# Battelle PNL
# Wallula Basalt Pilot 1
# Sonic Scanner Review

7 September 2009

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Schlumberger DCS

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# Agenda

- Review of Sonic Scanner tool and applications
- Compressional and Shear
- Shear Anisotropy
- Stoneley Fracture Analysis and Stoneley Mobility
- Isotropic Rock Properties
- Integration with FMI interpretation and Petrophysical Analysis

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# Summary of Results

- Two main directions of the fast shear azimuth were observed.
  - One was indicating N45ºW, which agreed with the direction of drilling induced and natural fractures interpreted from the FMI.
  - The other direction indicated E-W and seemed to be in agreement with the predominant direction of the segments interpreted with FMI.

- It was observed a very good matched between the Stoneley derived mobility and the intrinsic permeability derived from the petrophysical analysis.

- The isotropic elastic properties and stress profile show variation between lithology, indicating the possibility for barriers.

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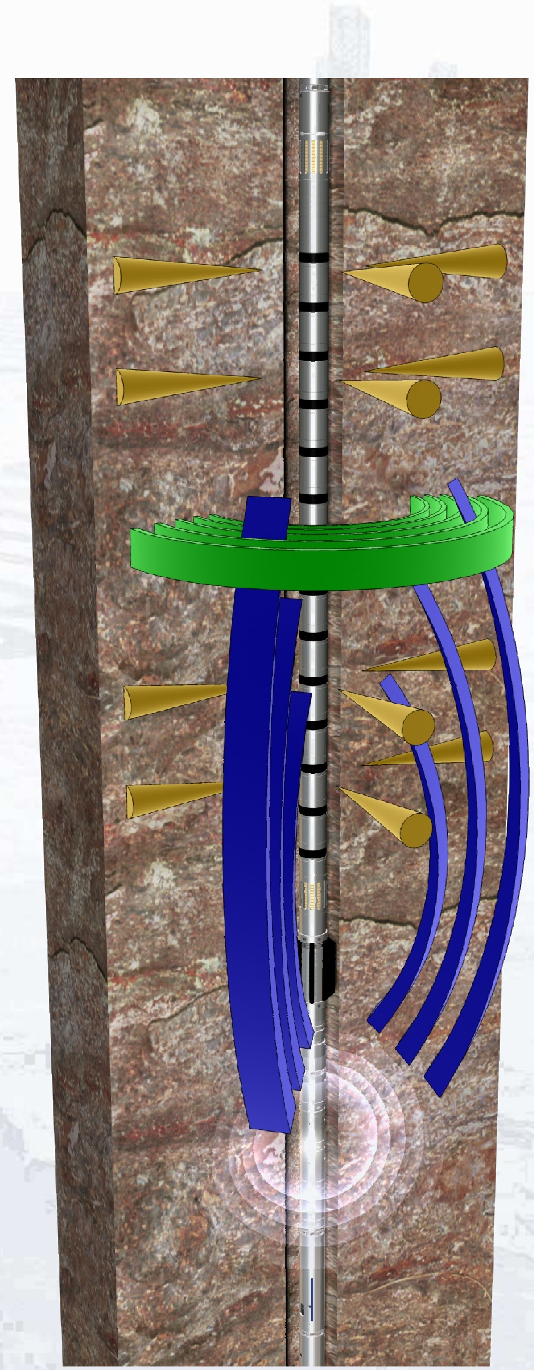
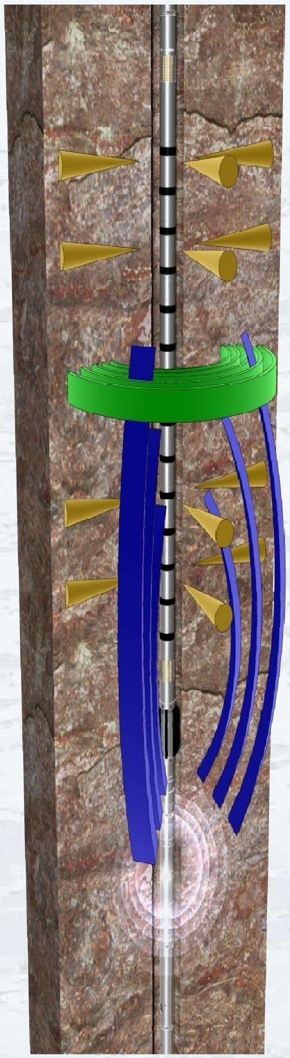
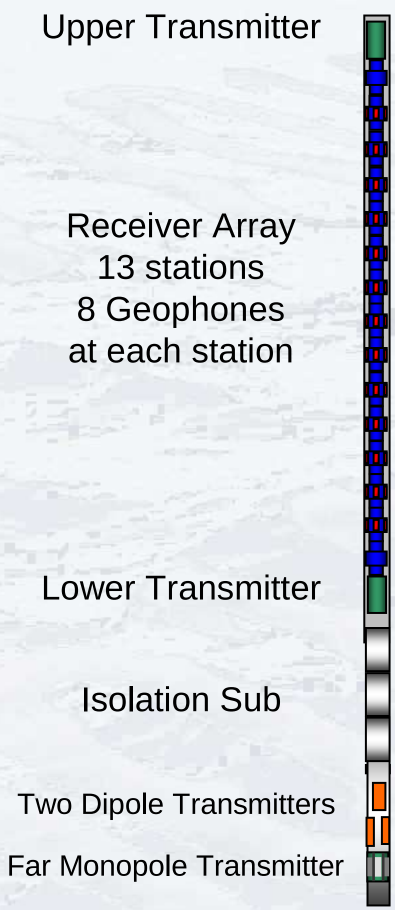
# Sonic Scanner Tool

- First industry acoustic tool providing axial, radial, and azimuthal measurements
- Wide frequency band for dipole transmitters and long and short monopole spacing giving various depth of investigation
- Improved receiver hardware and therefore signal to noise
- Better design so we can model the effect of the tool in the wellbore



# Sonic Scanner – The Tool for Geomechanics






## Receivers

13 station array (6' aperture) with 8 azimuthal receivers per station

Wide range of monopole T-R Spacings, from SS to LS (1 – 17 ft)

Each receiver individually digitized and calibrated

## Transmitters

Revolutionary "Shaker" dipole transmitters designed for high output, mode purity, wide bandwidth, reliability & low power consumption

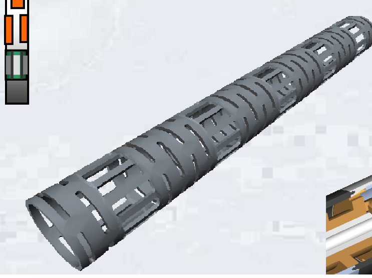
Wide band source Monopole transmitters with enhanced low frequency output

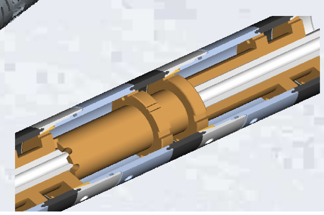
## Other features

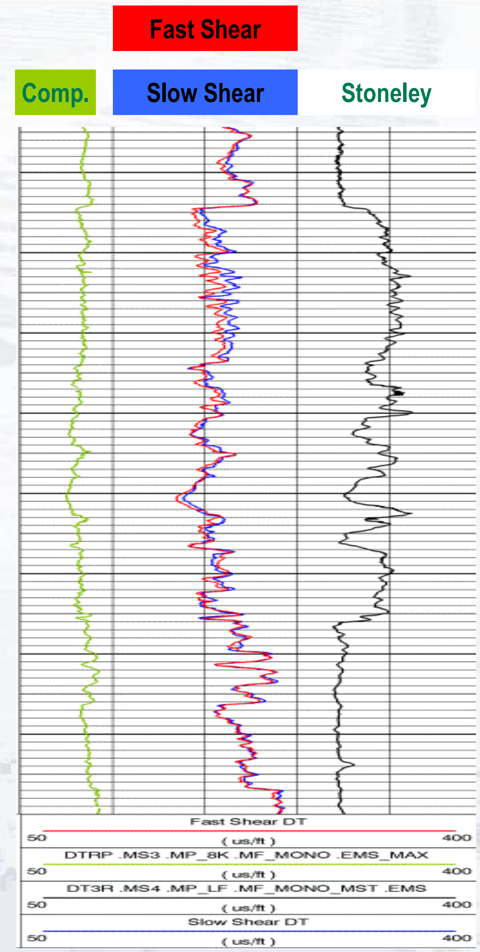
New telemetry - faster logging speed than the DSI

New combinable centralizers (PPC)

High signal/noise ratio in sonic wave forms due to advances in hardware





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# Sonic Scanner Solutions

- Tie to seismic
- Reservoir Characterization (anisotropy, fluid mobility, and elastic properties)
- Hydraulic Fracture/Injection
  - Planar vs. Complex
  - Drainage Patterns – Well Spacing
  - Propagation direction
  - Elastic Properties
  - Minimum horizontal stress magnitude
  - Barriers

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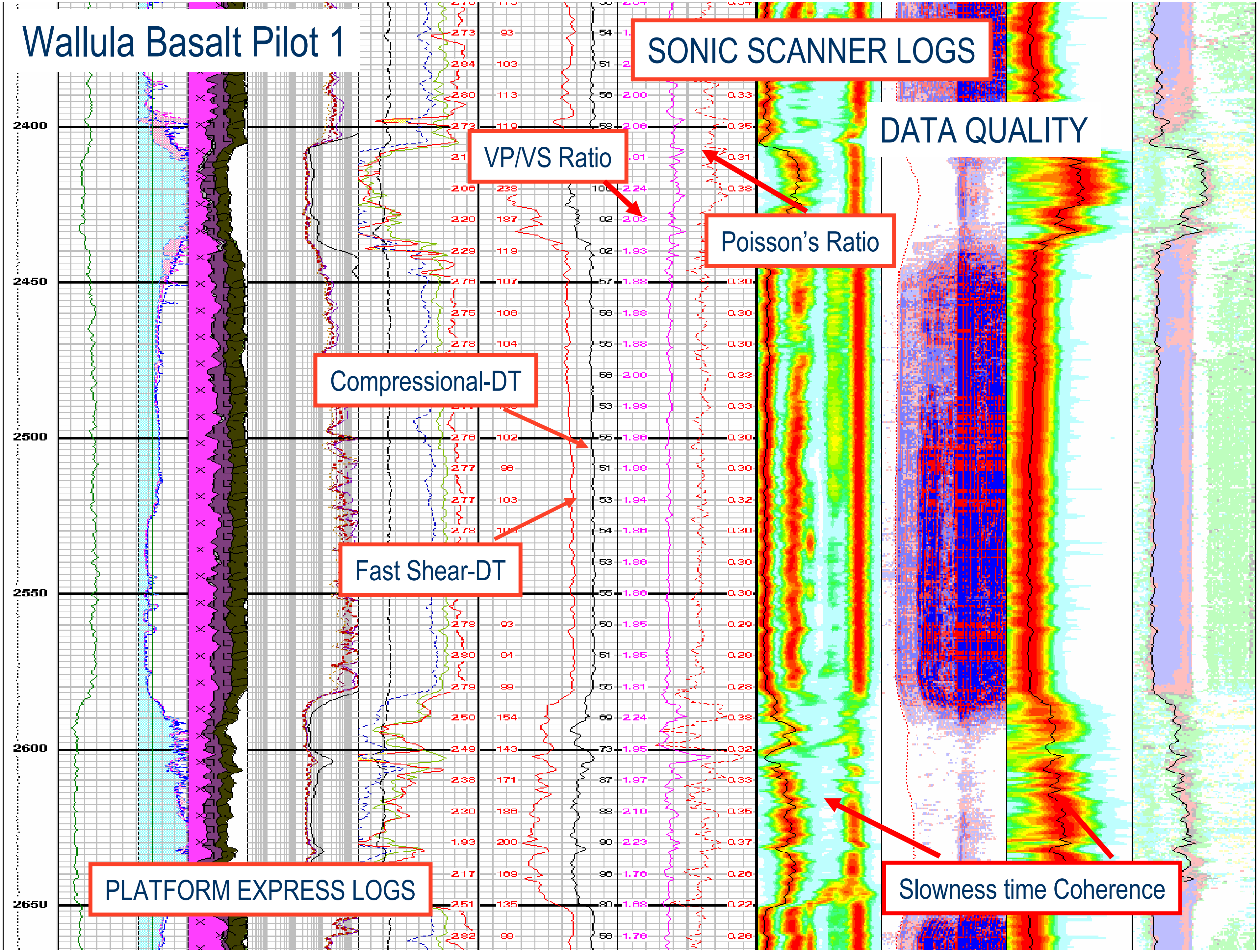

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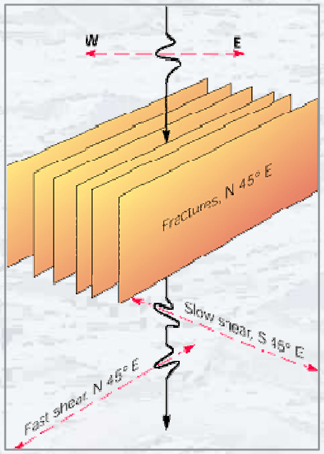
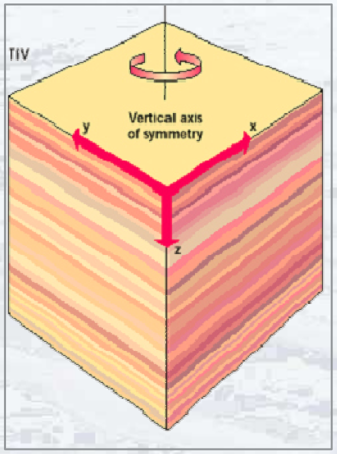
SONIC SCANNER LOGS
DATA QUALITY
VP/VS Ratio
Poisson's Ratio
Compressional-DT
Fast Shear-DT
PLATFORM EXPRESS LOGS
Slowness time Coherence
2400
2450
2500
2550
2600
2650

# Shear Anisotropy or Azimuthal Anisotropy

Anisotropy is the variation of a property with the direction in which it is measured

Intrinsic Anisotropy

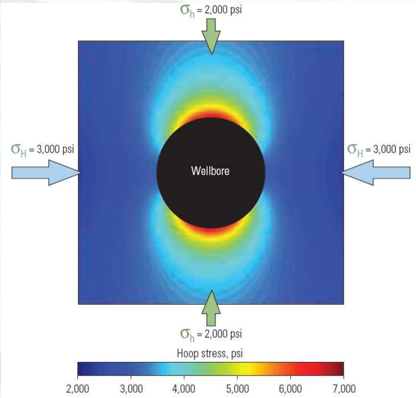



Fractures (**T**ransverse **I**sotropic **H**orizontal)

Shales, thin bedding (**T**ransverse **I**sotropic **V**ertical)

Stress-Induced Anisotropy




Fast shear is parallel to maximum stress

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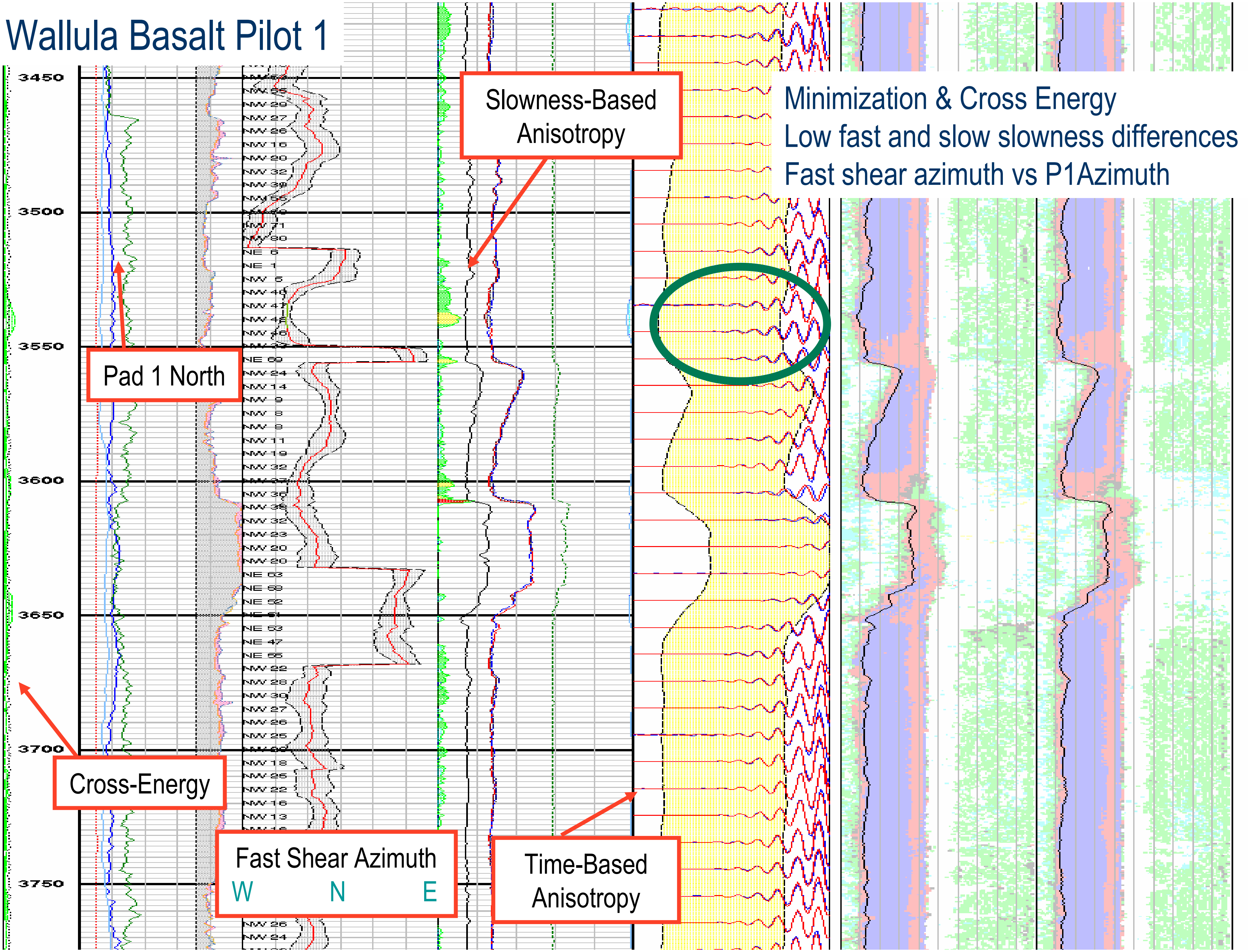
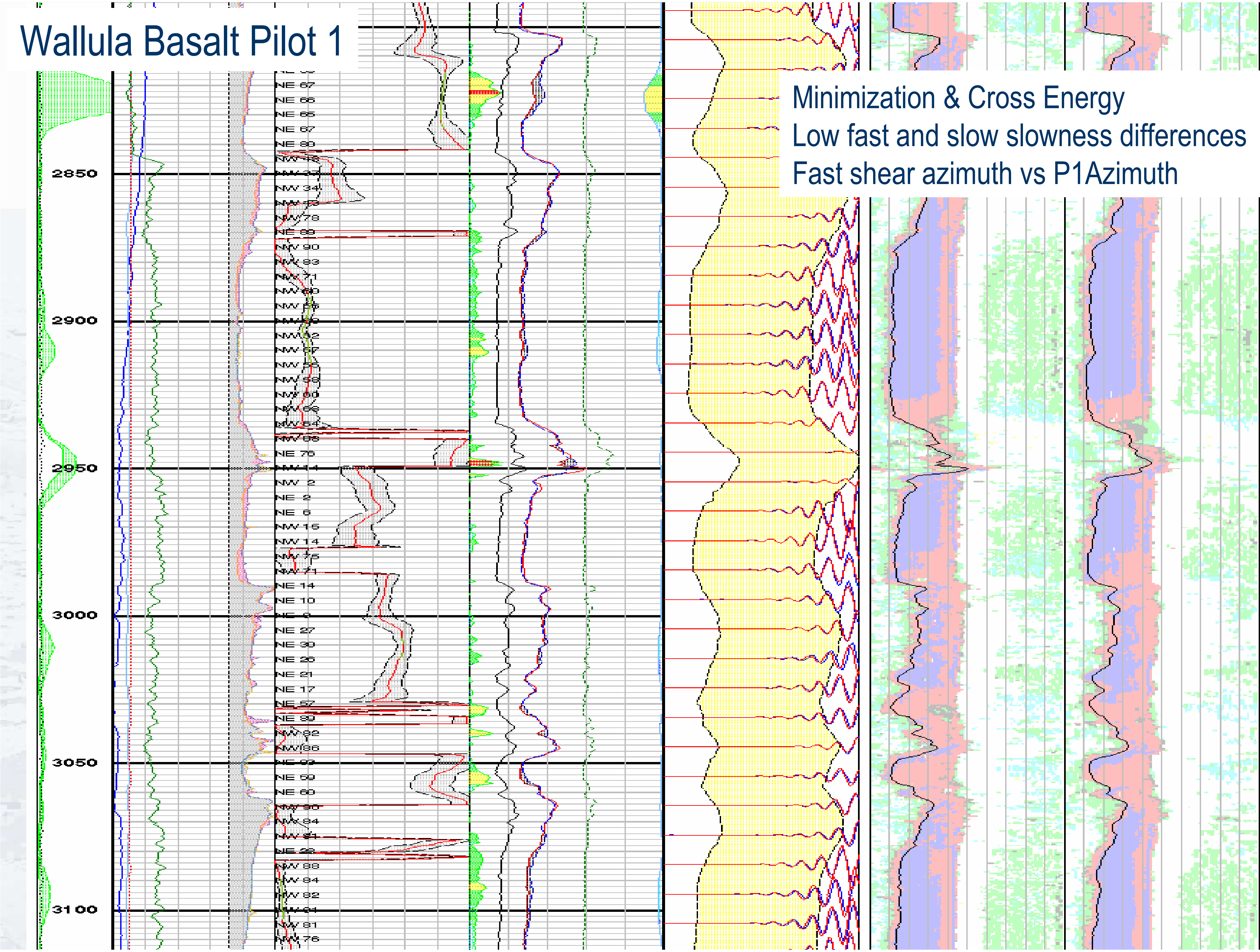


# Wallula Basalt Pilot 1



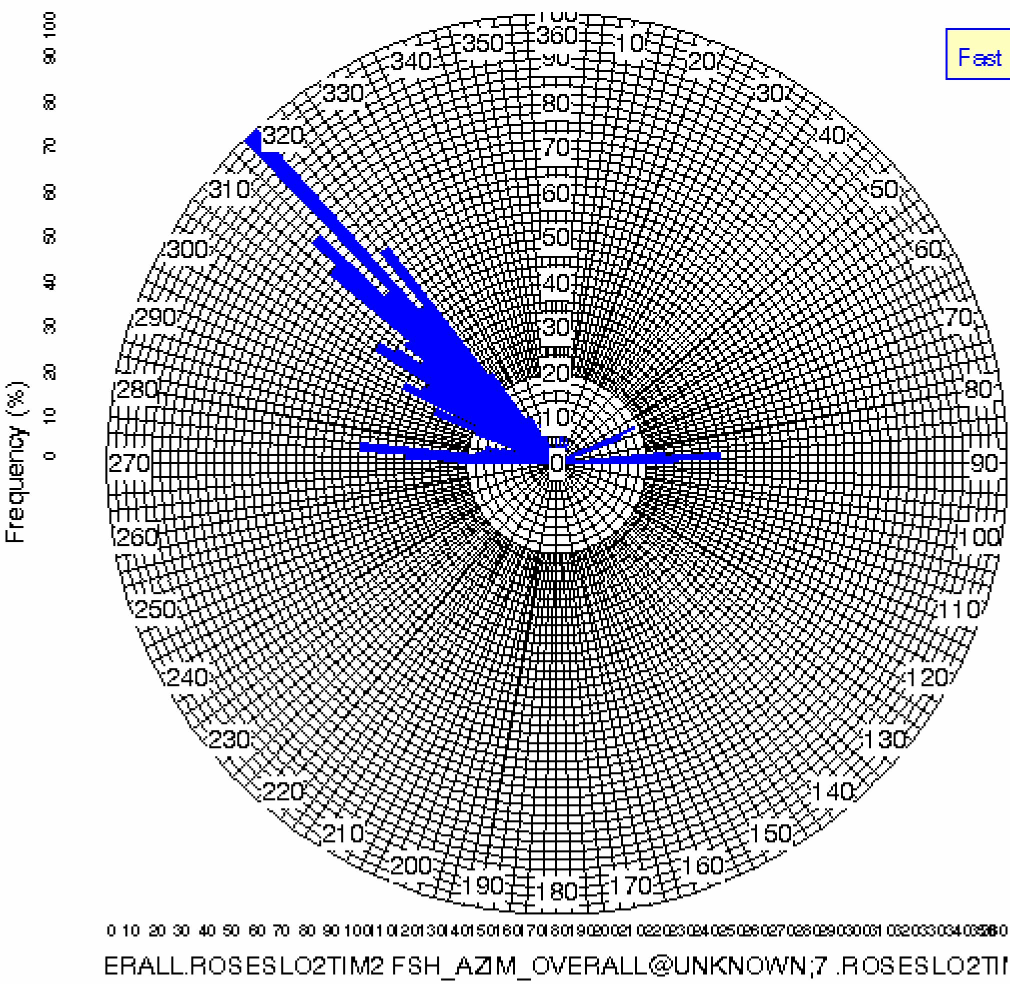

Minimization & Cross Energy

Low fast and slow slowness differences

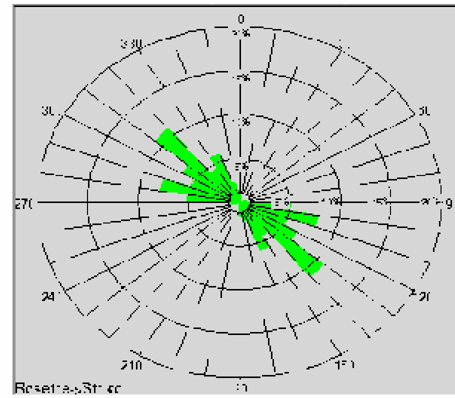
Fast shear azimuth vs P1Azimuth

# Wallula Basalt Pilot 1 Rose plot – Entire logged section

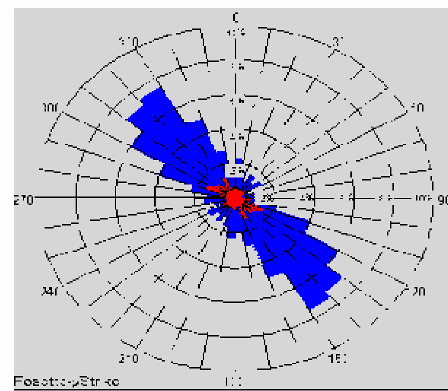
Fast Shear Azimuth for time-based and slowness-based anisotropy > 2 %




| | | | |
|---|---|---|---|
| | | # Points Total: | 5905 |
| Start Depth: | 4062 ft | # Points Plotted: | 1280 |
| Stop Depth: | 1110 ft | # Points Absent: | |
| Sampling Rate: | 0.5 ft | # Points Cut: | 4625 |
| X Max Value | 359.972 deg | # > X Scale Max: | 0 |
| X Min Value: | 0.0620155 deg | # < X Scale Min: | 0 |

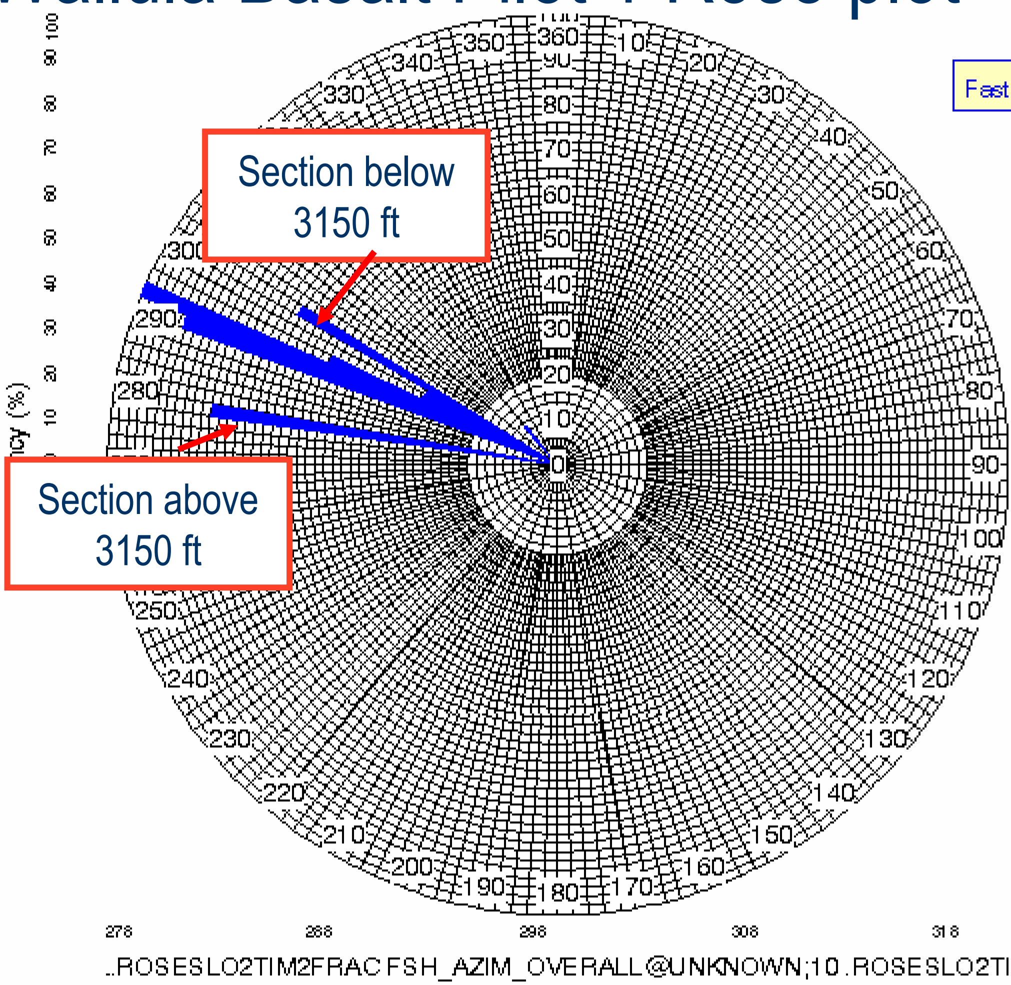


Stress-Induced Fractures



Open Natural Fractures

# Wallula Basalt Pilot 1 Rose plot – Fractured sections

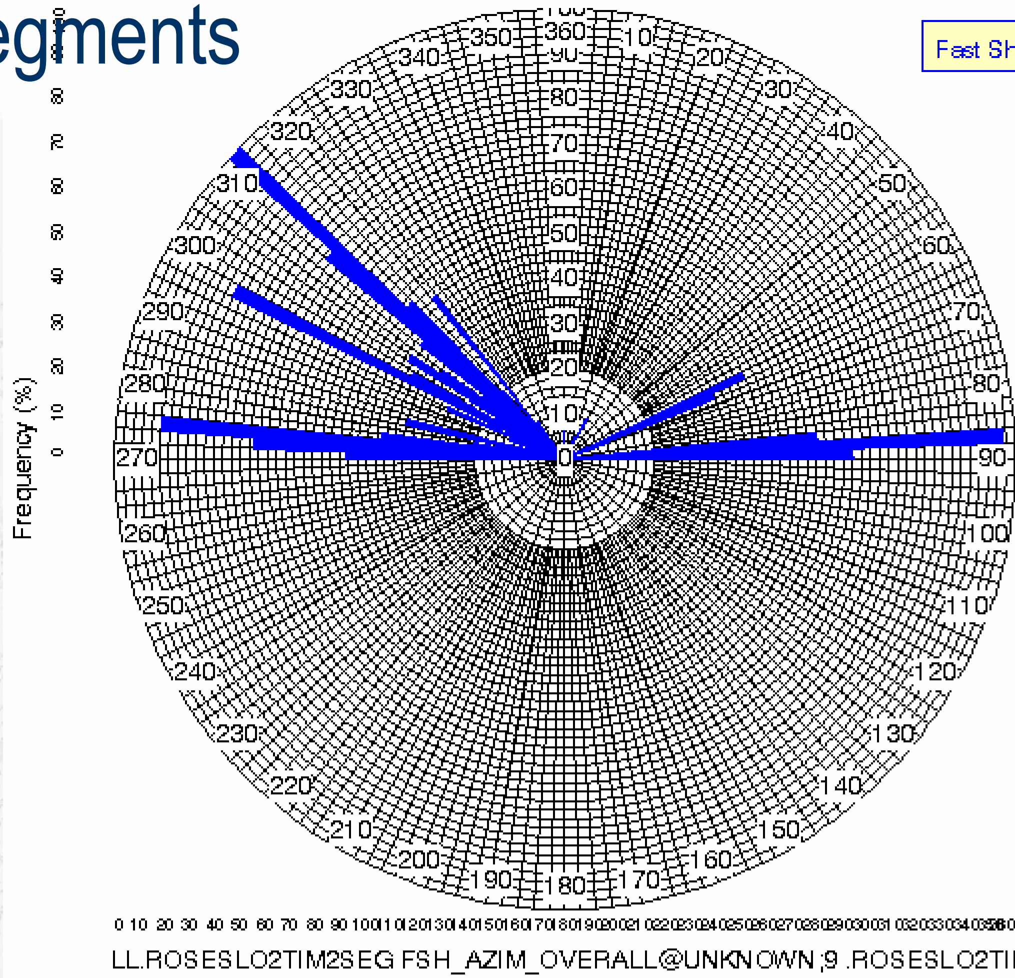



Fast Shear Azimuth for time-based and slowness-based anisotropy > 2 %

Sections that contain Fractures as interpreted in FMI. Full section

| | | | |
|---|---|---|---|
| | | # Points Total: | 3920 |
| Start Depth: | 4062 ft | # Points Plotted: | 43 |
| Stop Depth: | 1110 ft | # Points Absent: | 0 |
| Sampling Rate: | 0.5 ft | # Points Cut: | 3877 |
| X Max Value: | 320.325 deg | # > X Scale Max: | 0 |
| X Min Value: | 278.131 deg | # < X Scale Min: | 0 |

# Wallula Basalt Pilot 1 Rose plot – Sections with segments

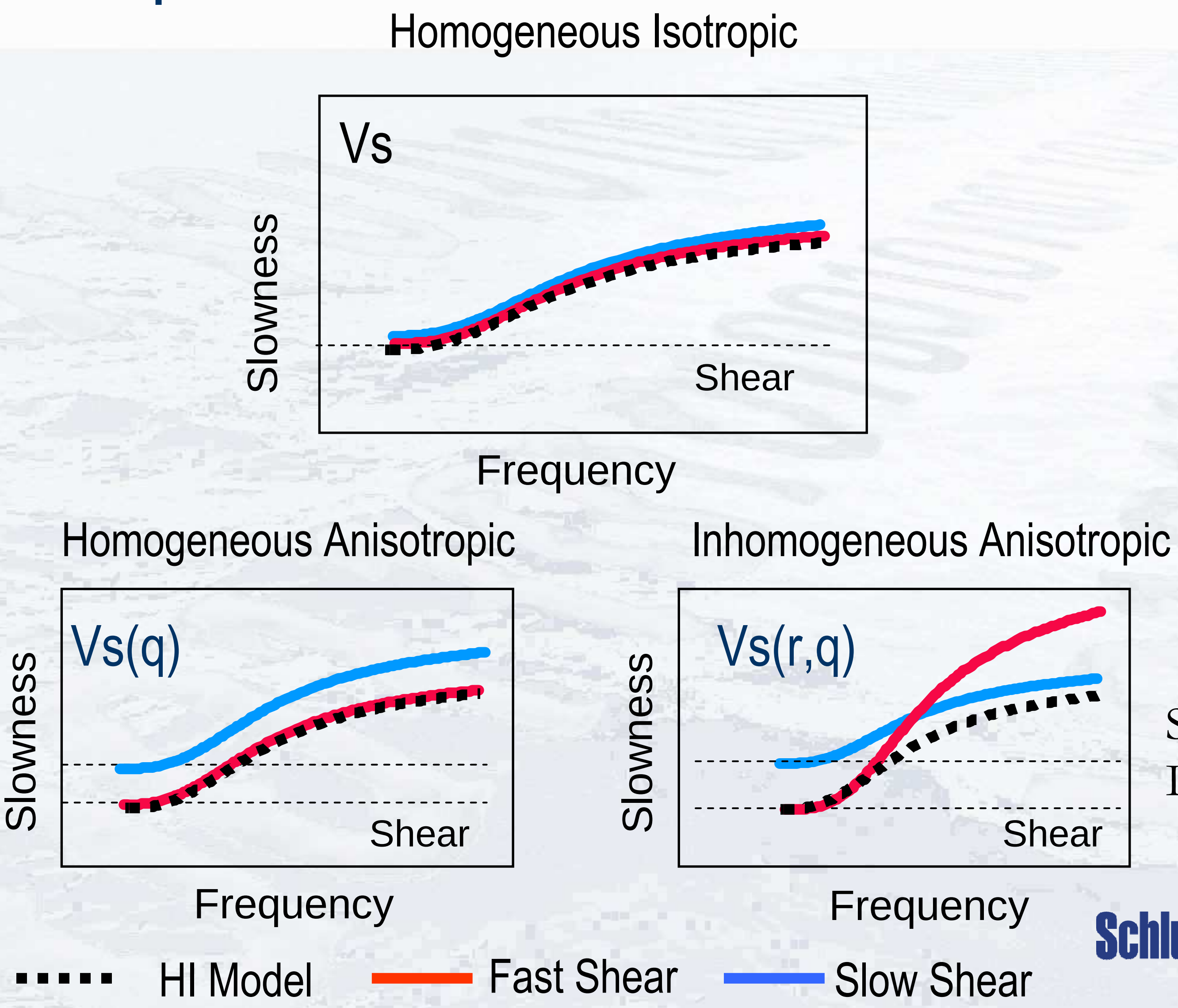



Fast Shear Azimuth for time-based and slowness-based anisotropy > 2 %

Sections that contain Segments as interpreted in FMI

| | | | |
|---|---|---|---|
| | | # Points Total: | 3921 |
| Start Depth: | 4062 ft | # Points Plotted: | 520 |
| Stop Depth: | 1110 ft | # Points Absent: | 0 |
| Sampling Rate: | 0.5 ft | # Points Cut: | 3401 |
| X Max Value: | 359.972 deg | # > X Scale Max: | 0 |
| X Min Value: | 0.0620155 deg | # < X Scale Min: | 0 |

# Diagnosing Anisotropy Source from Flexural Dispersion Curves




Intrinsic
-Shales
-Layering
-Fractures

Stress
Induced

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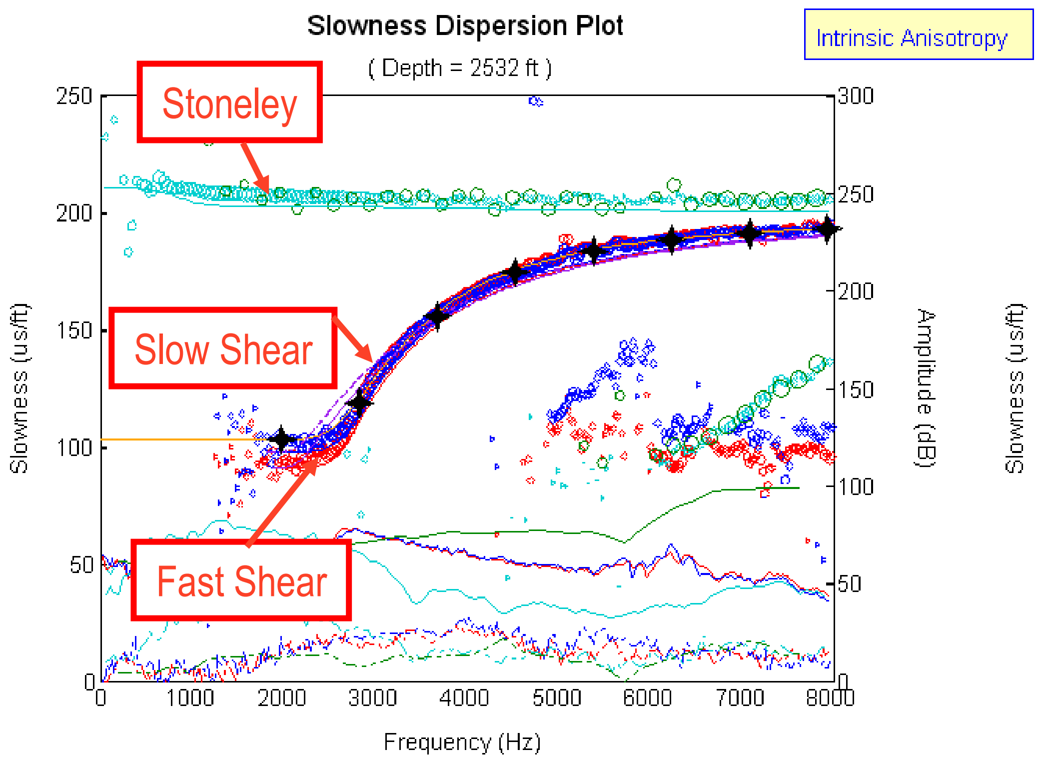
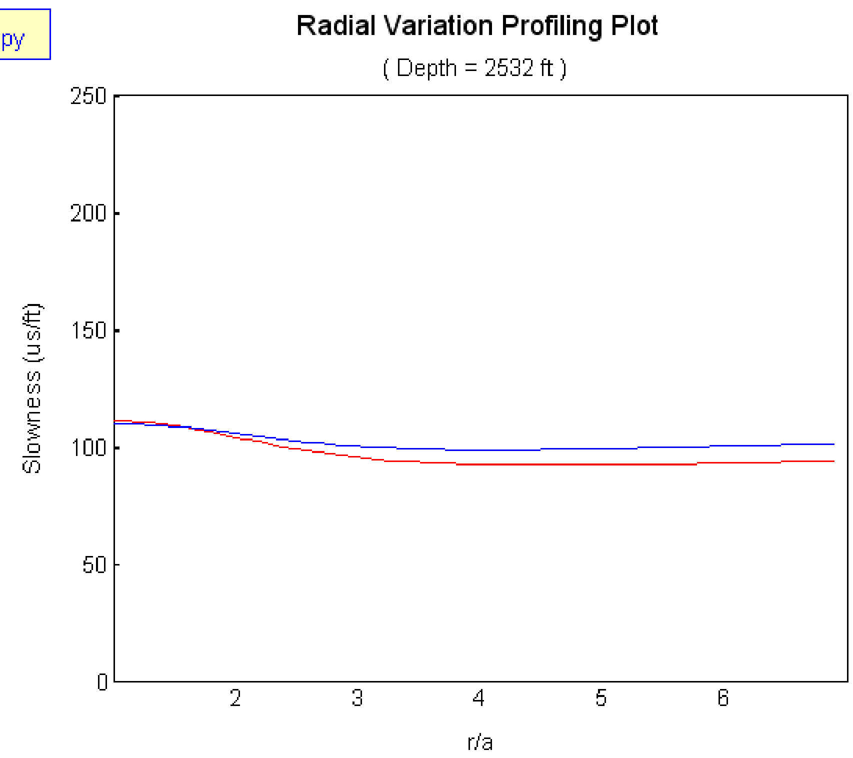
# Source of Azimuthal Anisotropy – Sonic Waveform Dispersion Analysis

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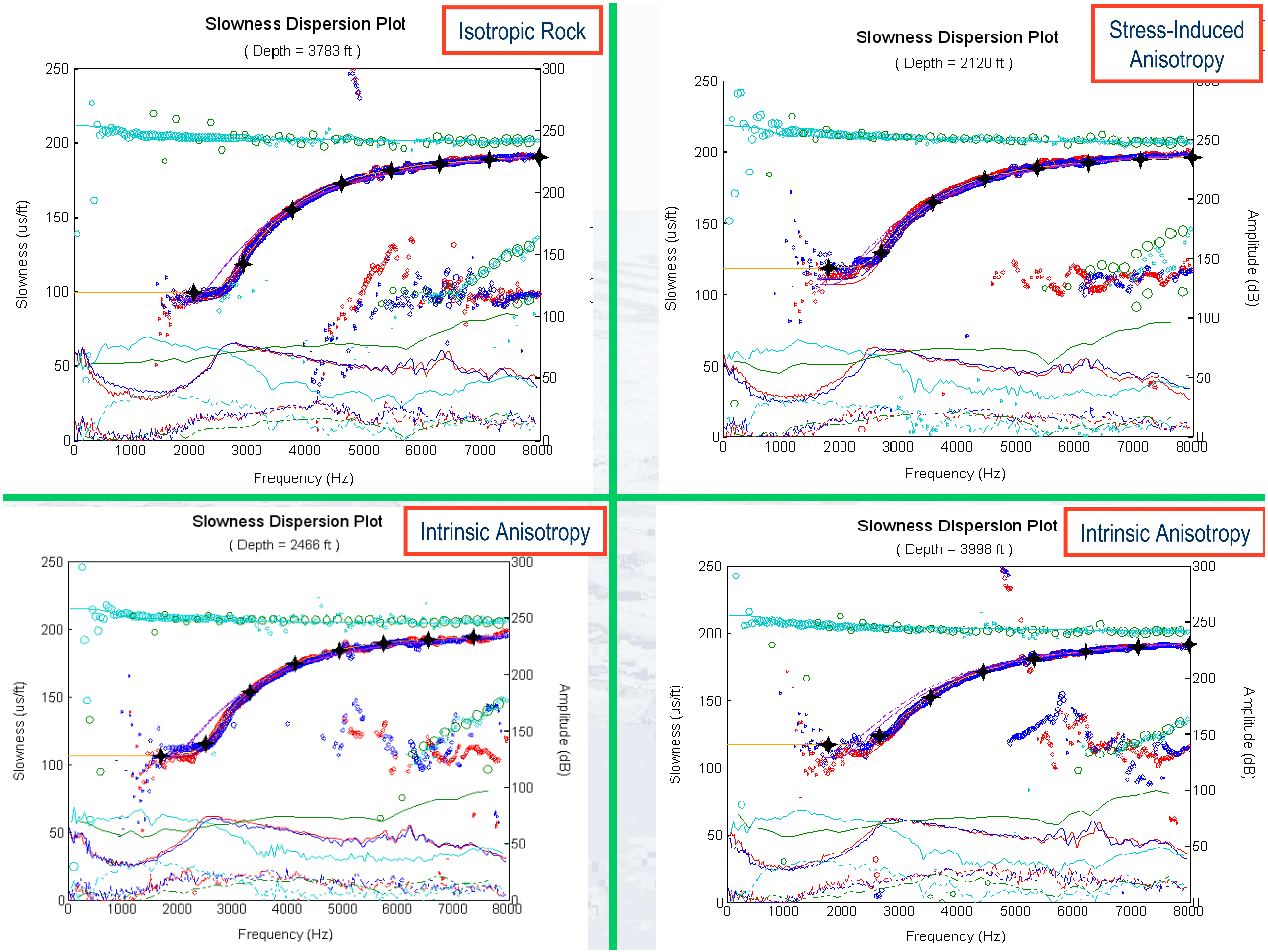
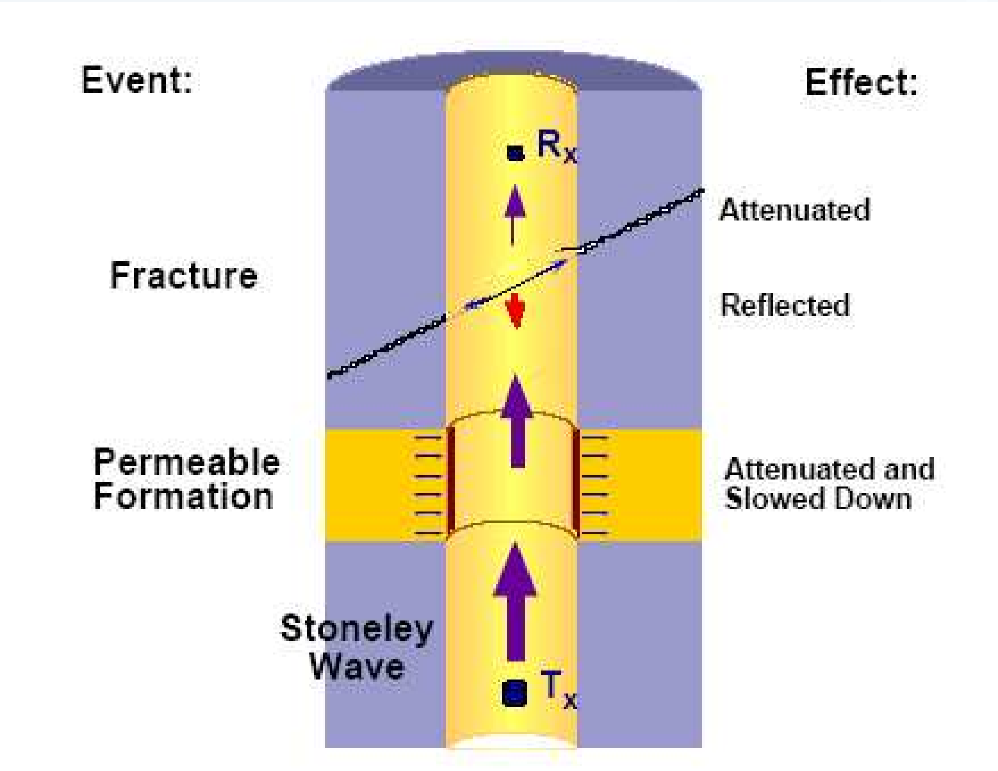


Slowness Dispersion Plot
( Depth = 3783 ft )
Isotropic Rock
Slowness (us/ft)
Frequency (Hz)
Slowness Dispersion Plot
( Depth = 2120 ft )
Stress-Induced Anisotropy
Slowness (us/ft)
Amplitude (dB)
Frequency (Hz)
Slowness Dispersion Plot
( Depth = 2466 ft )
Intrinsic Anisotropy
Slowness (us/ft)
Amplitude (dB)
Frequency (Hz)
Slowness Dispersion Plot
( Depth = 3998 ft )
Intrinsic Anisotropy
Slowness (us/ft)
Amplitude (dB)
Frequency (Hz)

# Stoneley Mode

Slowness is a function of frequency: dispersive mode




Low frequency fluid pressure pulse.

Piston-like propagation along borehole wall.

Energy decays exponentially away from borehole wall.

Sensitive to fractures and permeable zones.

Applications:

- Used to determine mobility
- Stoneley fracture detection is unreliable when sharp bed boundaries exist. Must only be used with FMI.

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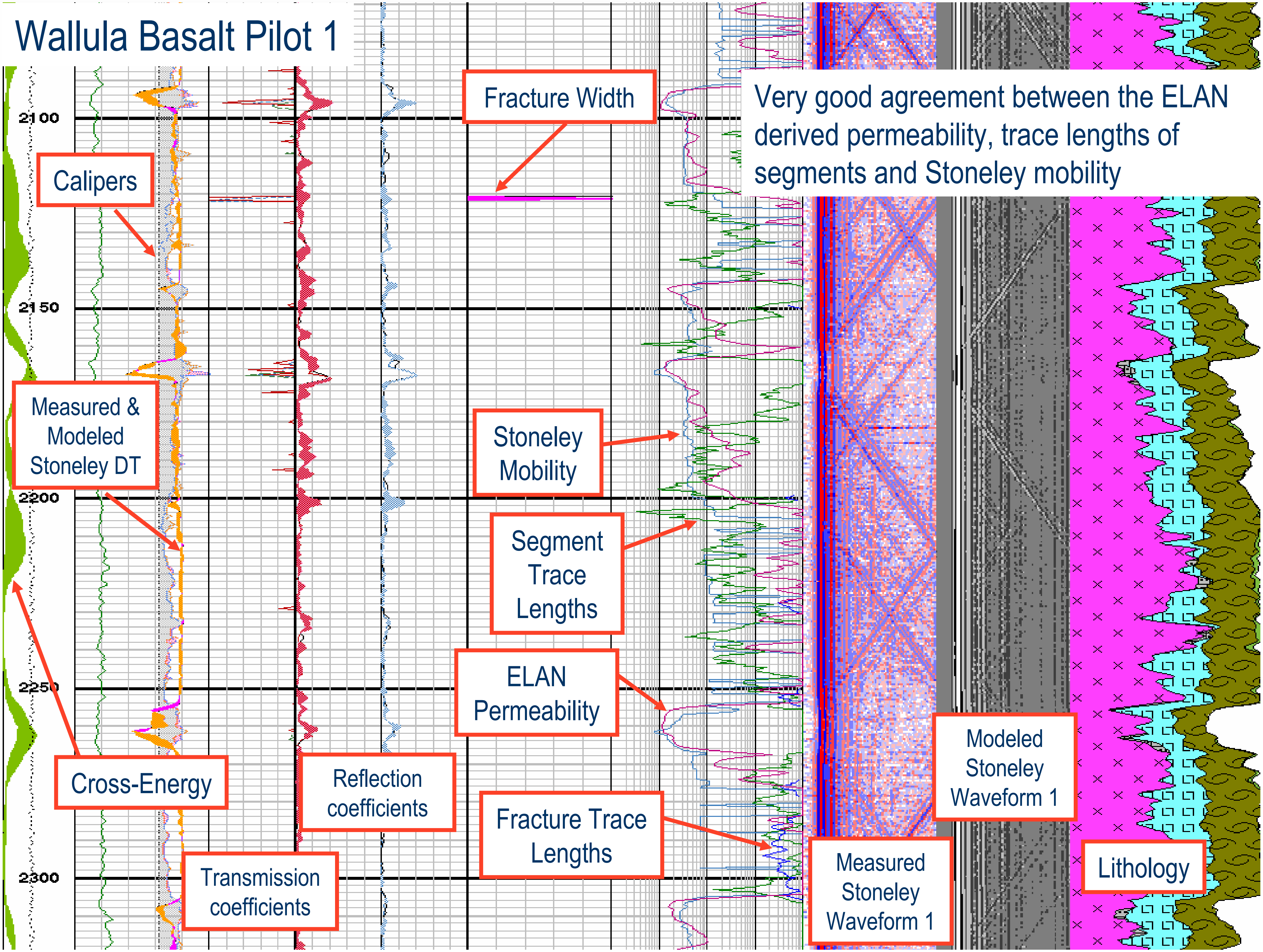
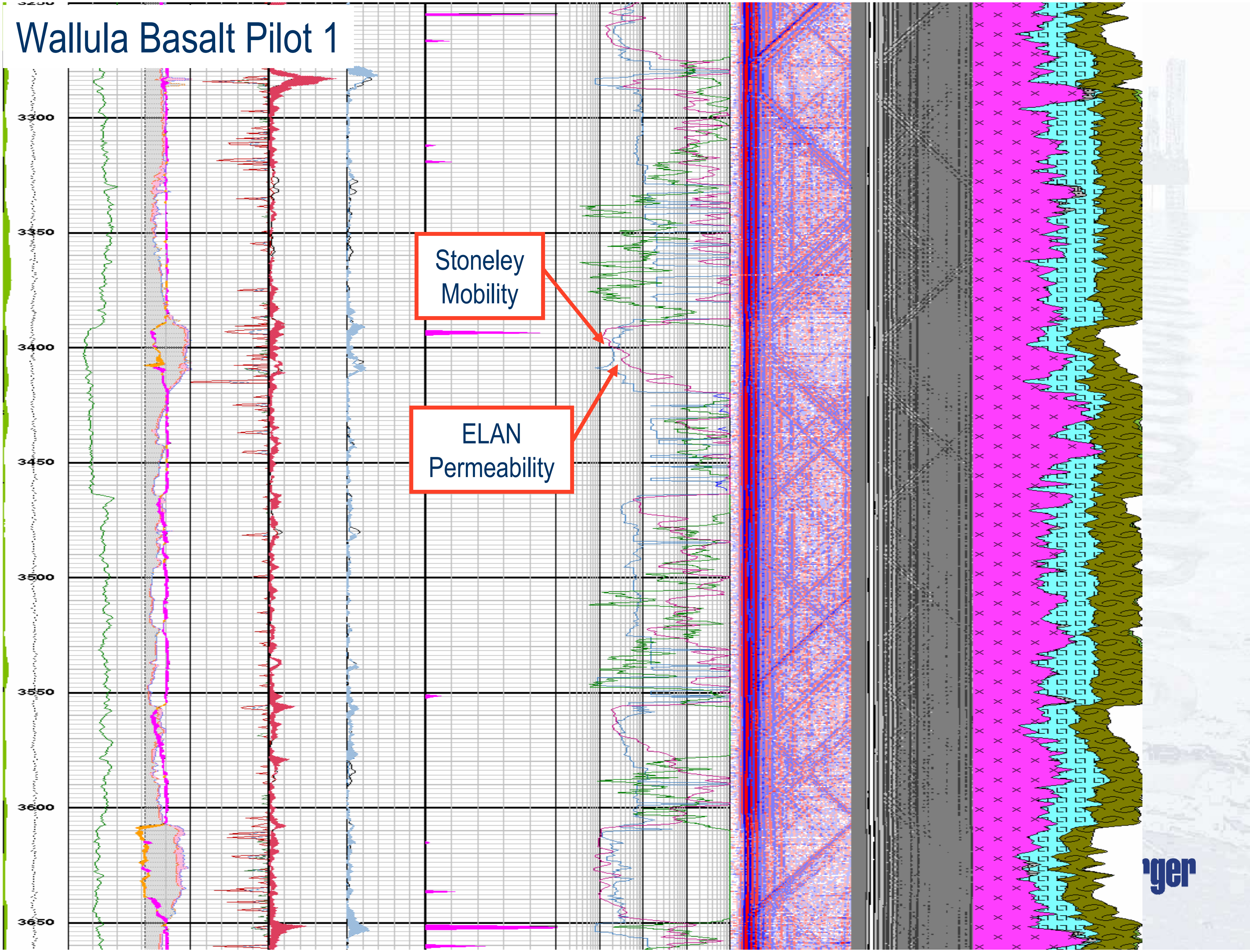
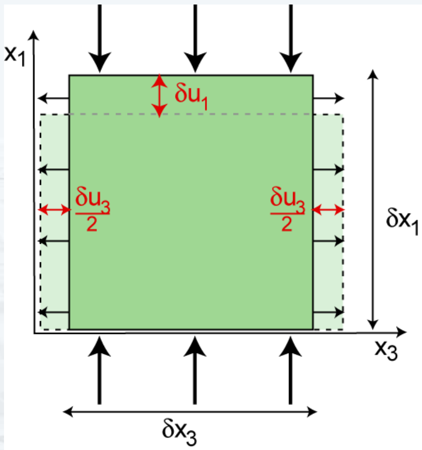
Very good agreement between the ELAN derived permeability, trace lengths of segments and Stoneley mobility



# Wallula Basalt Pilot 1



# Elastic Properties and Stress from Anisotropy

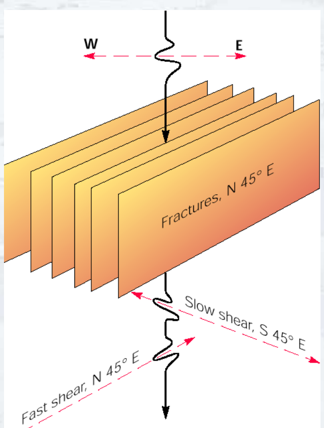



Young's Modulus:  Stiffness
Apply stress in one direction, measure strain in that direction

Poisson's Ratio:  Compressibility
Apply strain in one direction, measure strain in perpendicular direction

$$\upsilon = \frac{3K_{bulk} - 2G}{6K_{bulk} + 2G}$$

$$\nu = \frac{V_p^{\,2} - 2V_s^{\,2}}{2(V_p^{\,2} - V_s^{\,2})}$$




Elastic Properties are a function of:
DT-Compressional, DT-Fast shear, and bulk density

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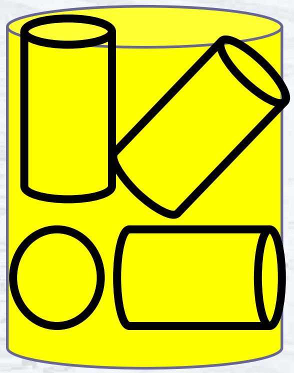
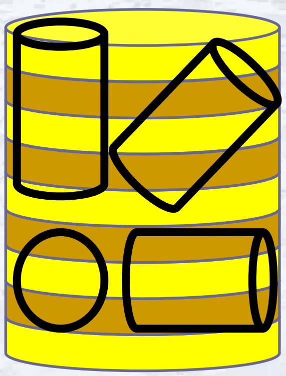
# Transverse Anisotropy – Impact on Stress Calculations



**Stress Equation with Isotropic Rock Properties**

$$\sigma_h - \sigma_p = \frac{\upsilon_v}{1-\upsilon_v}\left(\sigma_v - \sigma_p\right) + tectonics$$



**Stress Equation with Anisotropic Rock Properties**

$$\sigma_h - \sigma_p = \frac{E_h}{E_v}\frac{\upsilon_v}{1-\upsilon_h}\left(\sigma_v - \sigma_p\right) + tectonics$$

Equation for TIV, modified for TIH

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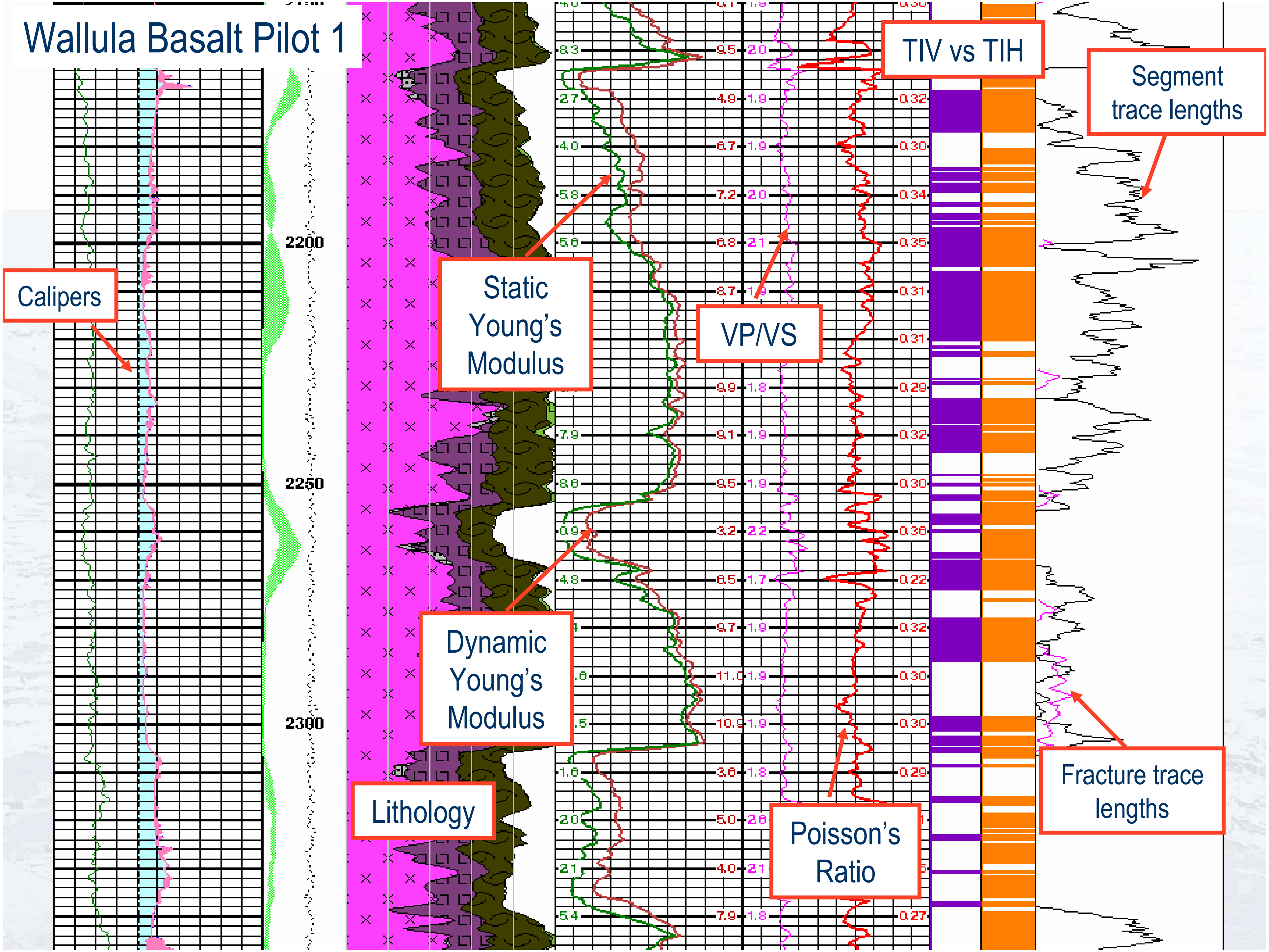

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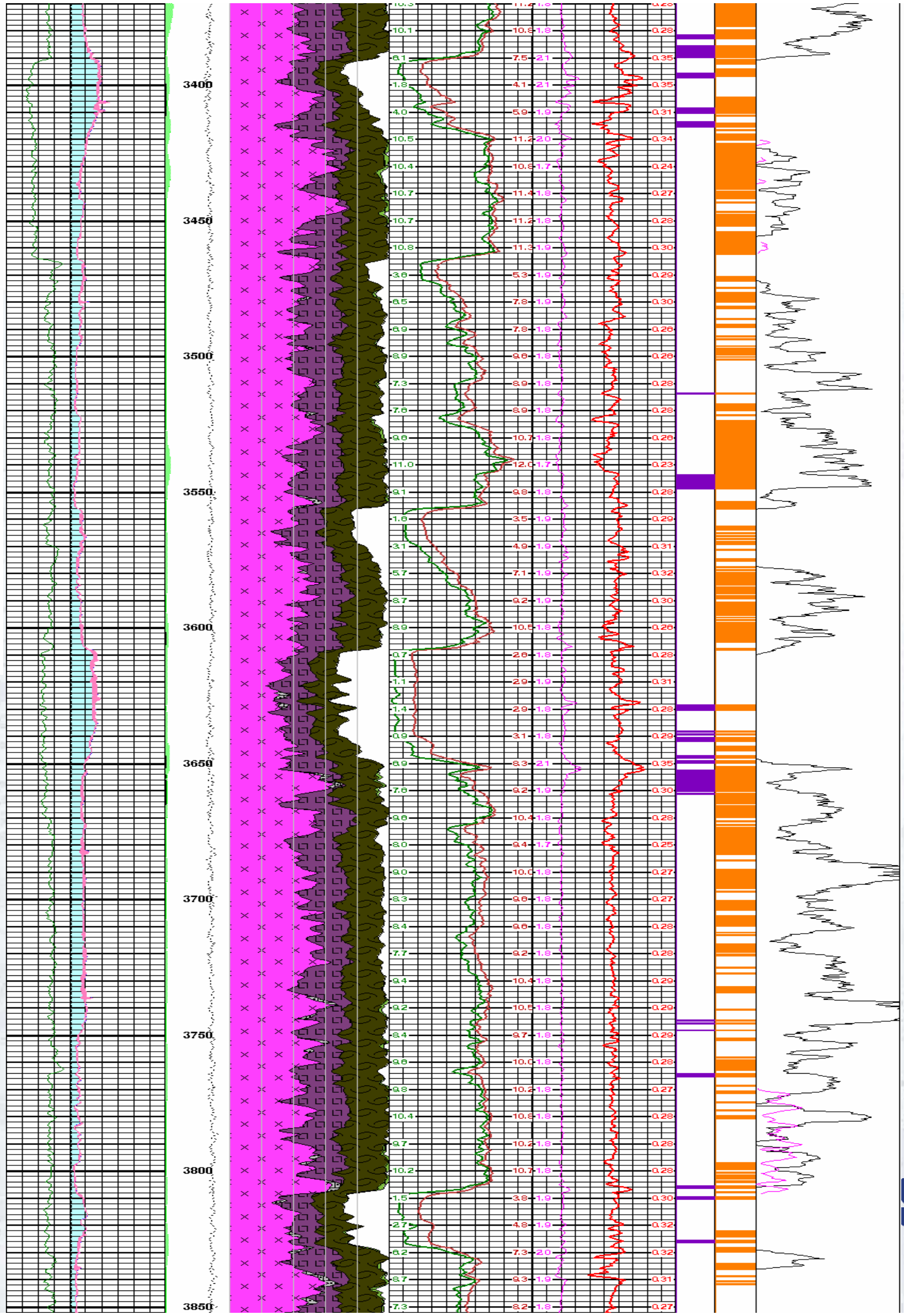
Poisson's Ratio remains relatively constant throughout the logged section.

Young's Modulus is highly affected by the rock lithology and porosity.

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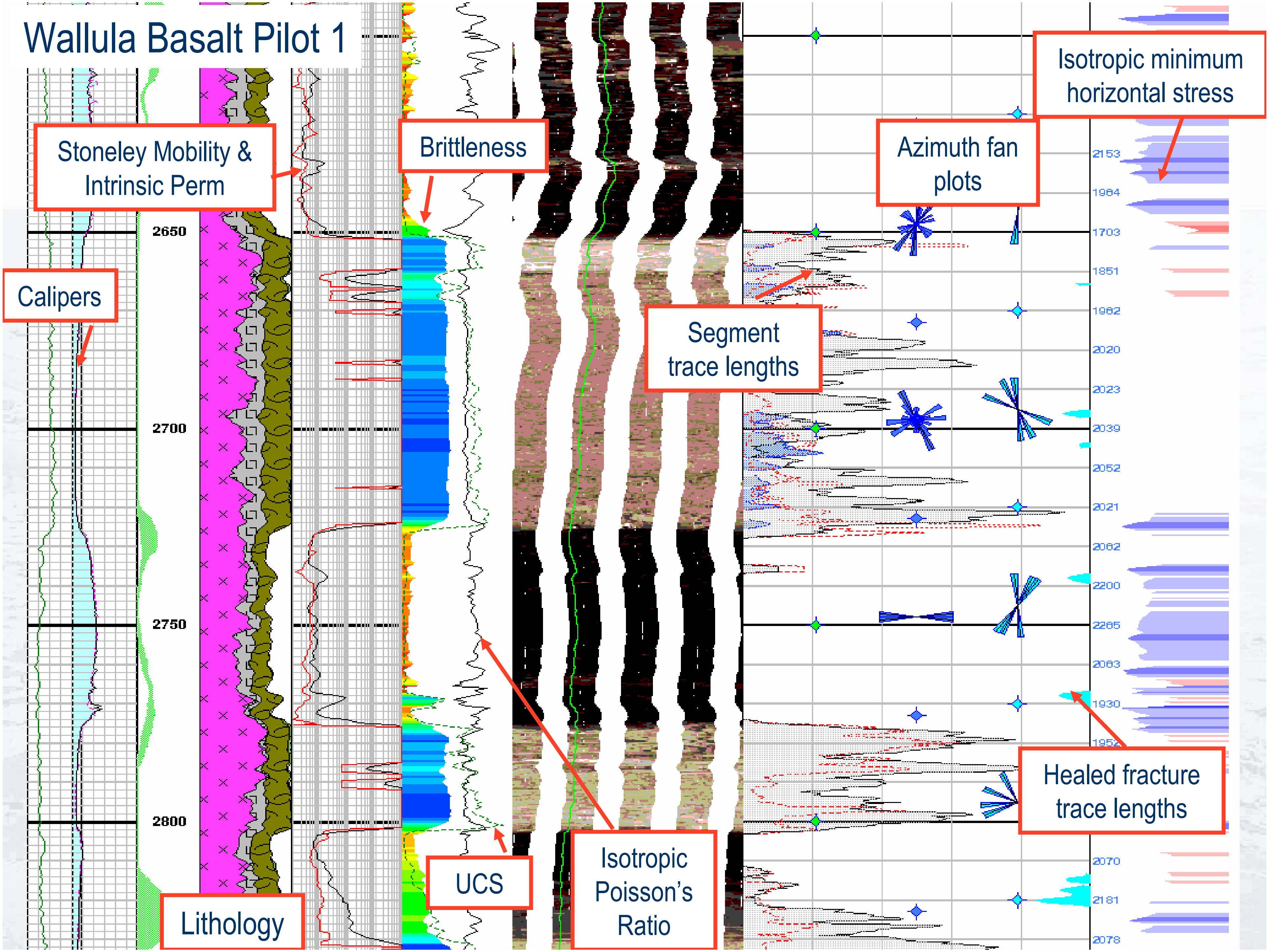
# Wallula Basalt Pilot 1



# Summary

## Azimuthal anisotropy

- Azimuthal anisotropy is present throughout the logged section.
- Two main directions of the fast shear azimuth were observed. One was indicating N45ºW, which agreed with the direction of drilling induced and natural fractures interpreted from the FMI. The other direction indicated E-W and seemed to be in agreement with the predominant direction of the segments interpreted with FMI.
- Intrinsic anisotropy as well as stress-induced anisotropy were defined from the sonic waveform dispersion analysis.

## Rock Properties

- Rock properties are affected by lithology and porosity with the greatest effect on the Young's Modulus rather than the Poisson's Ratio.
- There are some stress variations throughout the well which may be possible barriers.

## Stoneley Mobility Analysis

- It was observed a very good matched between the Stoneley derived mobility and the intrinsic permeability derived from the petrophysical analysis.
- In some sections with abundant segments, Stoneley mobility was also present.

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