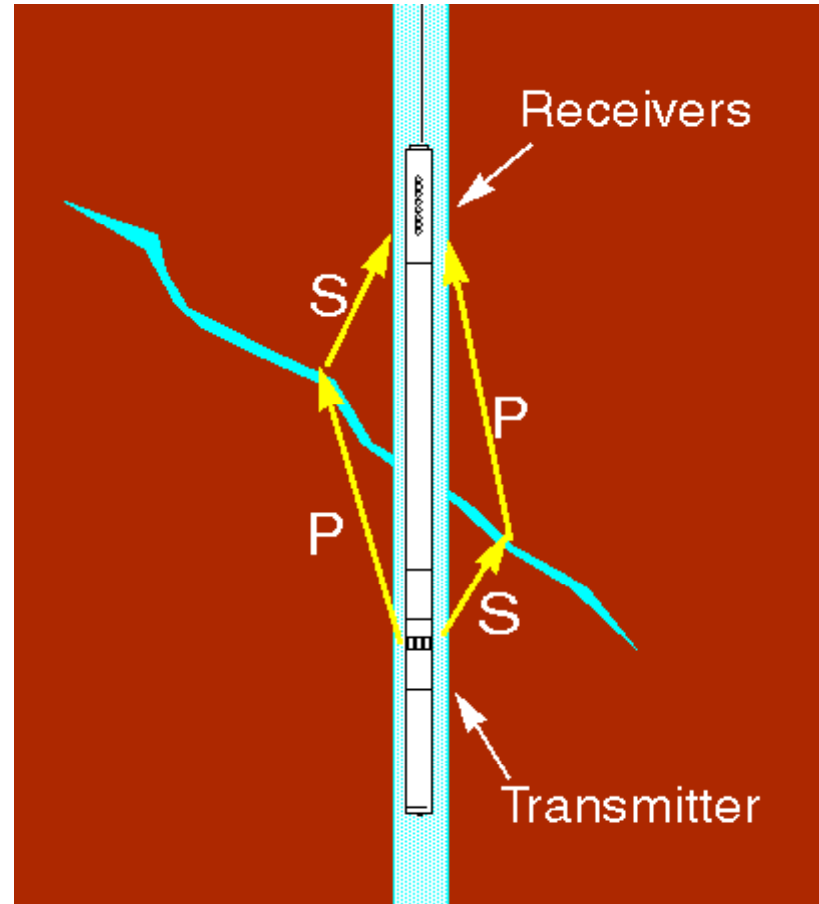
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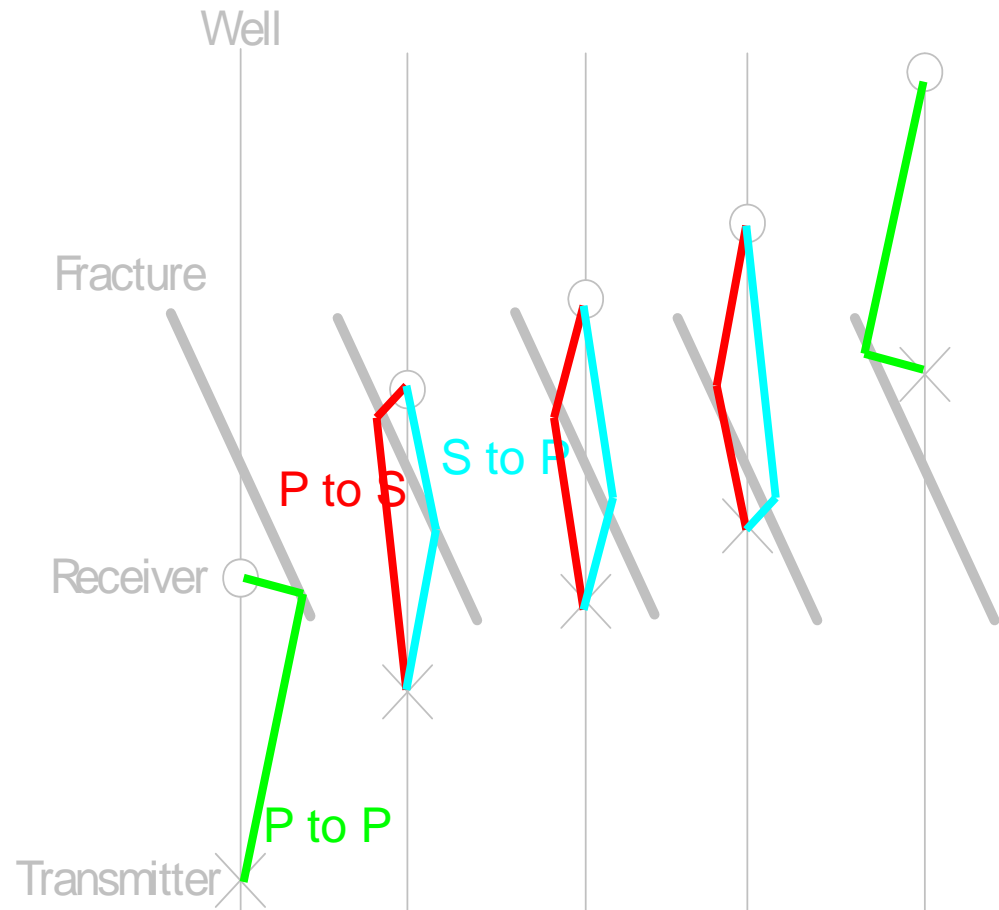
# Fracture Imaging from Borehole Acoustic Reflection Surveys (BARS)



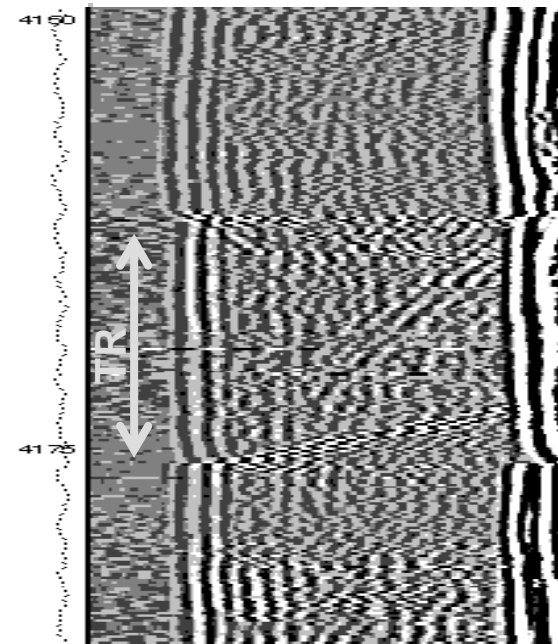
# or, Fracture Imaging by Mode Conversions



# Reflections and Refractions



P-to-S sees up-dip fractures and S-to-P sees down-dip fractures in a vertical well

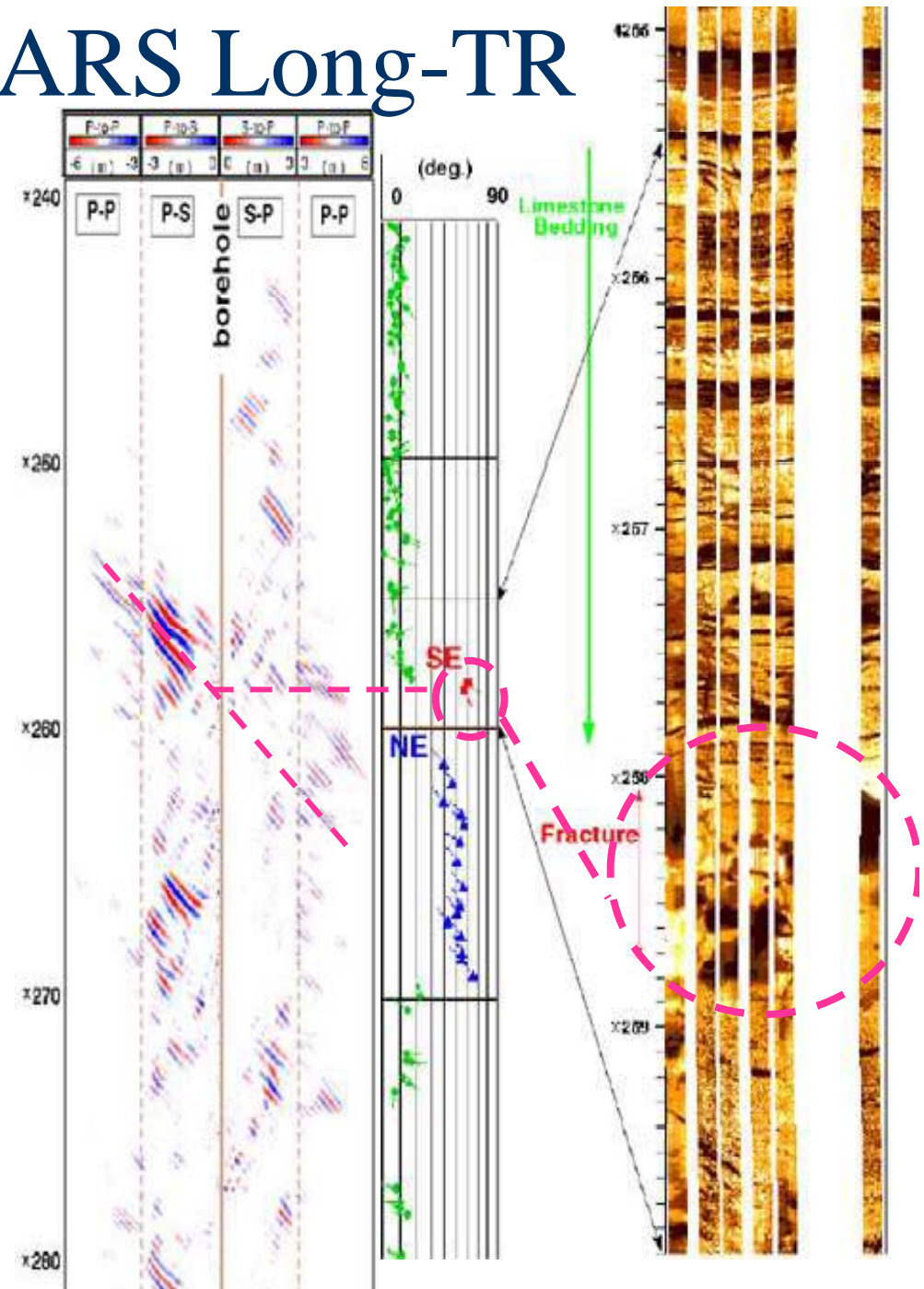


Time

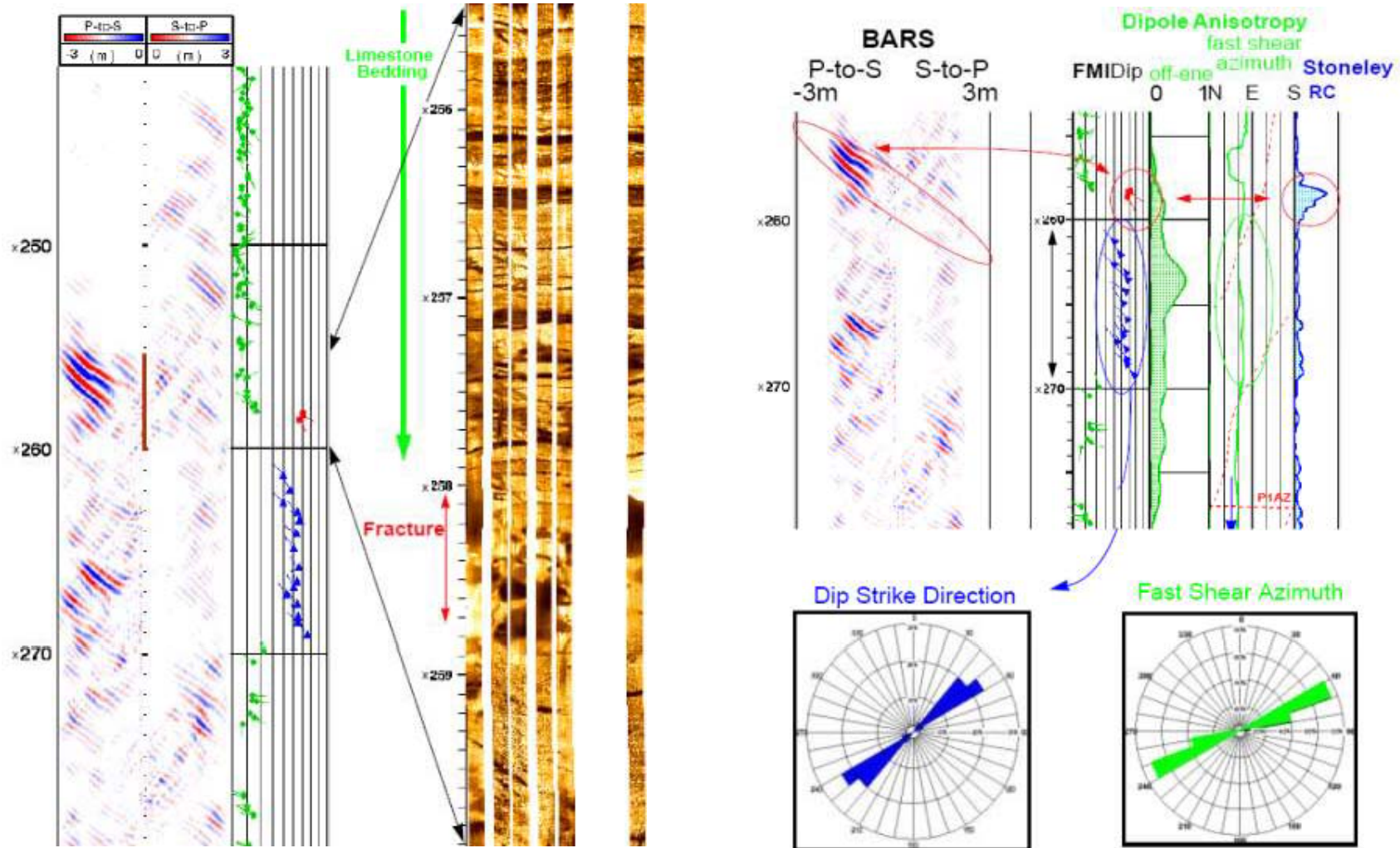


# Fracture Imaging - BARS Long-TR

- Close to borehole < 3 m
  - Mode converted transmission image
- Further away > 3 m
  - Reflection image
- Imaging fractures extending to formation up to 5 m from the borehole



# Fracture Imaging - integrated with borehole images, sonic Stoneley, shear



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