A satellite image of Earth showing the Western Hemisphere, with North America and the Gulf of Mexico visible. The image is set against a brown background with a grid of latitude and longitude lines.

# Sensitivity of Seismic Response to Variations in the Woodford Shale

Na Shan

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# Outline

- Overview
- Well log Observation
- Seismic Modeling and Sensitivity Study
  - VTI Model and Sensitivity Study
  - HTI Model and Sensitivity Study
  - Orthorhombic Model
  - Vp/Vs, Anisotropy and Gas Saturations
- Conclusion

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
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# Distribution of Devonian Black Shale



 Outcrop belt  
 Mostly subsurface

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from John Comer, Juergen Schieber,

# Areas having greatest gas production potential and most prospective lithologies

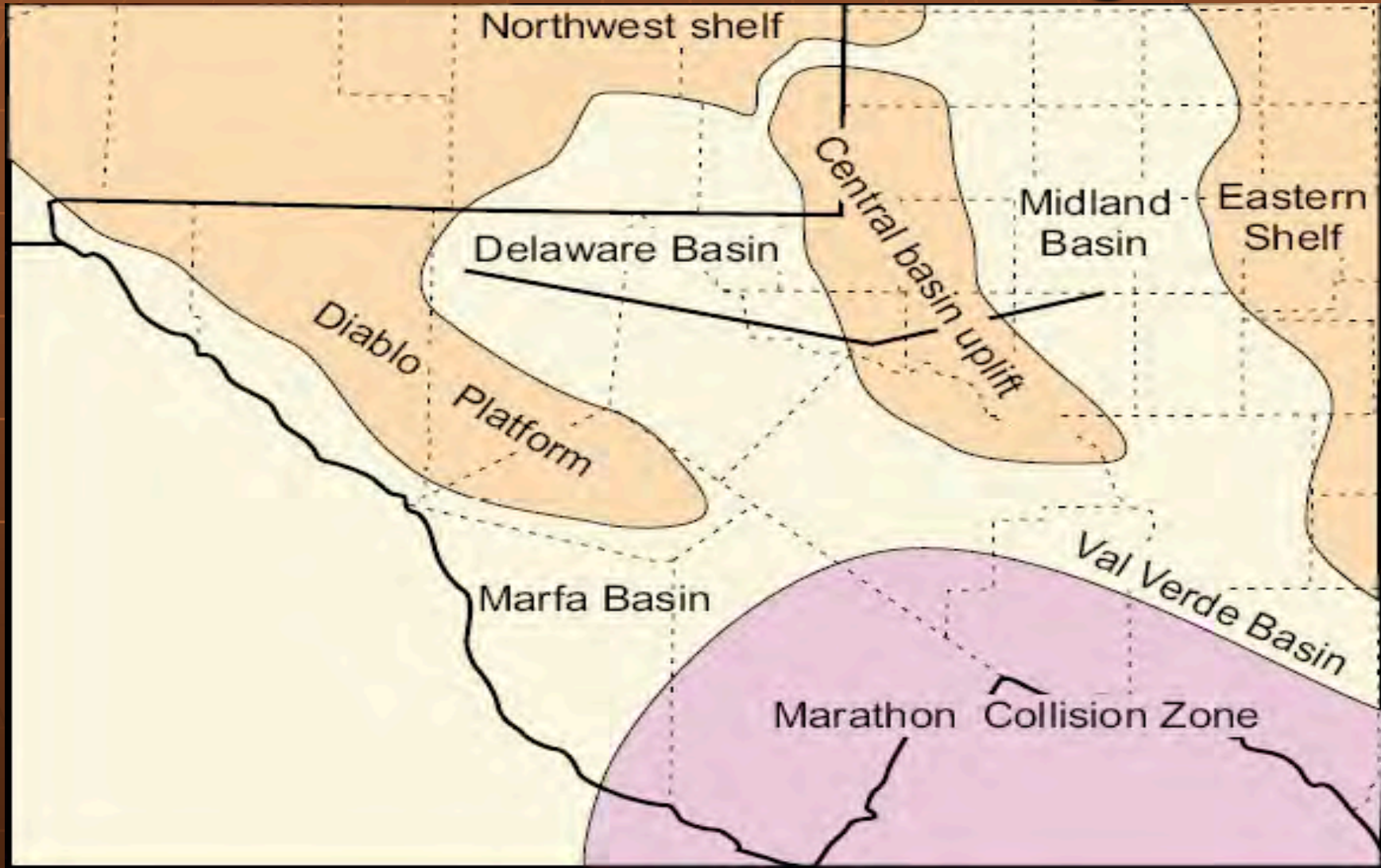
- Anadarko Basin in Oklahoma (siltstone and silty black shale)
- Arkoma Basin in Oklahoma and Arkansas (silty black shale)
- Frontal zone of Ouachita fold belt in Oklahoma (chert)
- Delaware Basin in Texas and New Mexico (siltstone and silty black shale)
- Val Verde and Midland Basins in Texas (siltstone and silty black shale)

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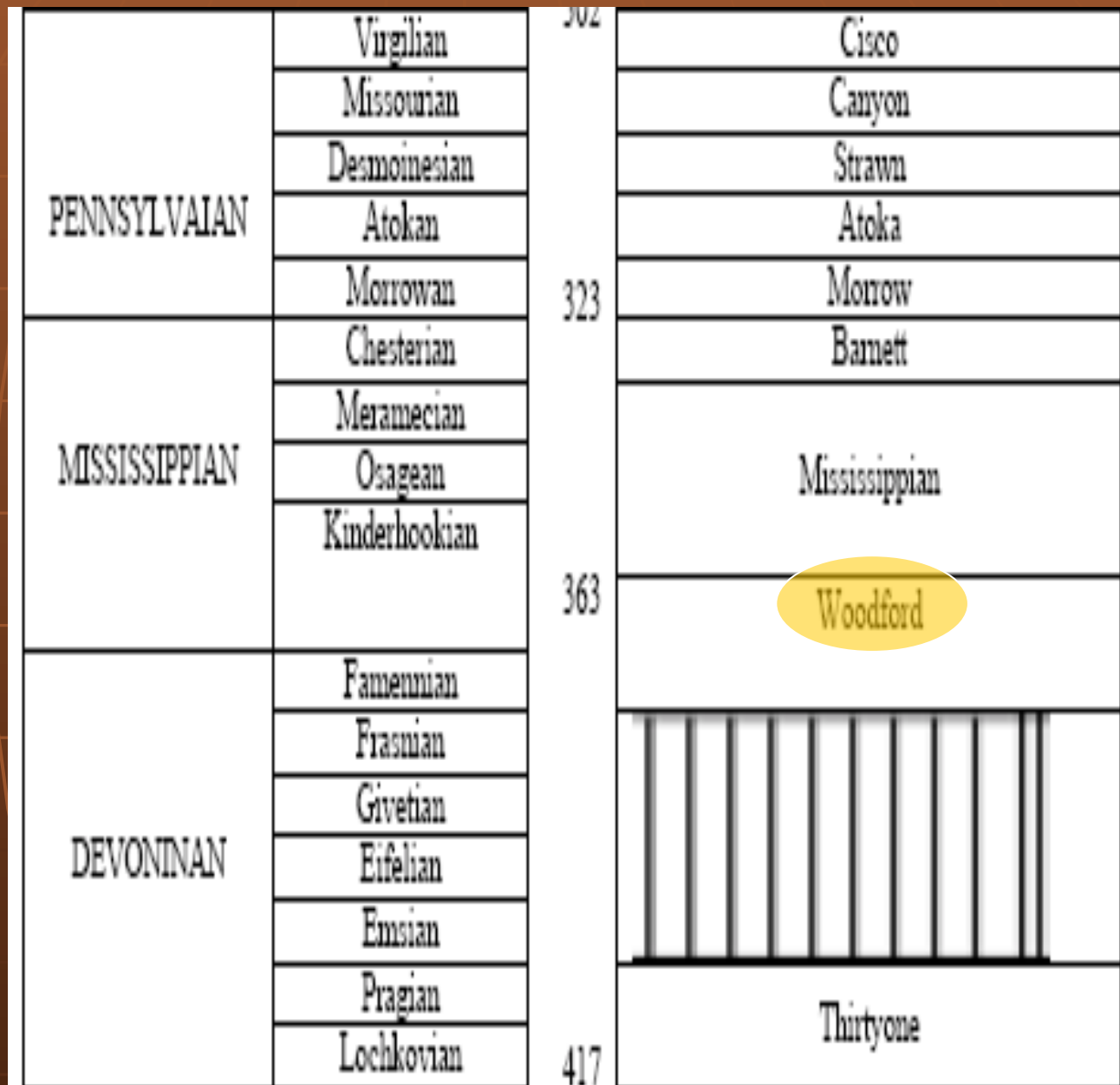
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# West Texas Setting



Modified by Walaa Ali, M from King, 1942. Steve Ruppel.

# Delaware Basin Stratigraphy



# Woodford Formation

- High organic matter (high GR), brownish-black fissile shale
- Thickness varies from 96- 460ft (30 m to 200 m), in the Delaware Basin
- In West Texas and southeastern New Mexico, it contains about  $80 \times 10^9$  bbl of oil ( $240 \times 10^{12}$  ft<sup>3</sup> of natural gas equivalent)
- Production usually contains viable lithofacies like chert, sandstone, dolostone and siltstone where are highly fractured.

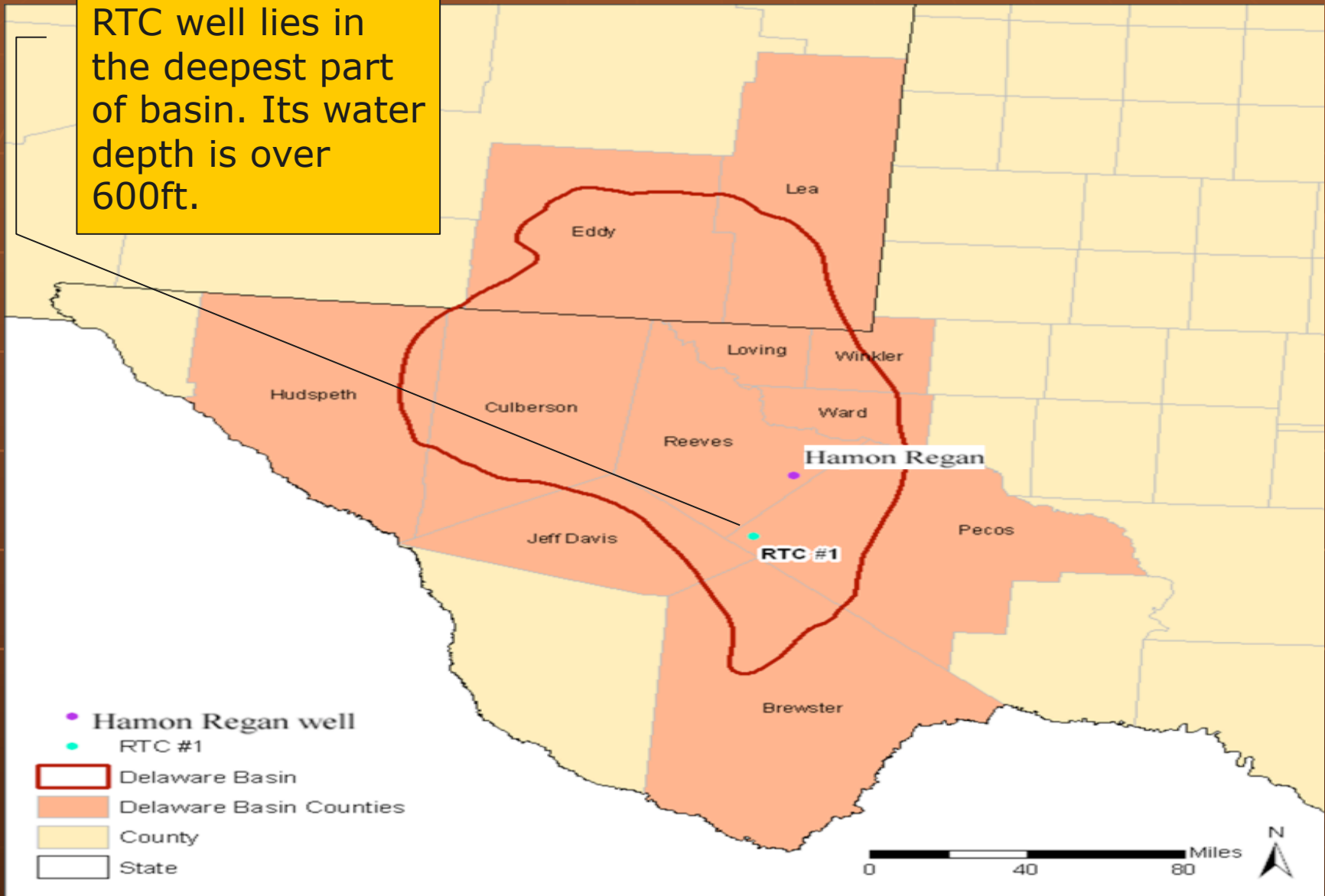
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RTC well lies in the deepest part of basin. Its water depth is over 600ft.



Modified by Walaa Ali

# Outline

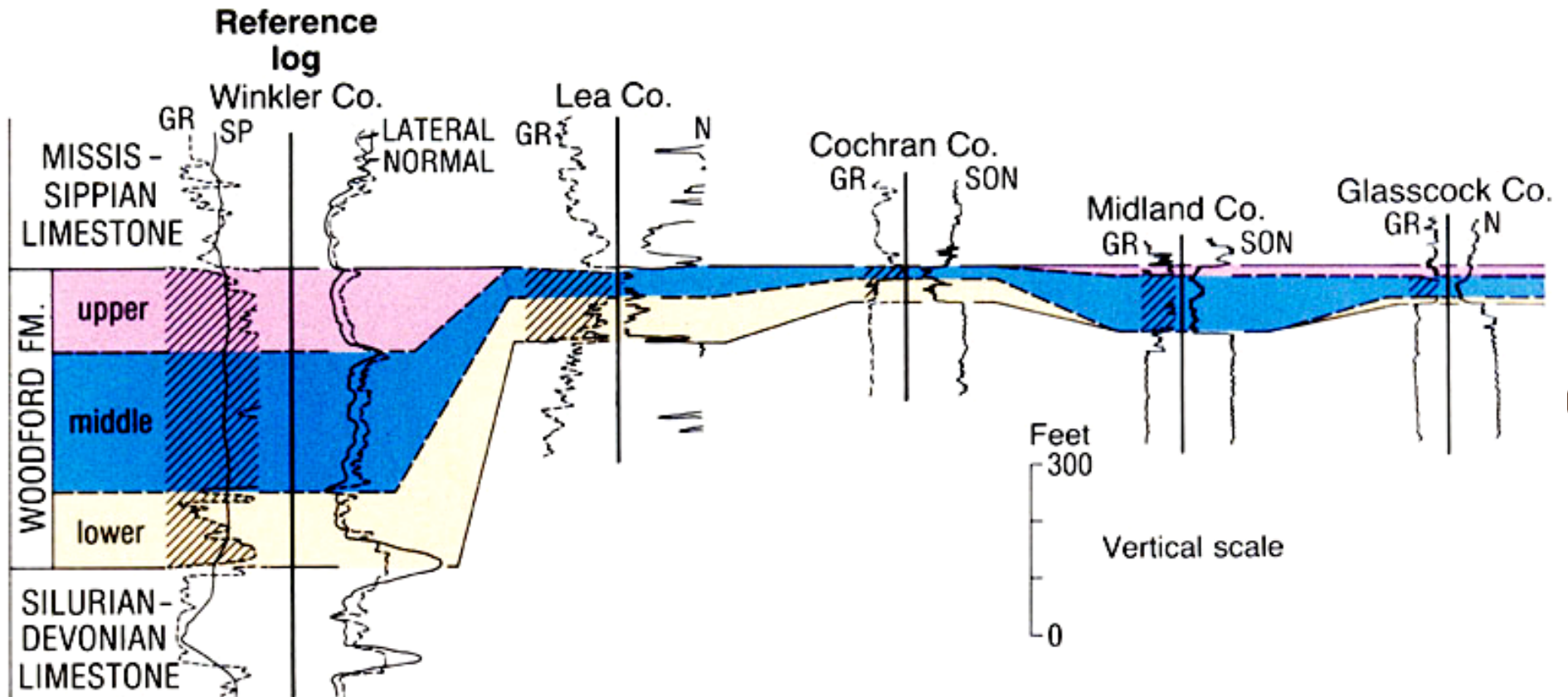
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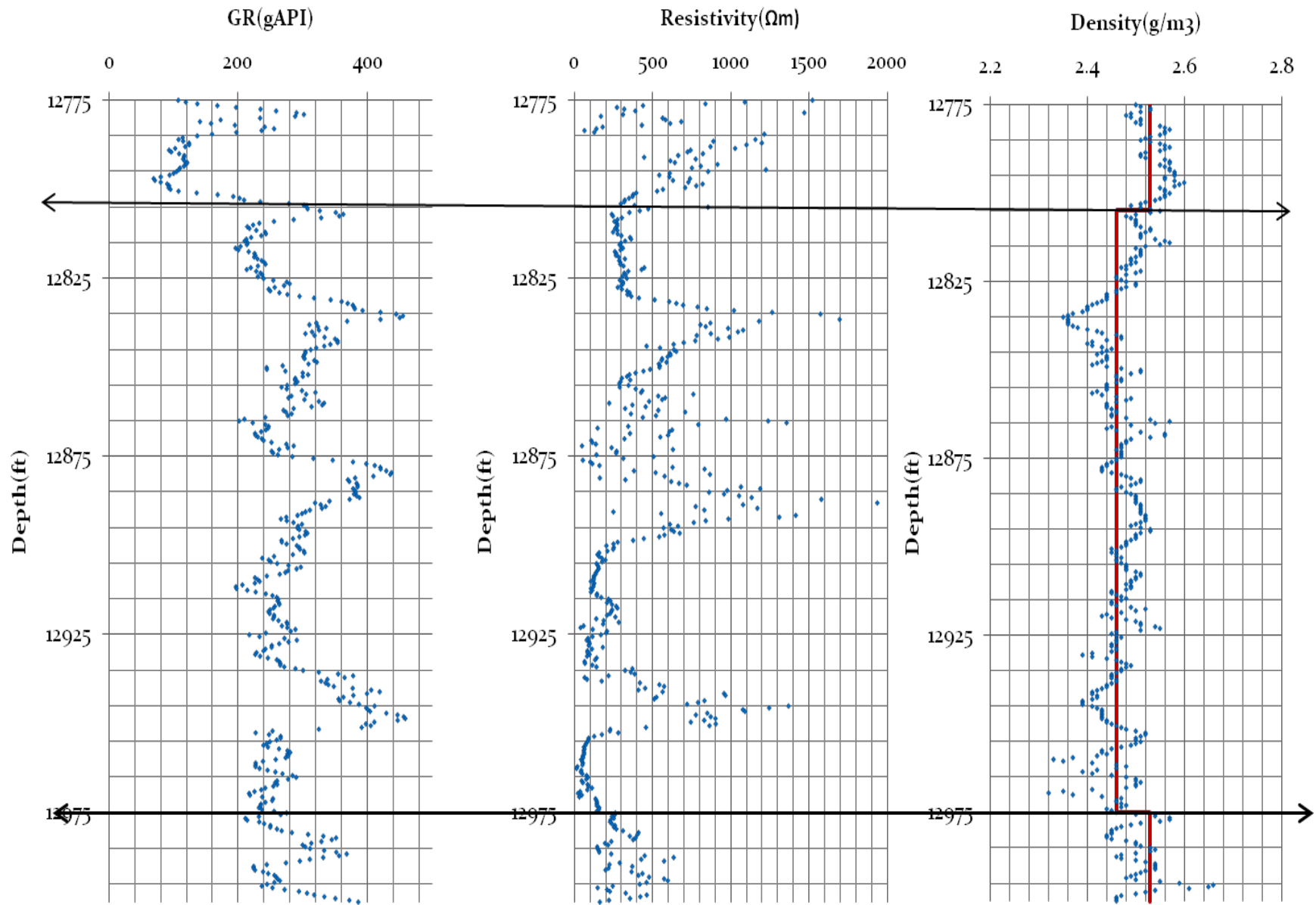
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# Log Characteristics Texas and New Mexico



Reference log from Ellison (1950)

Comer (1991) Fig. 7

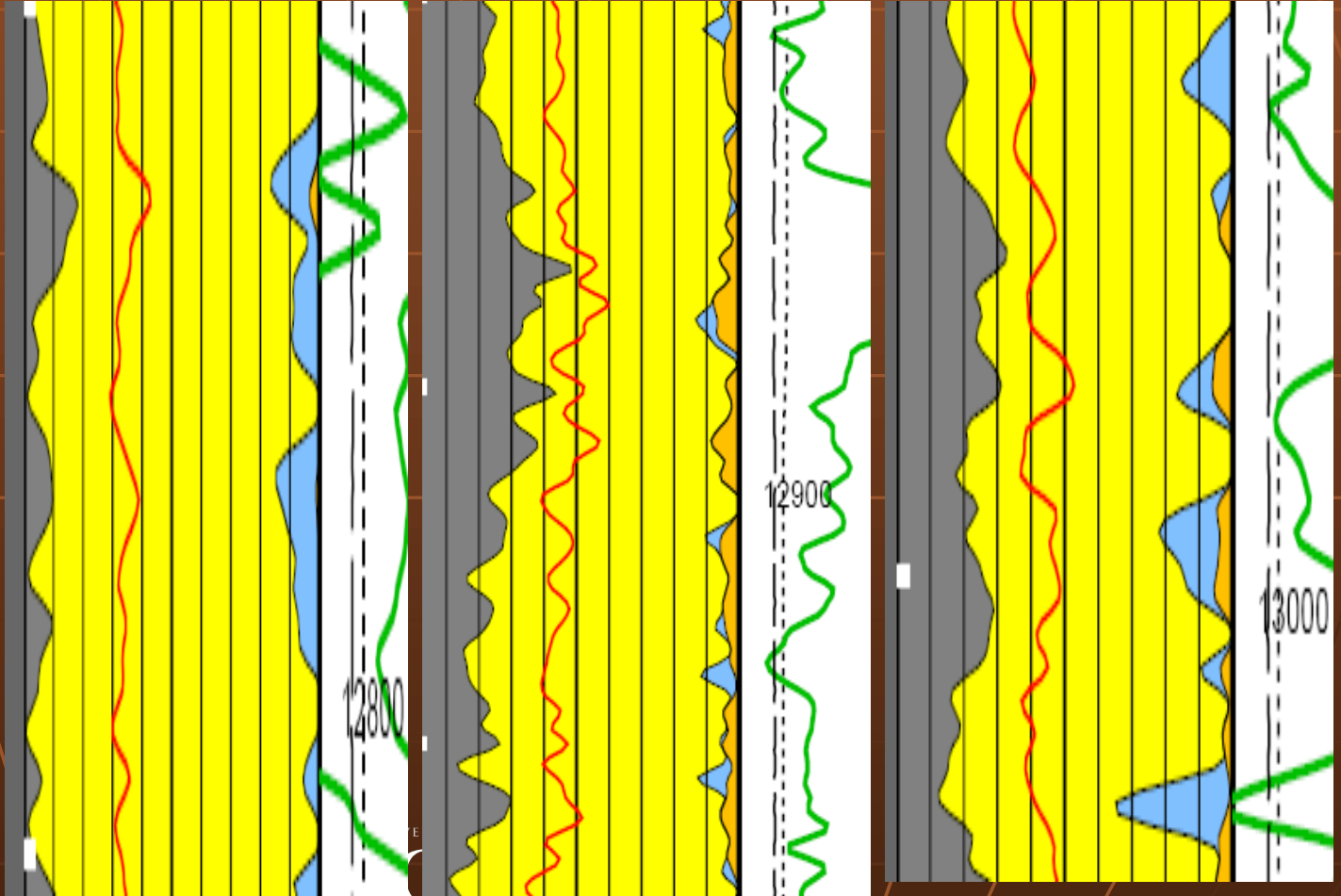




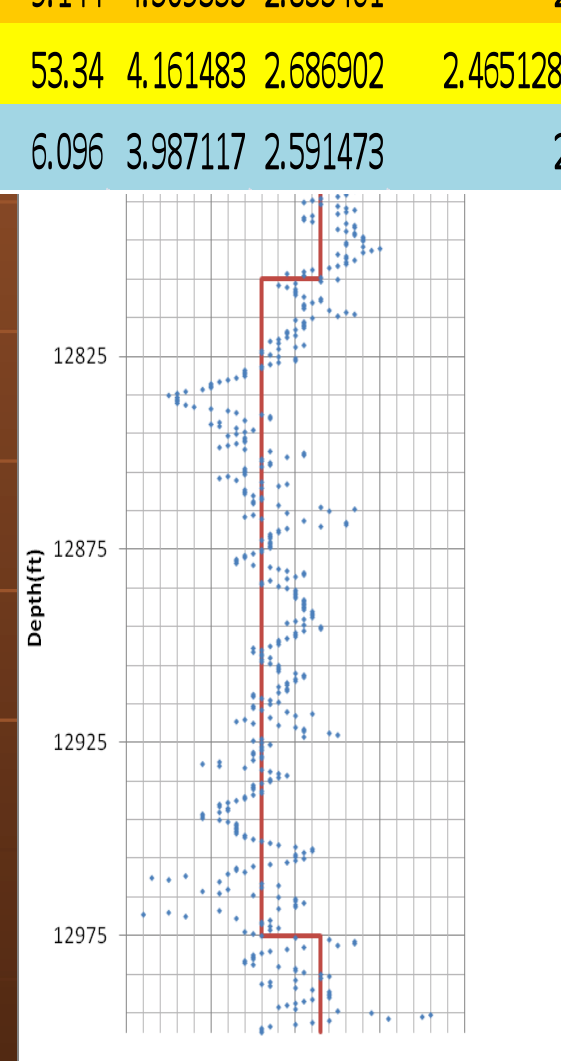
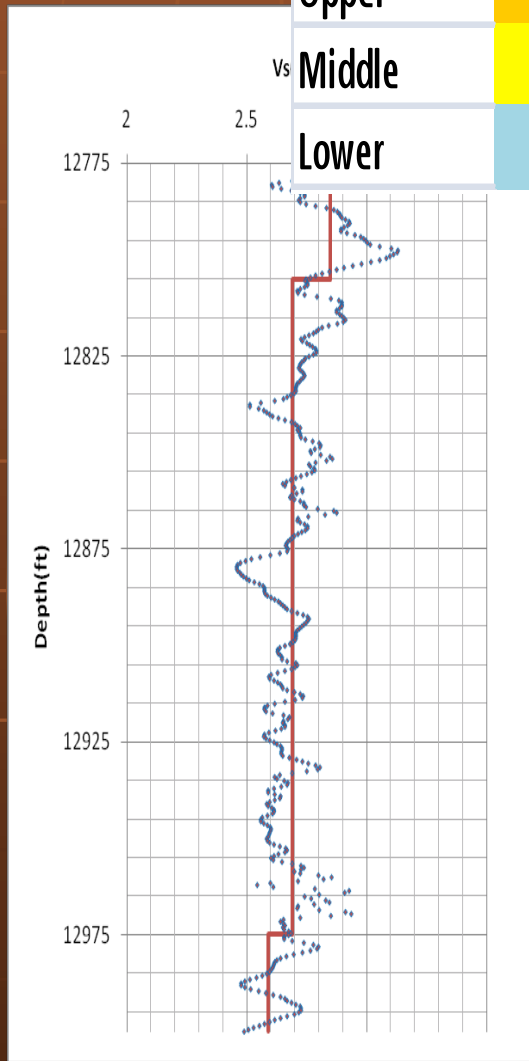
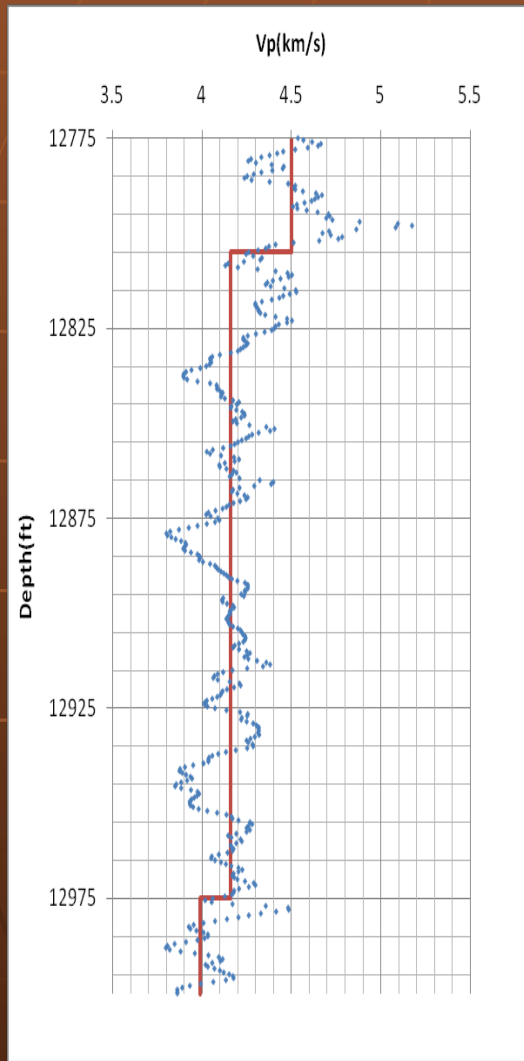
**UPPER**

**MIDDLE**

**LOWER**



Woodford	Thickness(m)	Vp(km/s)	Vs(km/s)	Density(g/cm3)
Upper	9.144	4.509353	2.855461	2.53
Middle	53.34	4.161483	2.686902	2.465128412
Lower	6.096	3.987117	2.591473	2.53



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# Introduction to Seis

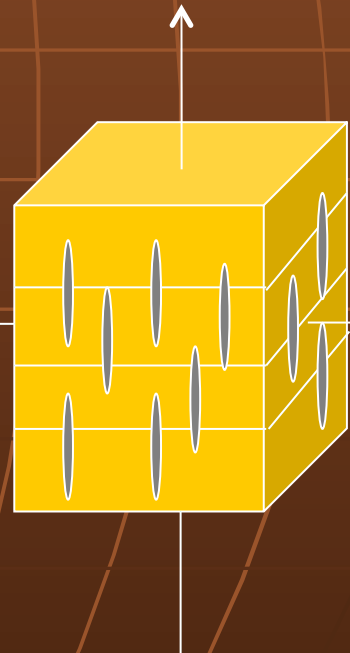
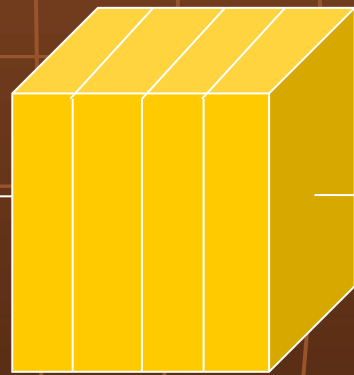
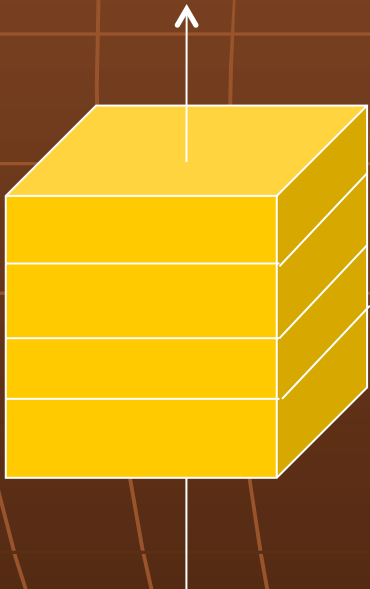
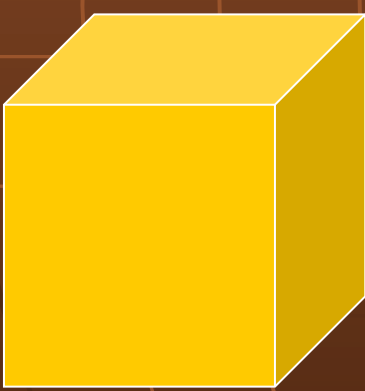
**Vertical Impulsive Source**  
Generate PP, PS and SS wave  
Z Component (Vertical), X  
Component (Radial)

**Isotropic**

**VTI**

**HTI**

**Orthorhombic**





# Outline

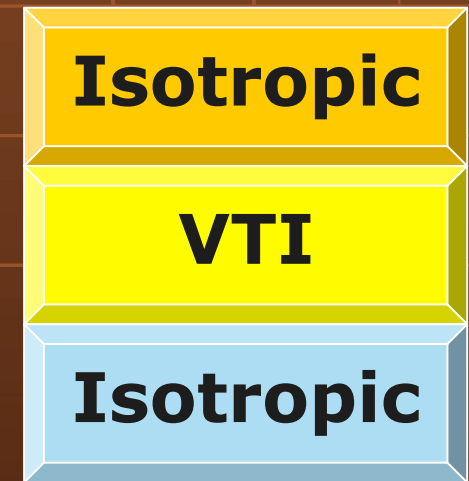
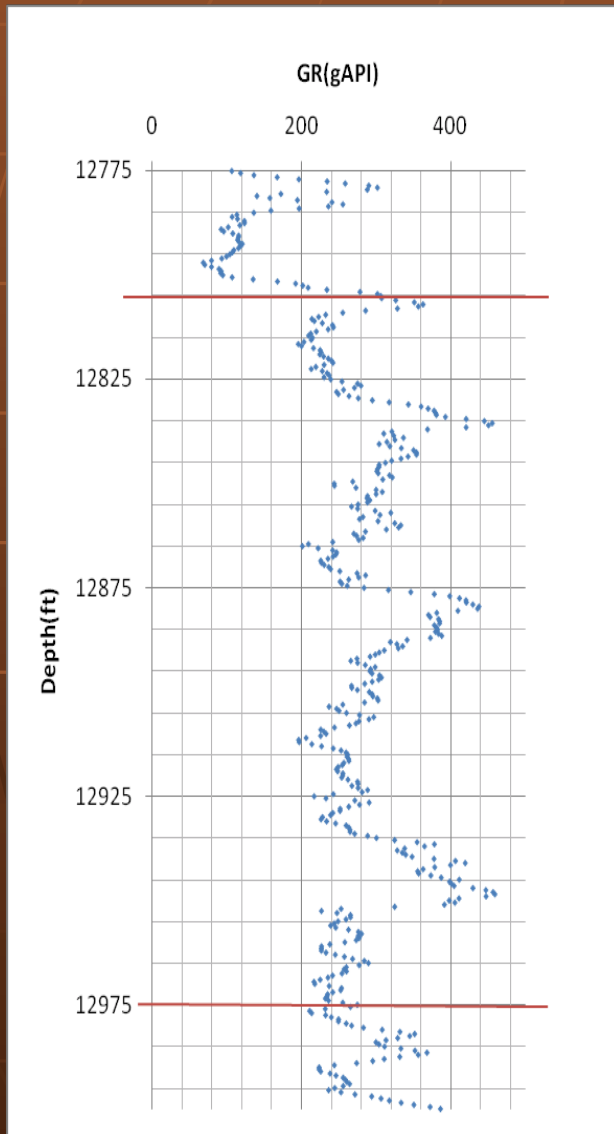
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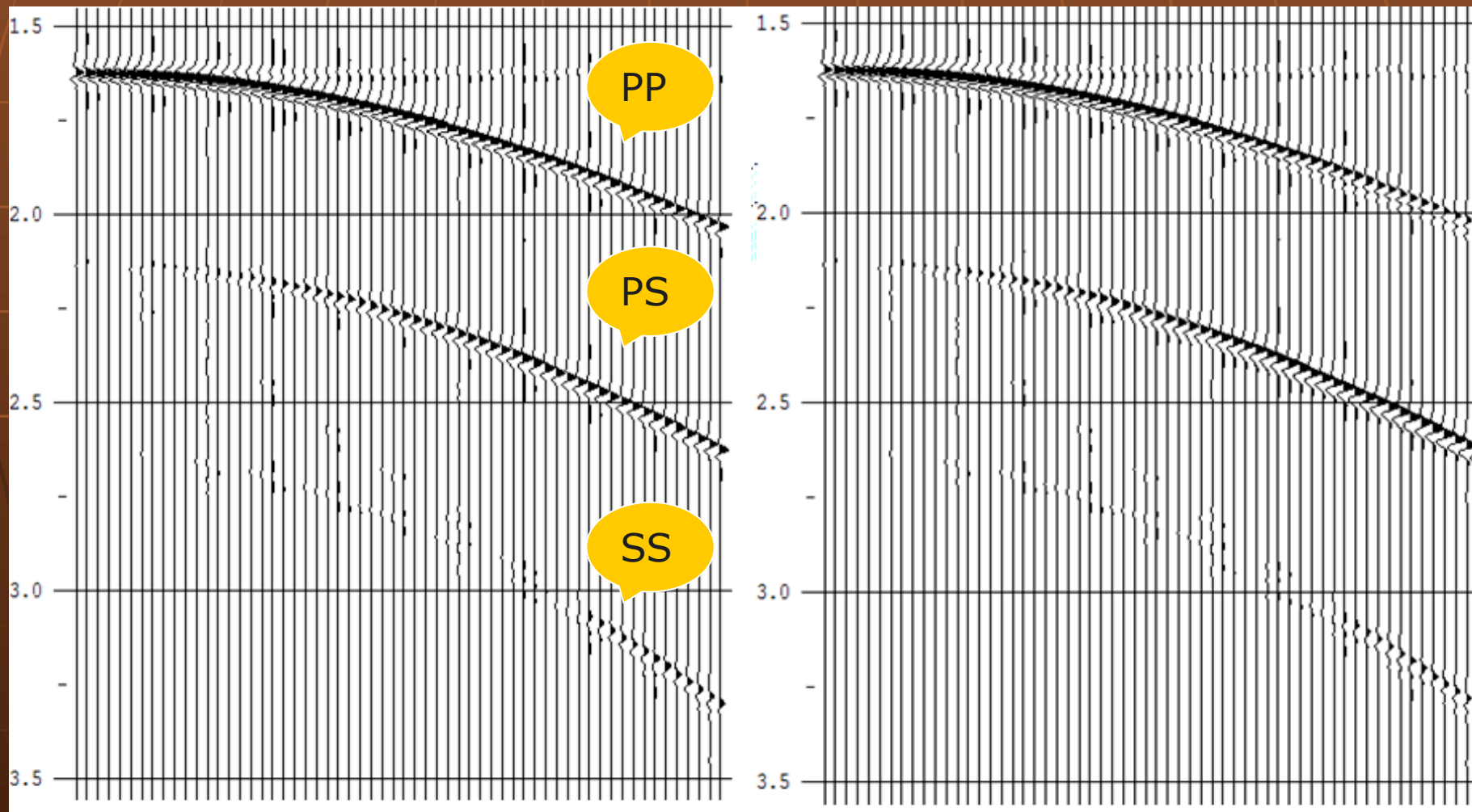
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# VTI-Middle Layer

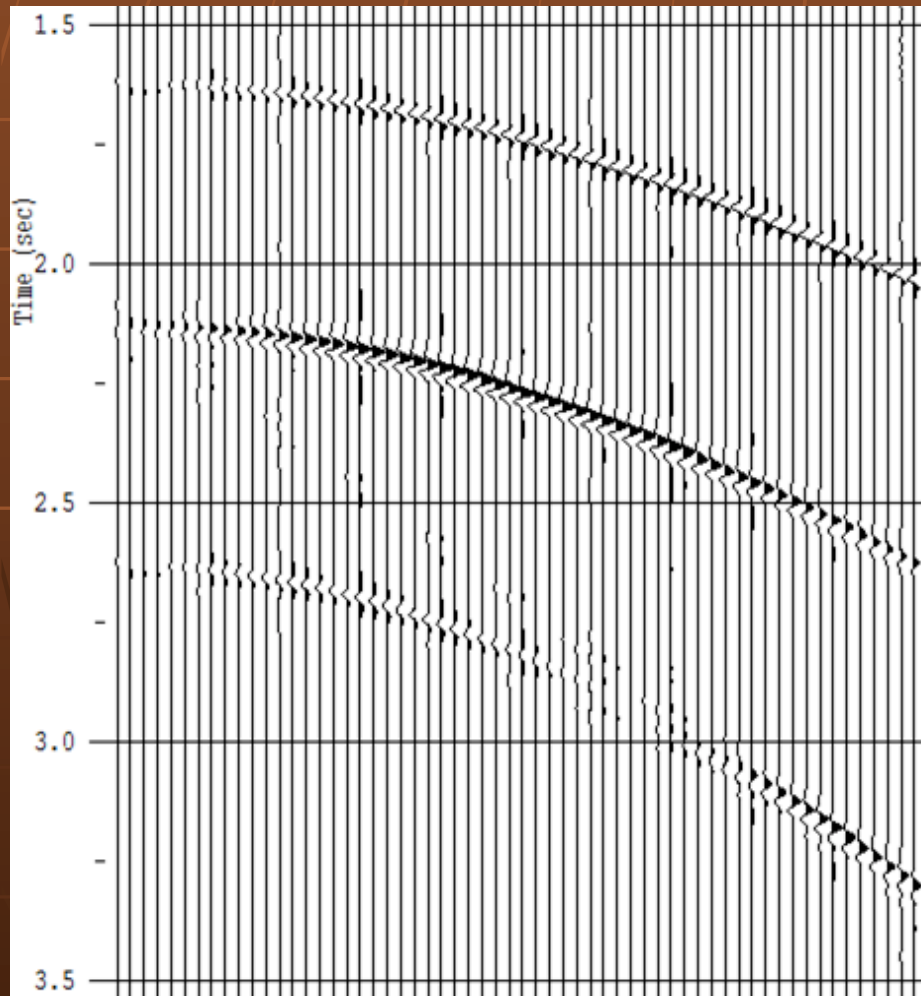


**Isotropic  
Z Component**

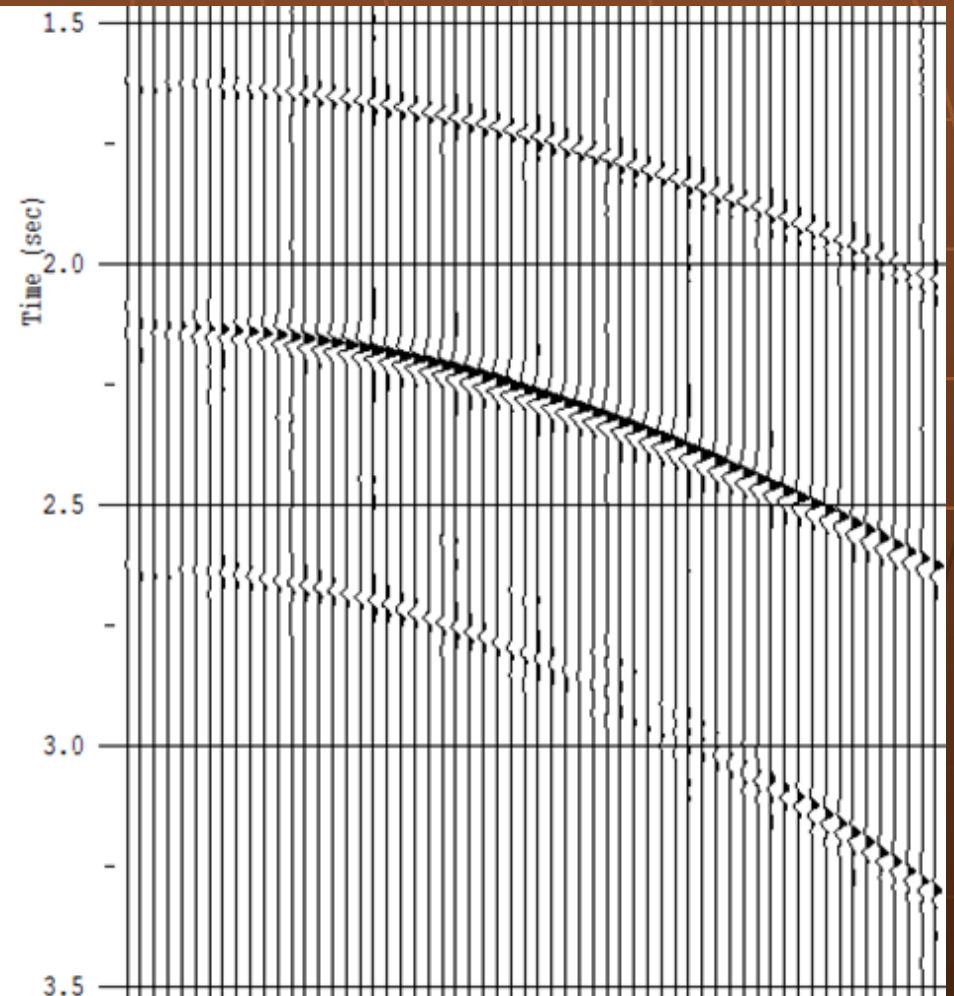
**VTI  
Z Component**



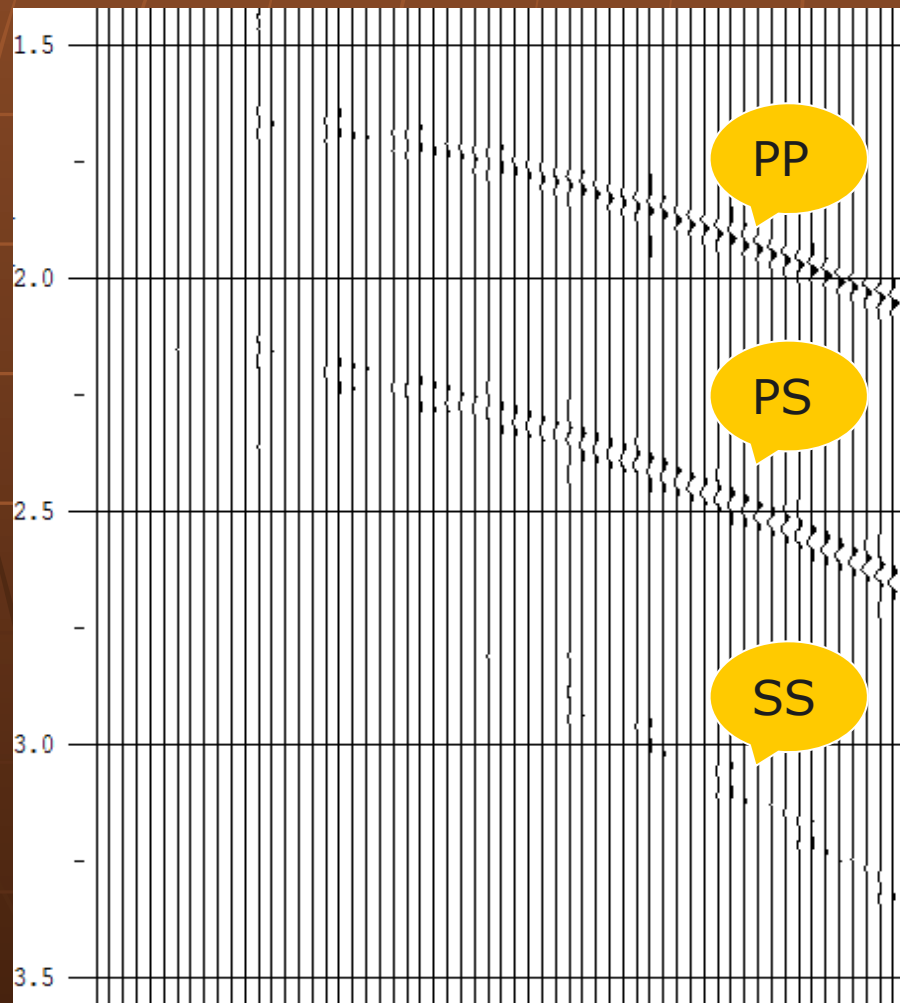
**Isotropic  
X Component**



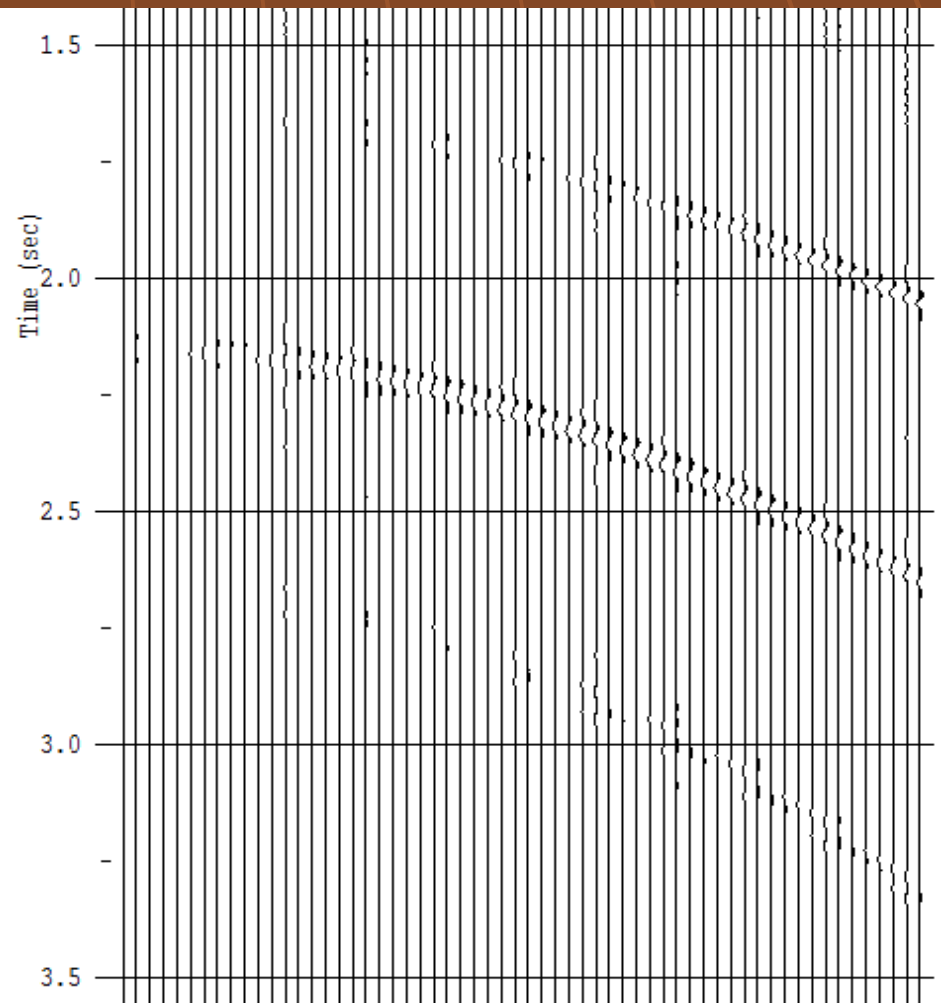
**VTI  
X Component**



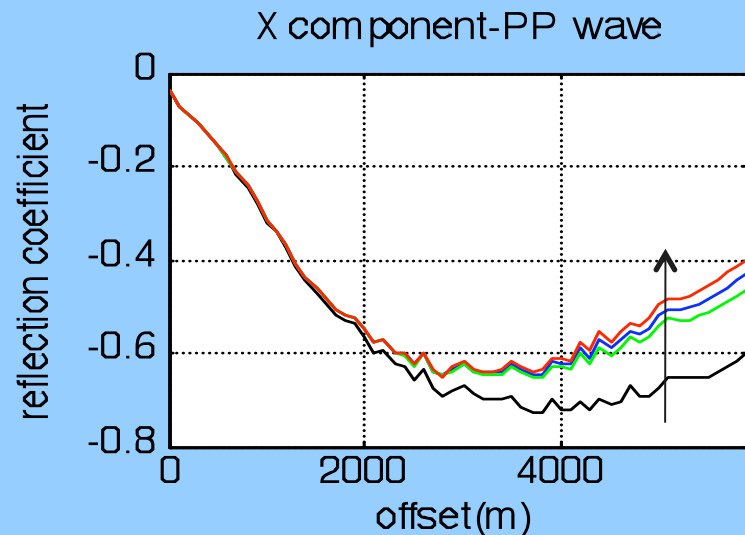
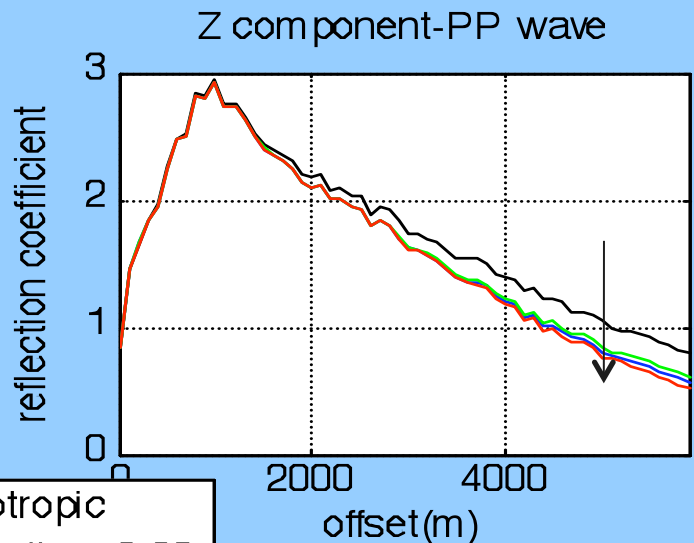
**VTI-Isotropic  
Z Component**



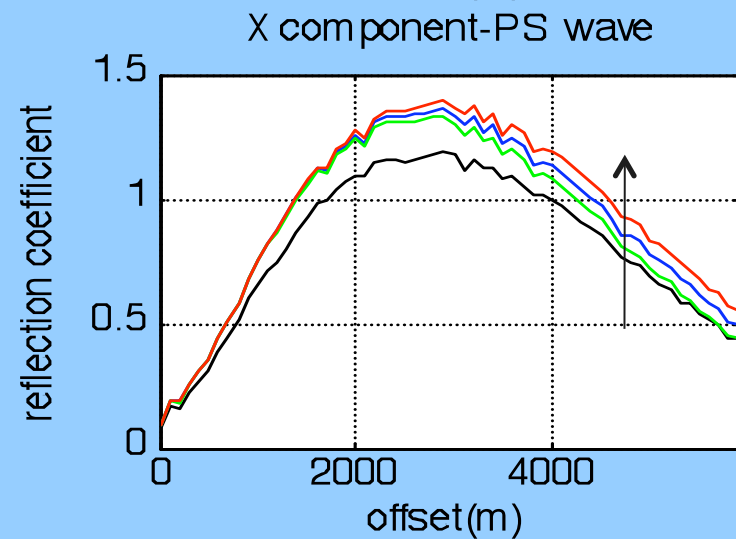
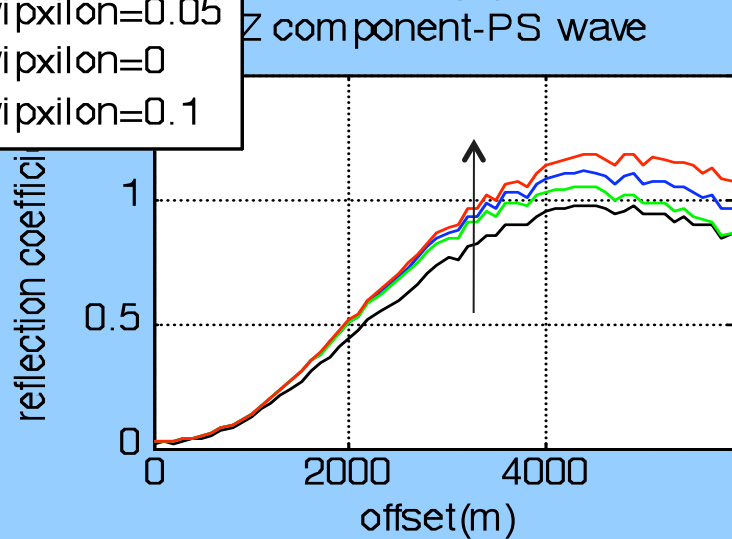
**VTI-Isotropic  
X Component**



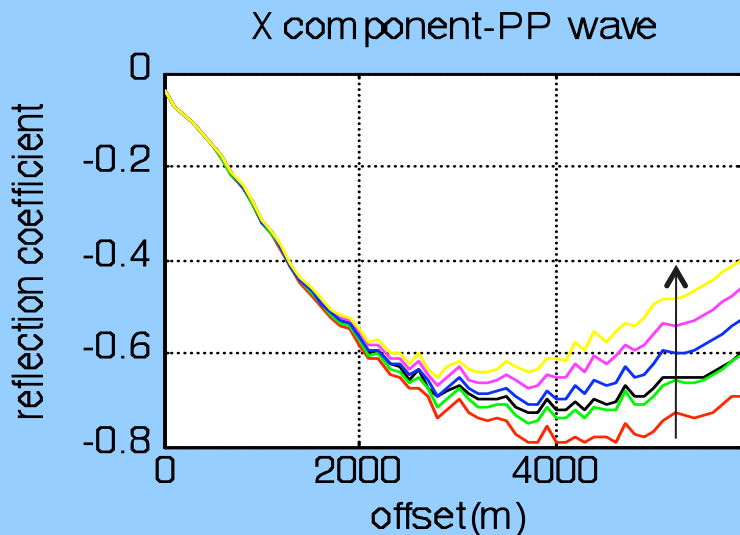
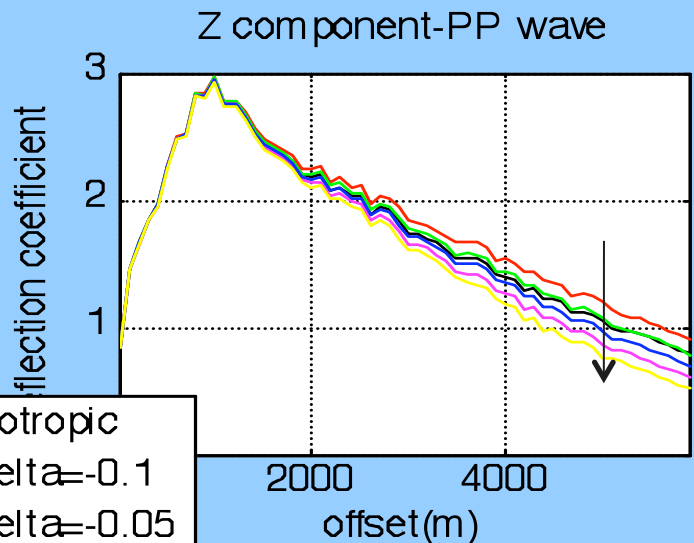
**VTI  $\gamma=0.1, \delta=0.1$**



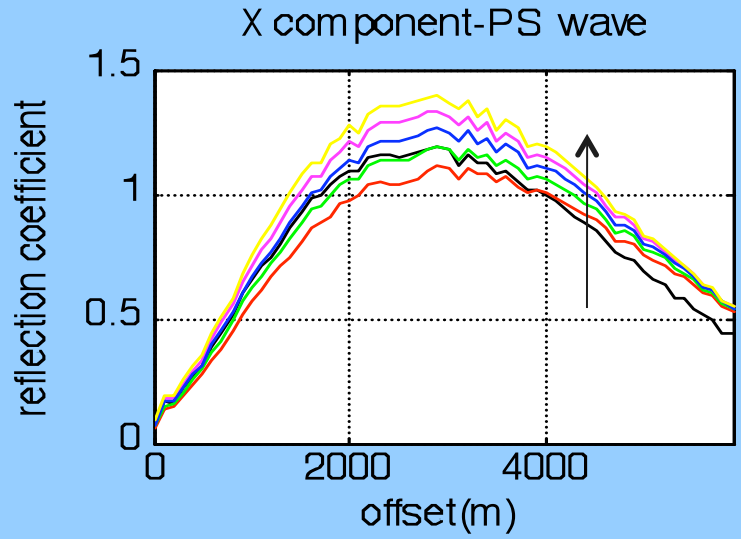
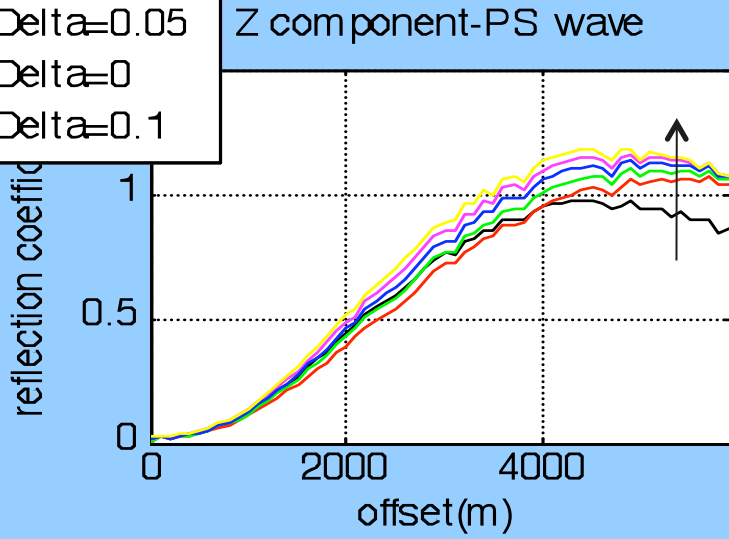
- isotropic
- $\gamma=0.05$
- $\gamma=0$
- $\gamma=0.1$



**VTI  $\gamma=0.1, \epsilon=0.1$**



- isotropic
- Delta=-0.1
- Delta=-0.05
- Delta=0.05
- Delta=0
- Delta=0.1



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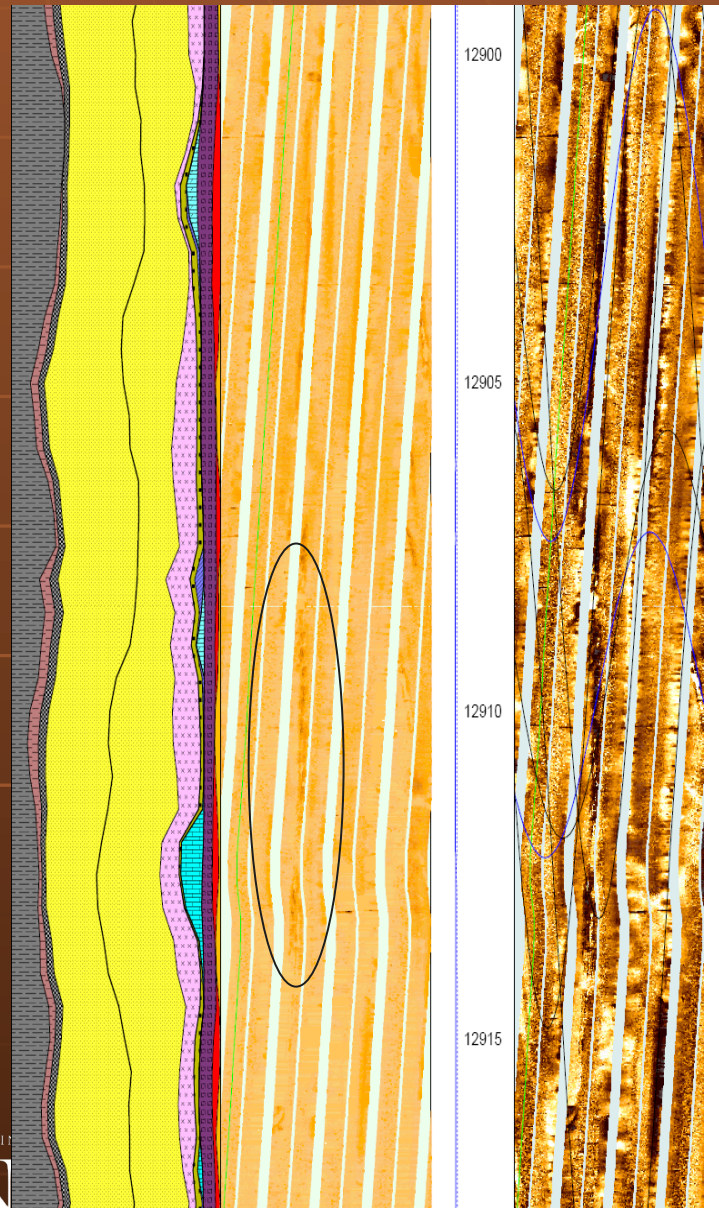
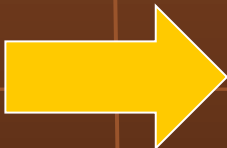
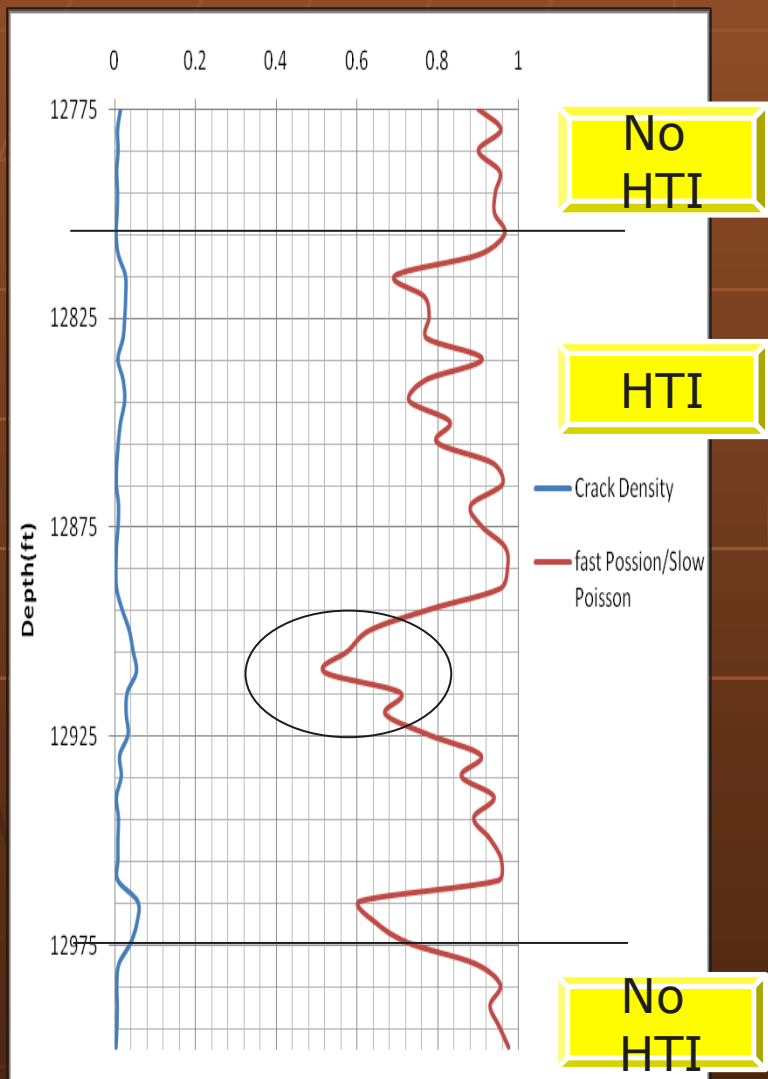
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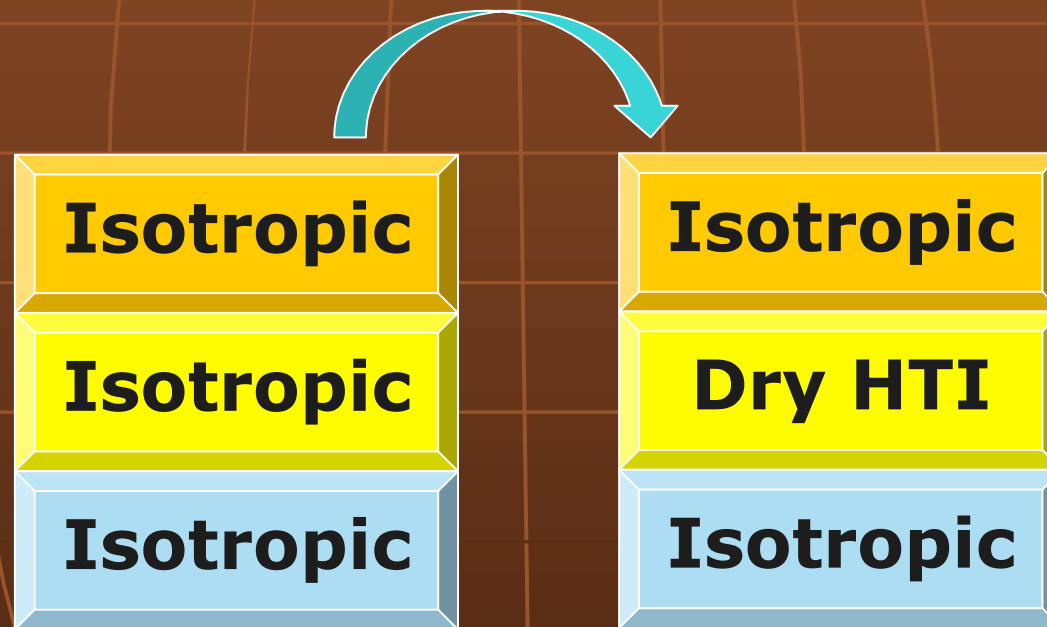


# HTI Model



# HTI Model

Assumptions  
Bakulin(Hudson Model)  
Isolated Penny Shaped Cracks  
Dry Cracks Only  
Crack Density: 0.08 ( $<0.1$ )



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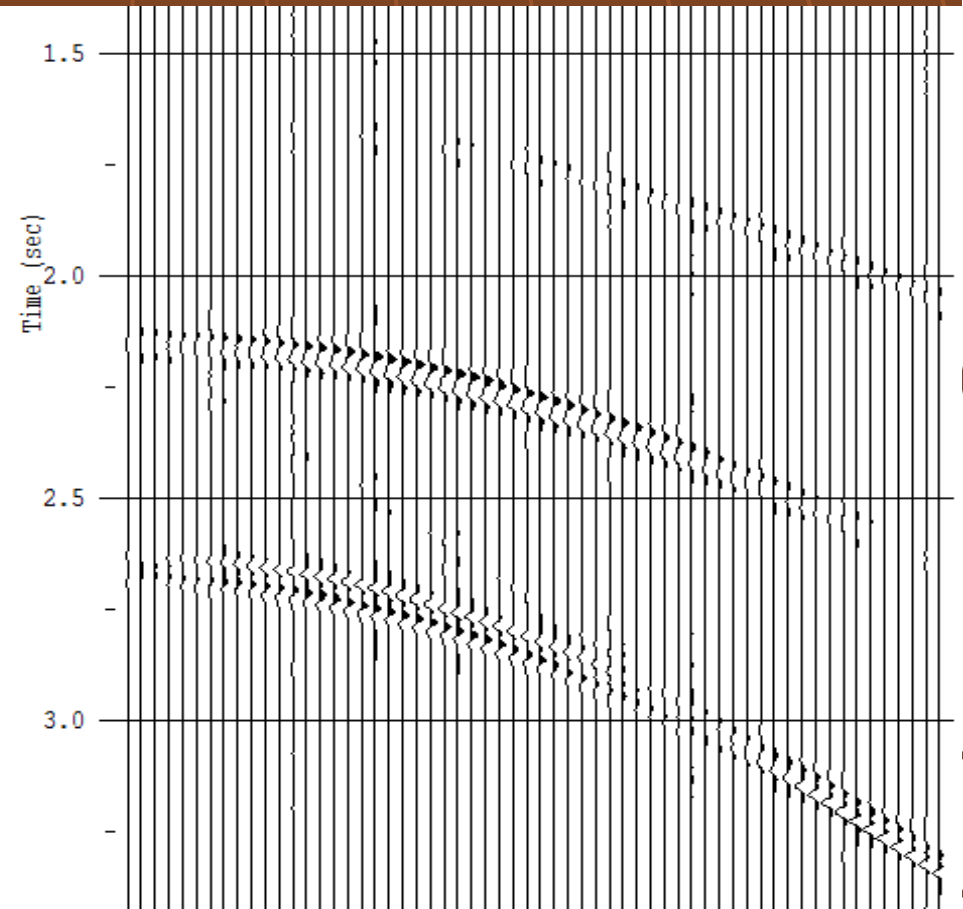
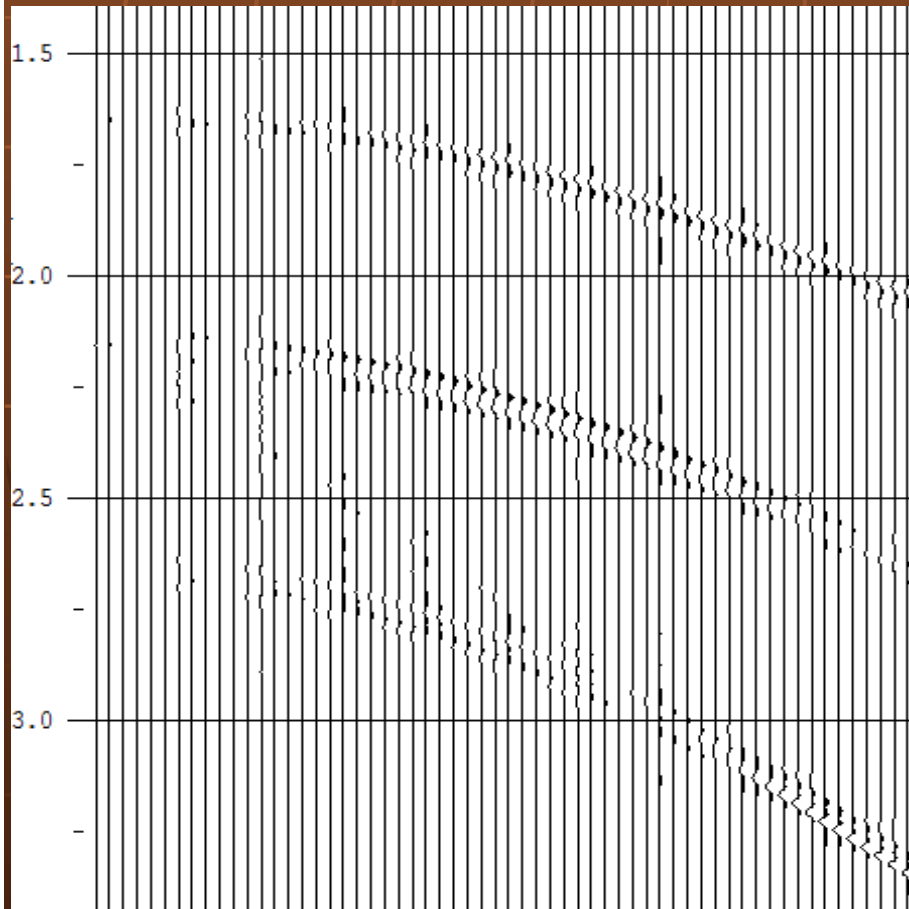
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# Difference

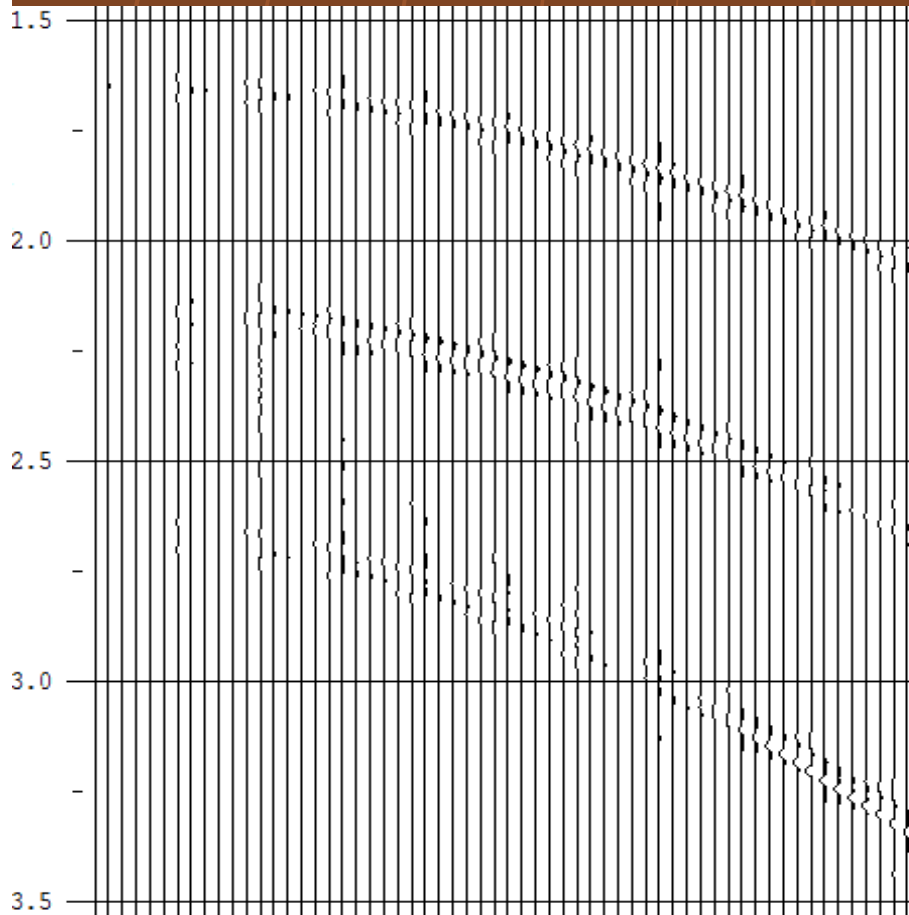
HTI-Isotropic  $\theta=0$   
**Z Component**

HTI-Isotropic  $\theta=0$   
**X Component**

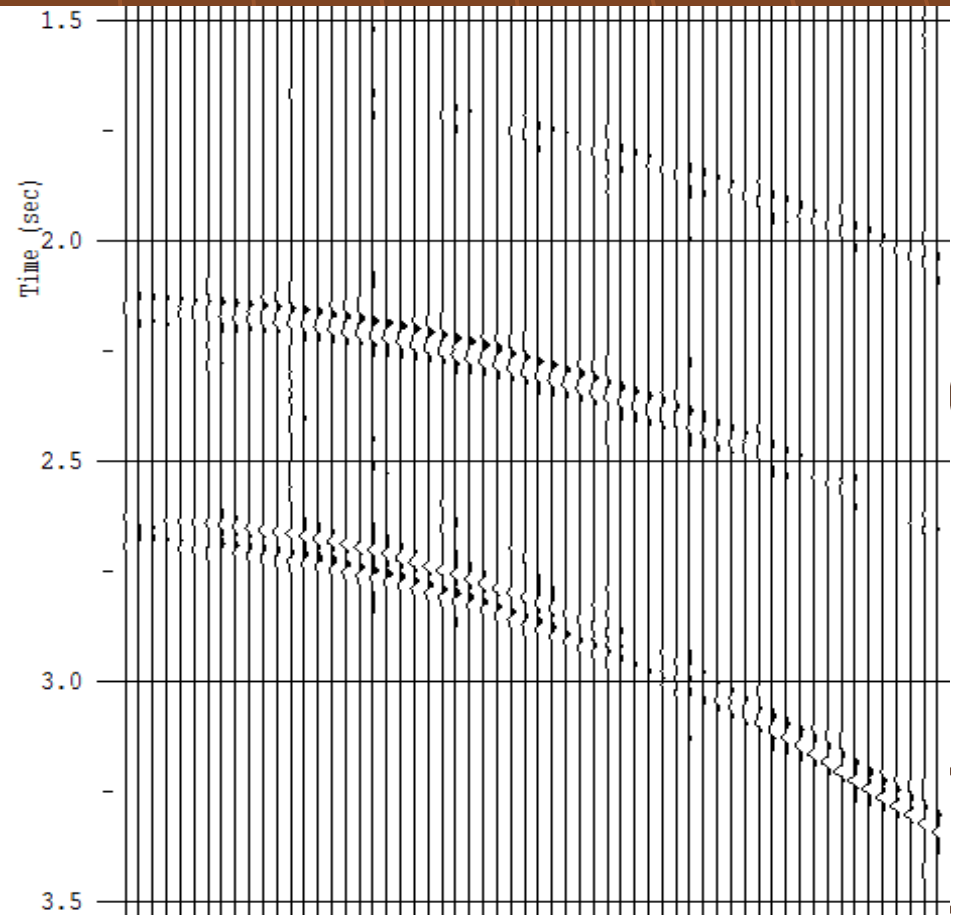


# Difference

HTI-Isotropic  $\theta=30$   
**Z Component**



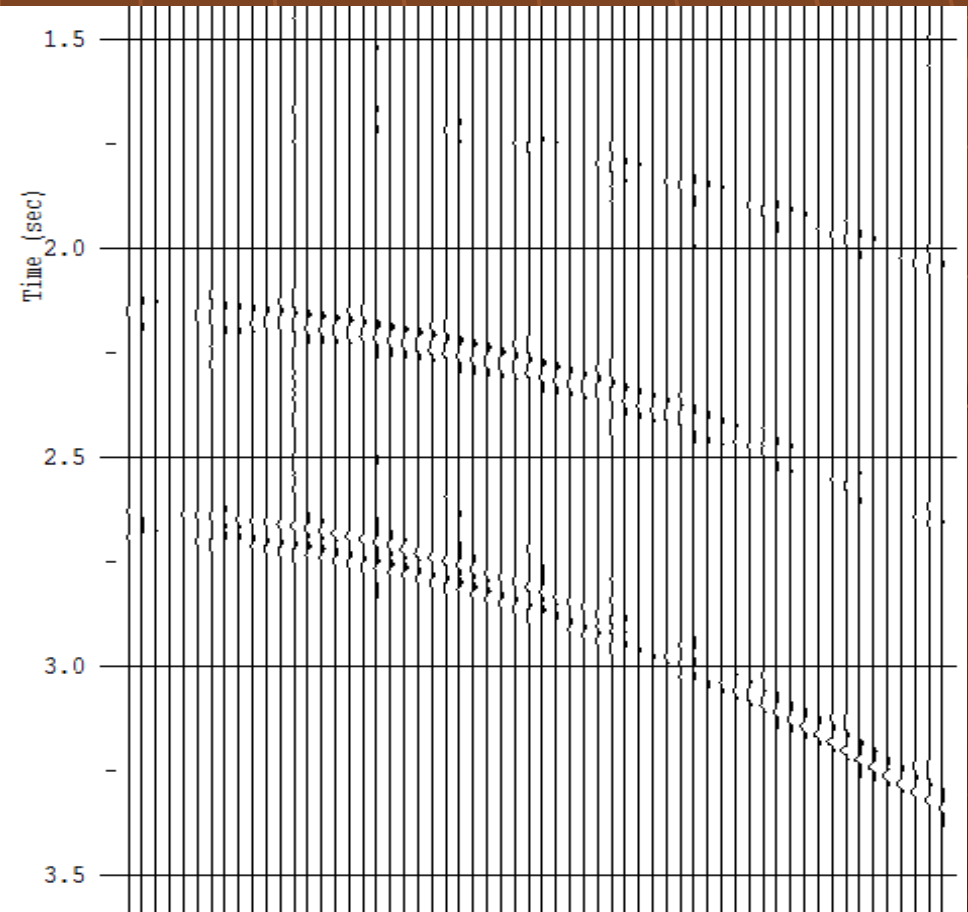
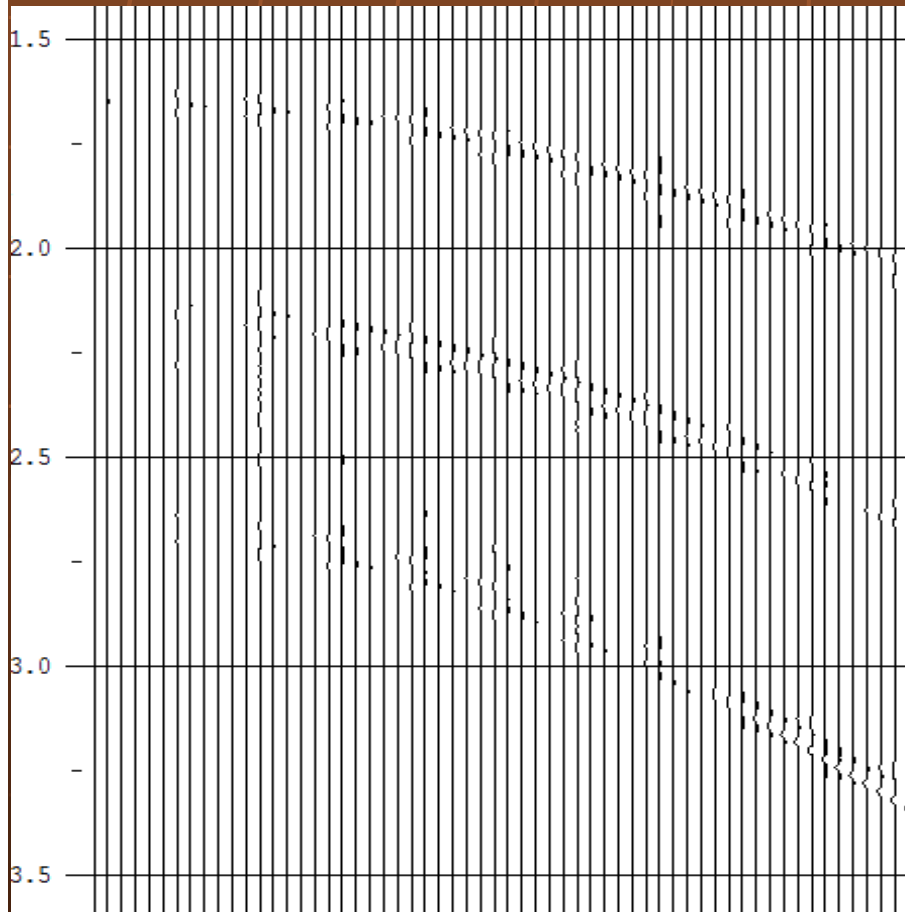
HTI-Isotropic  $\theta=30$   
**X Component**



# Difference

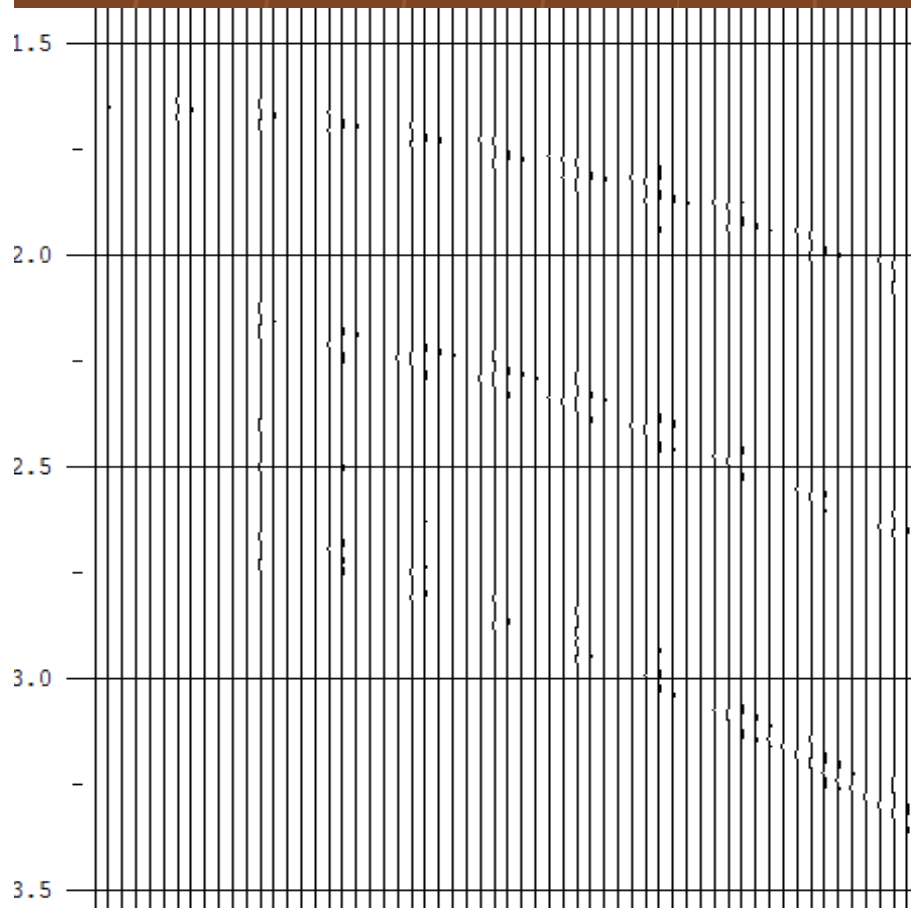
HTI-Isotropic  $\theta=45$   
**Z Component**

HTI-Isotropic  $\theta=45$   
**Z Component**

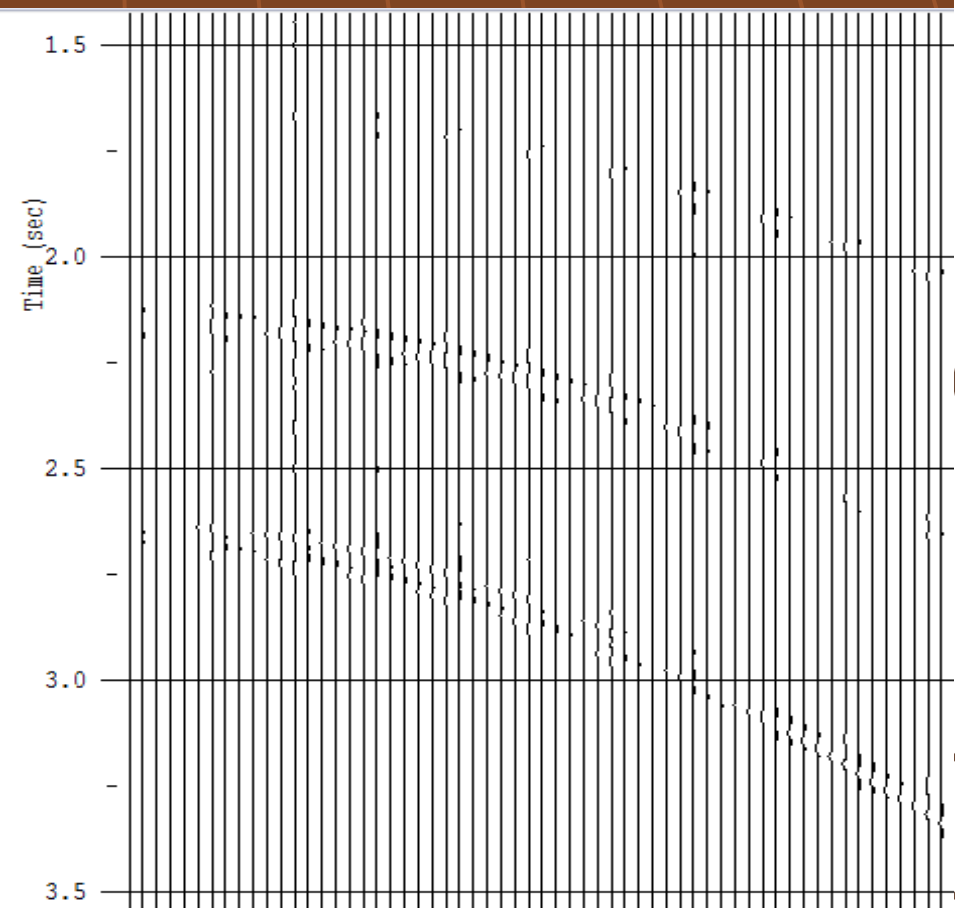


# Difference

HTI-Isotropic  $\theta=60$   
**Z Component**

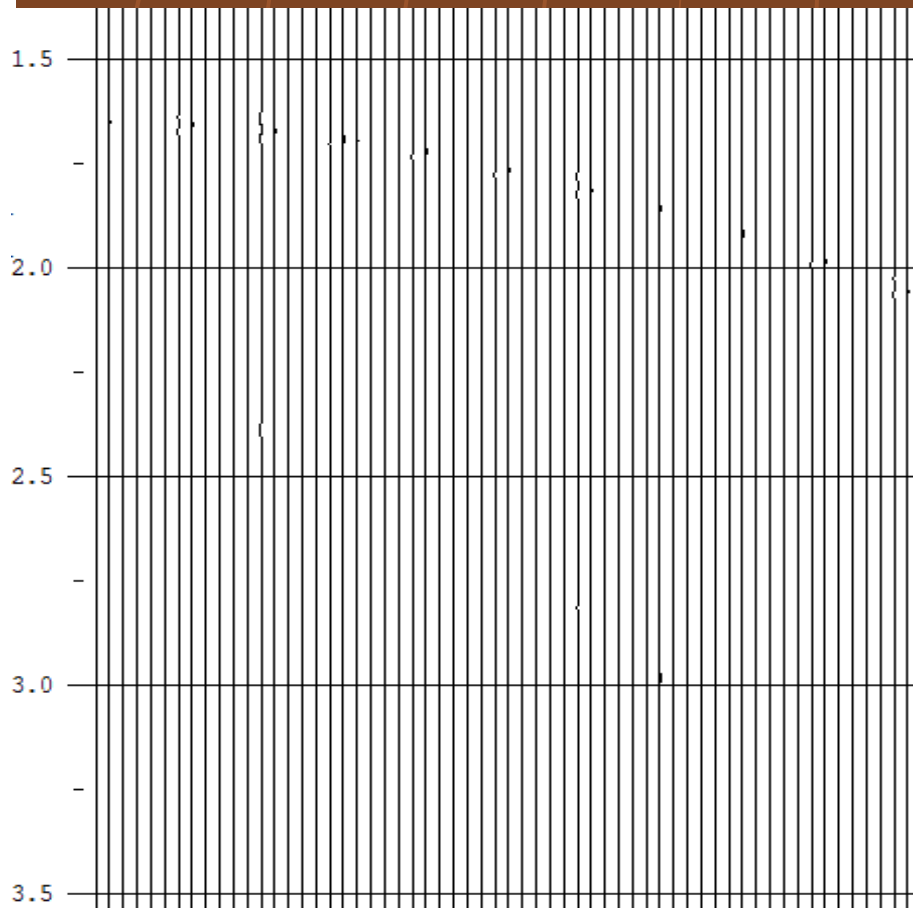


HTI-Isotropic  $\theta=60$   
**X Component**

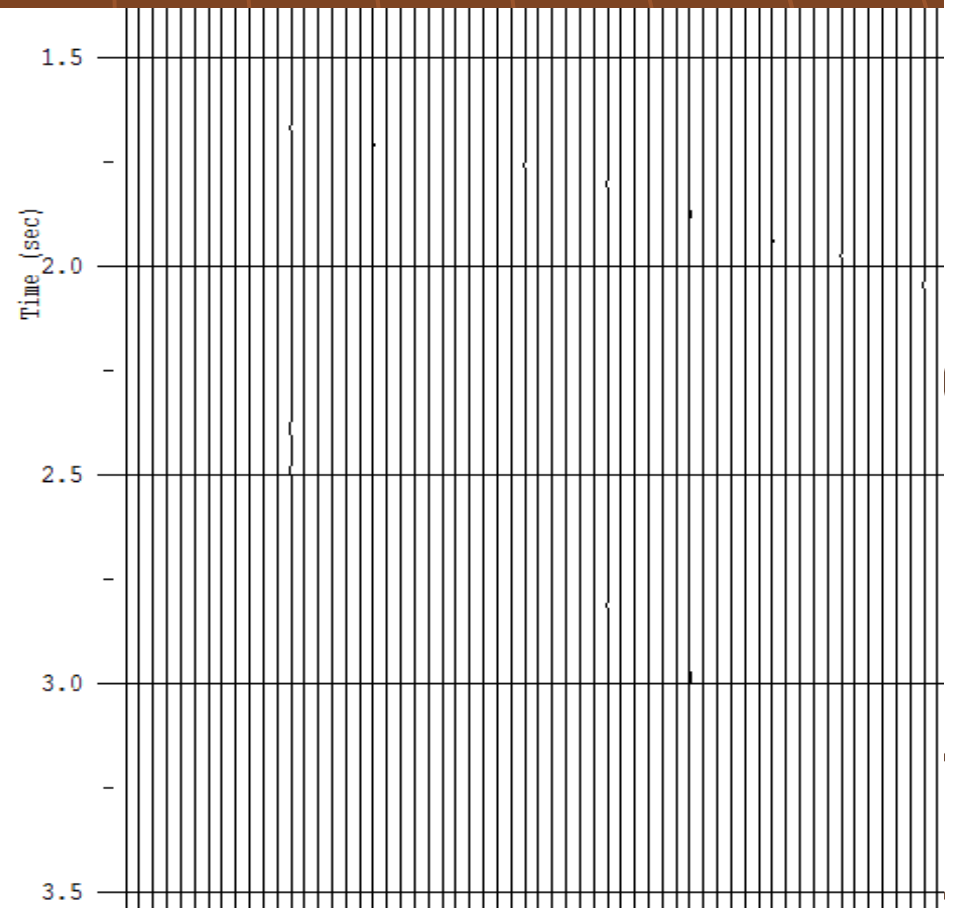


# Difference

HTI-Isotropic  $\theta=90$   
**Z Component**

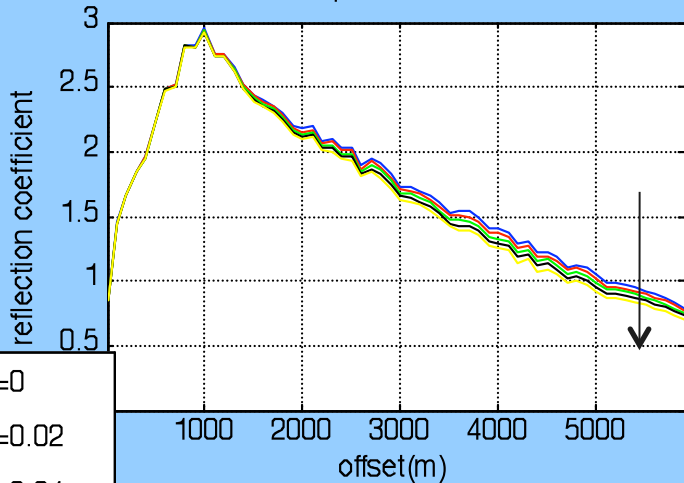


HTI-Isotropic  $\theta=90$   
**X Component**

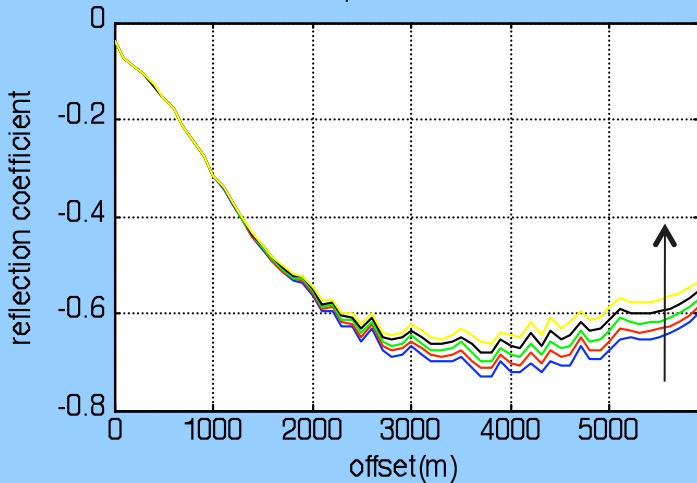


# HTI-Crack Density

Z component-PP wave

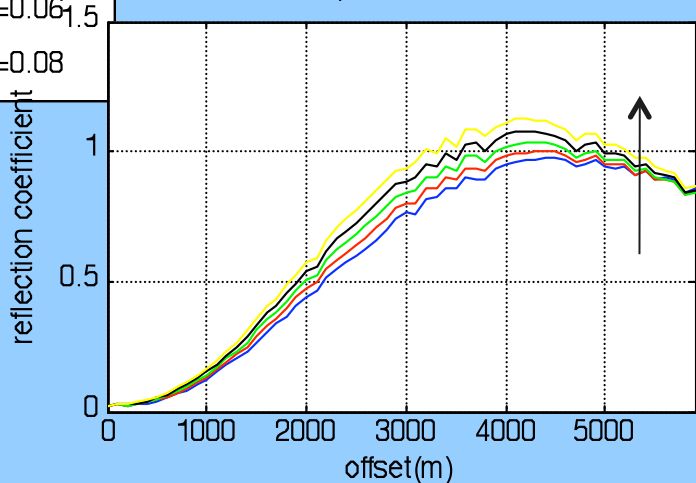


X component-PP wave

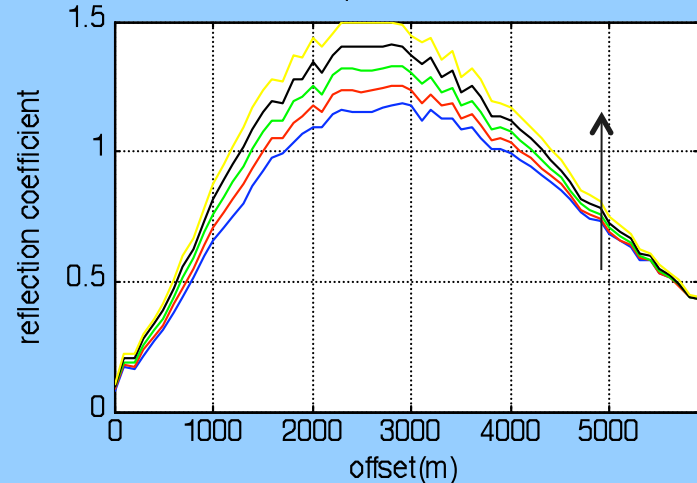


- crack=0
- crack=0.02
- crack=0.04
- crack=0.06
- crack=0.08

Z component-PS wave



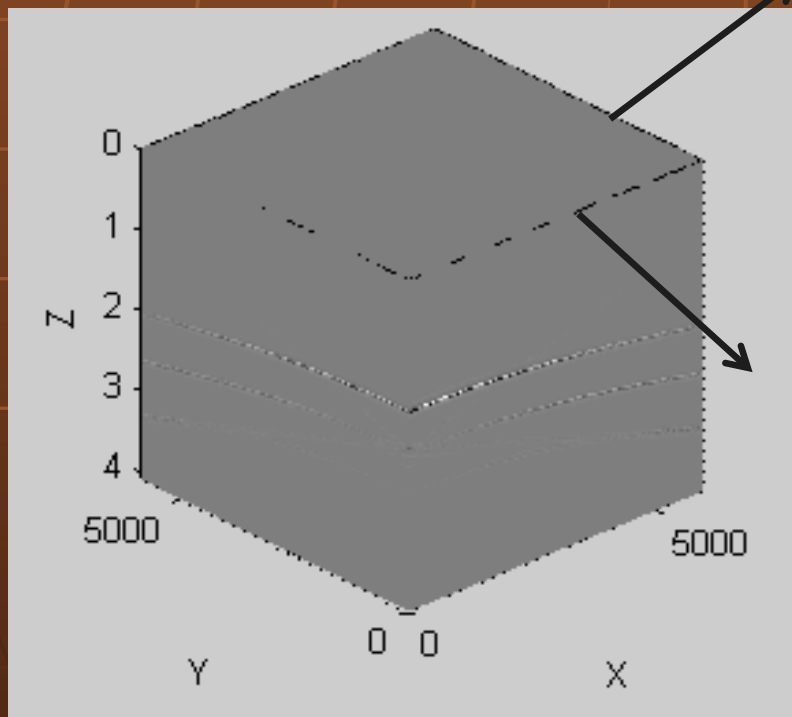
X component-PS wave



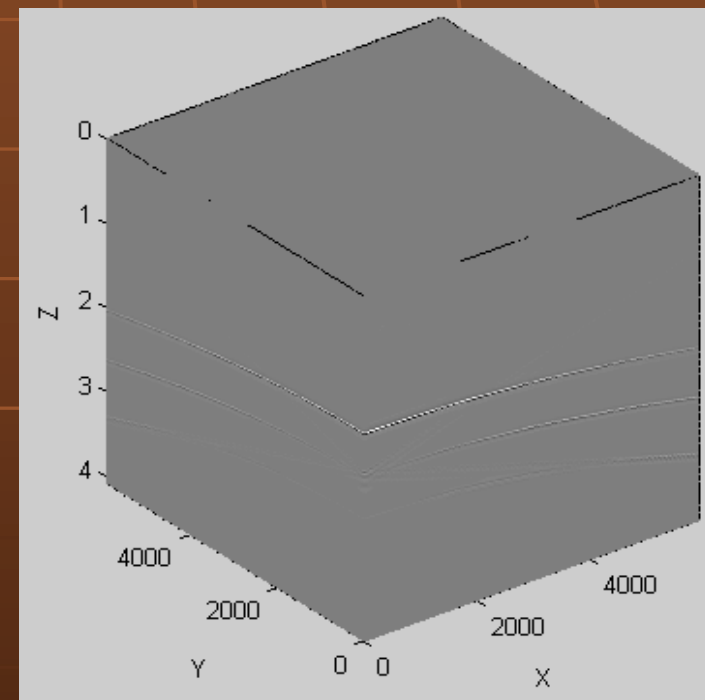


# Shot at (0,0) 2D grid of receivers in XY Plane

Isotropic  
**Vertical Component**



HTI(Dry)  
**Vertical Component**



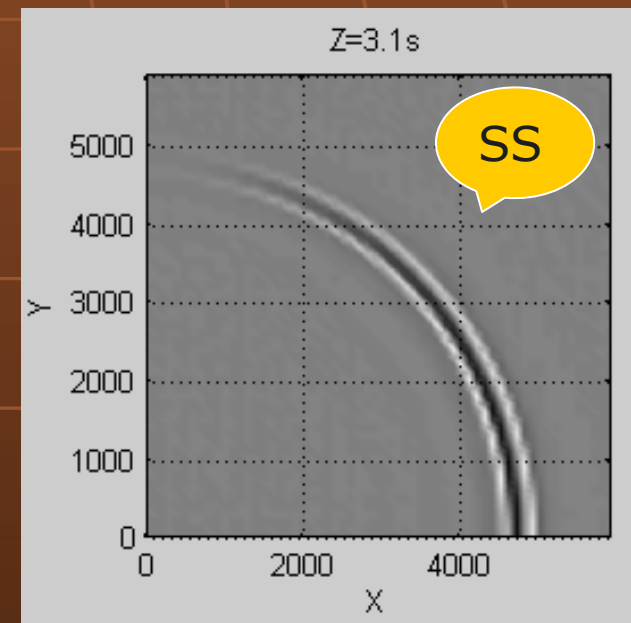
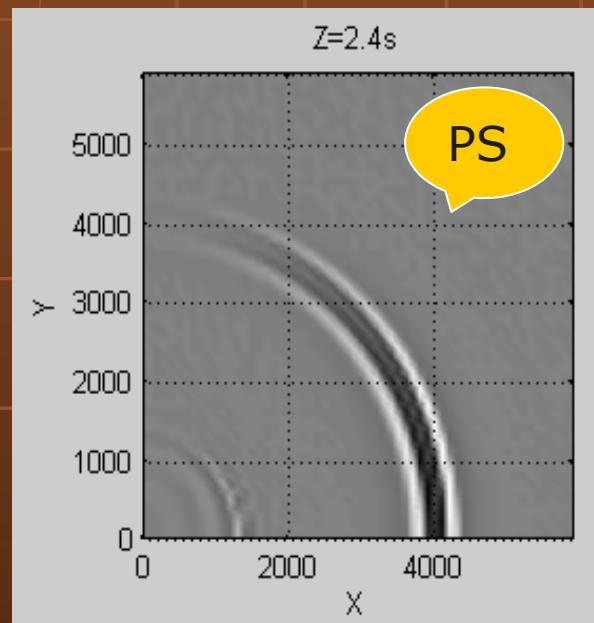
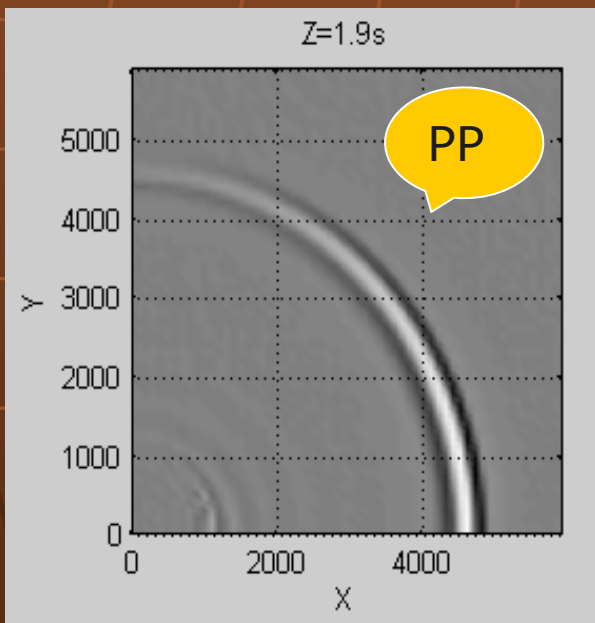
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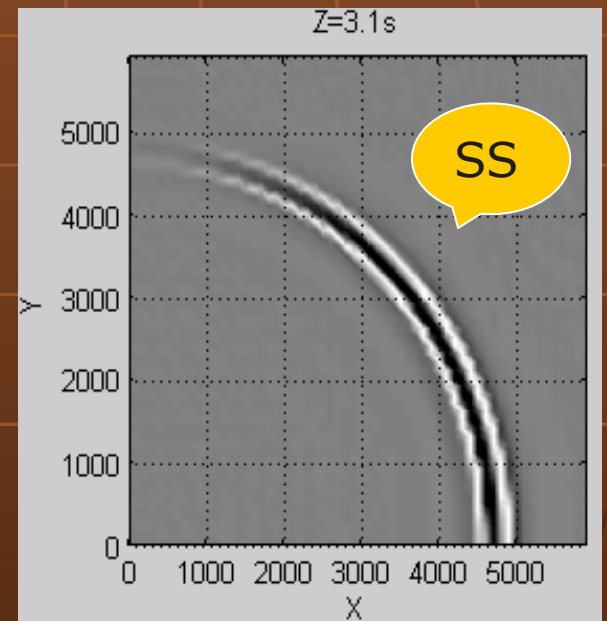
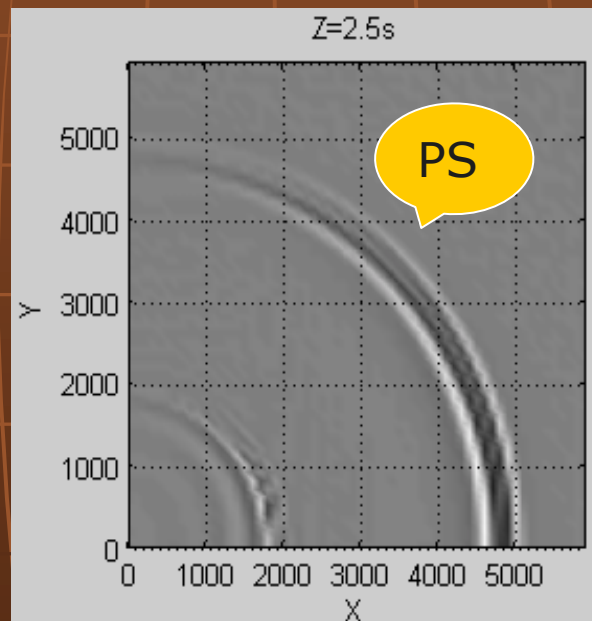
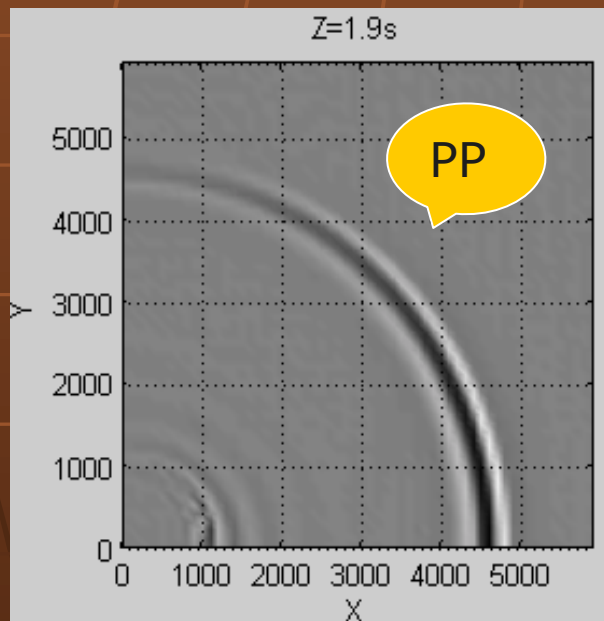
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# HTI(Dry)-Isotropic Vertical Component

The largest  
difference lies at  
X direction.



# HTI(Dry)-Isotropic Radial Component

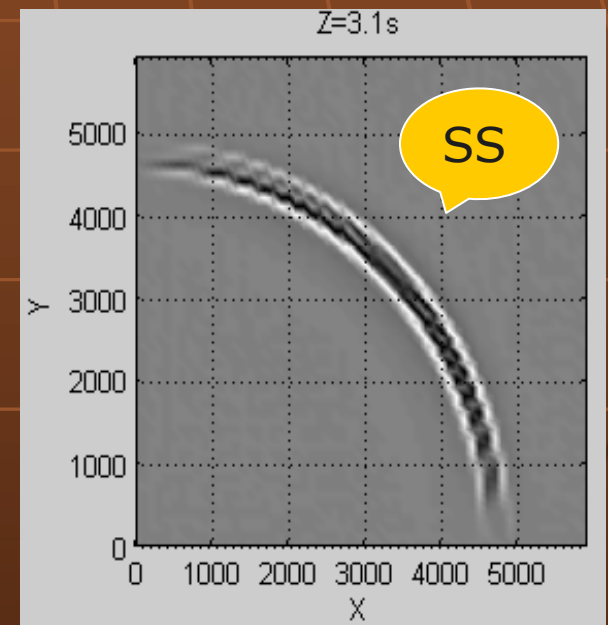
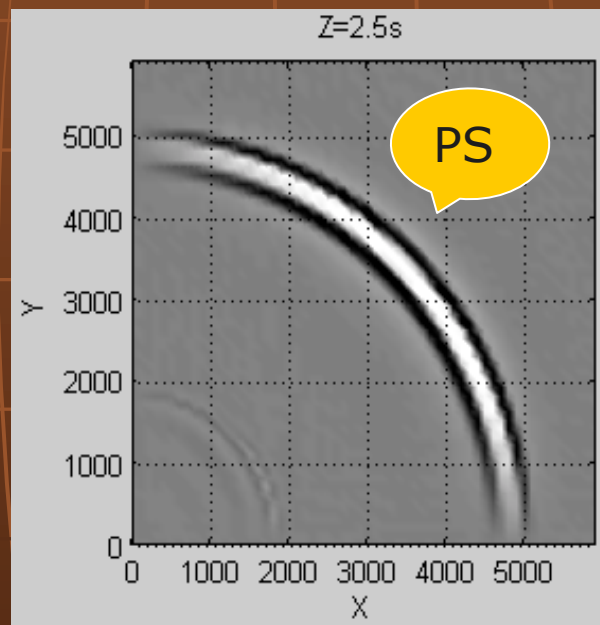
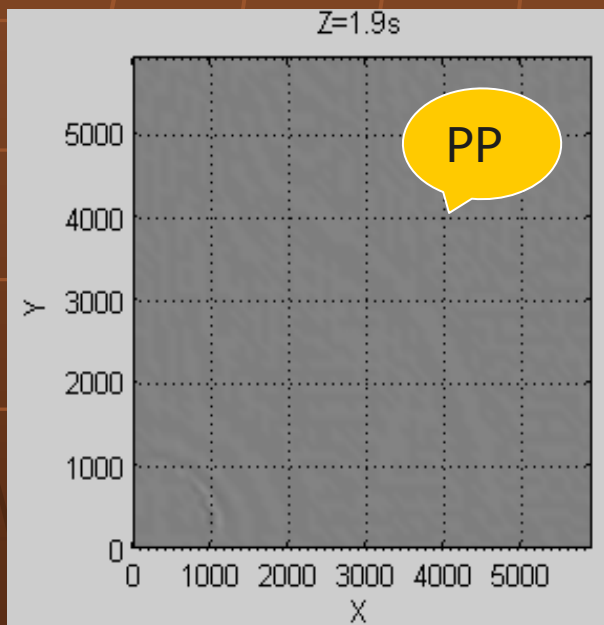


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# HTI(Dry)-Isotropic Transverse Component



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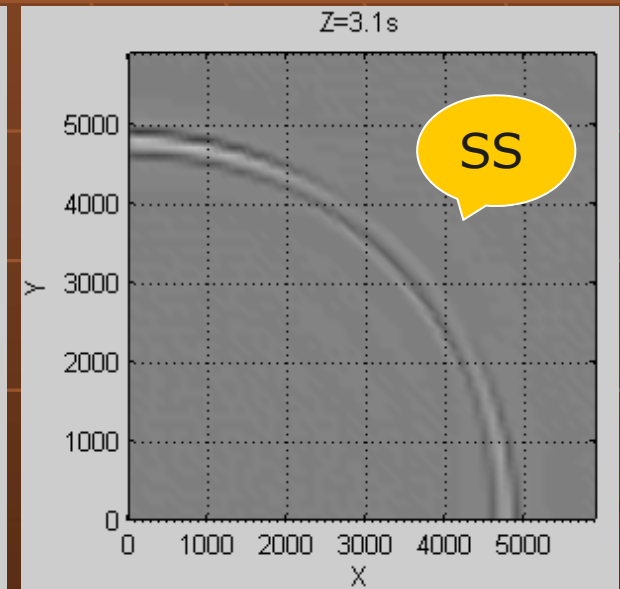
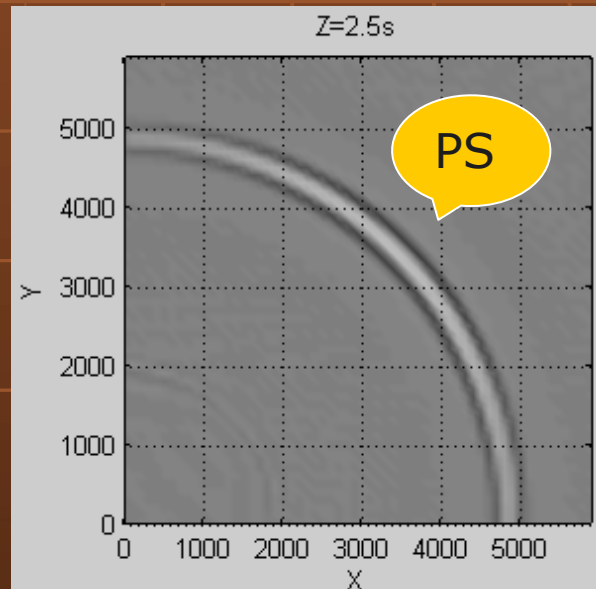
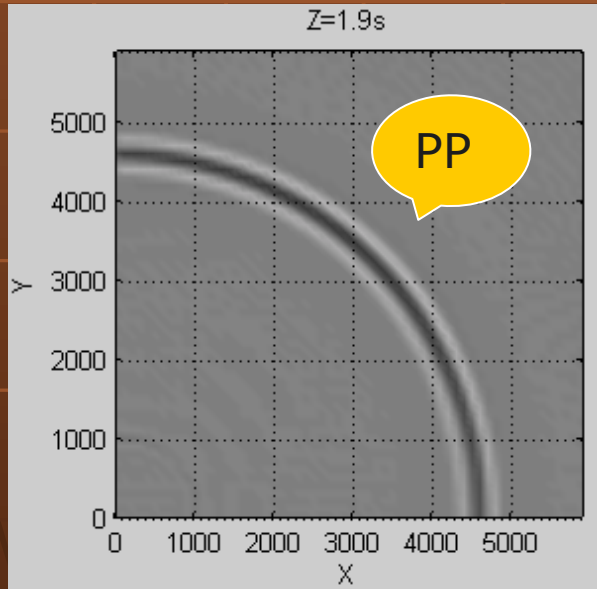
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# Orthorhombic - Isotropic Vertical Component

Can't find a certain  
azimuth of largest  
amplitude difference

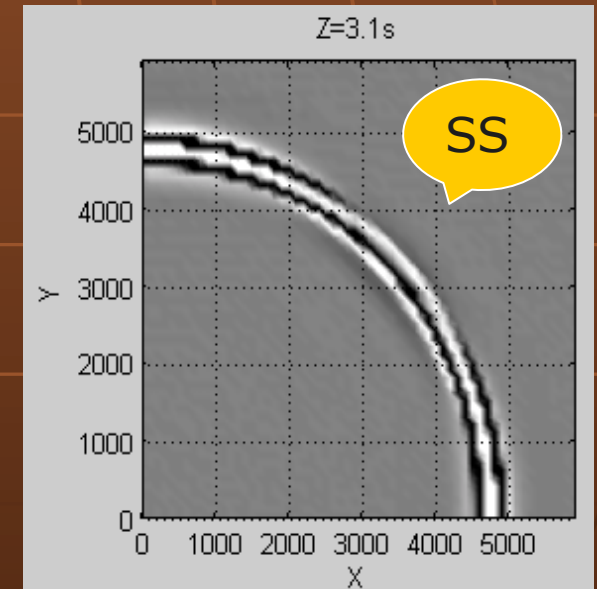
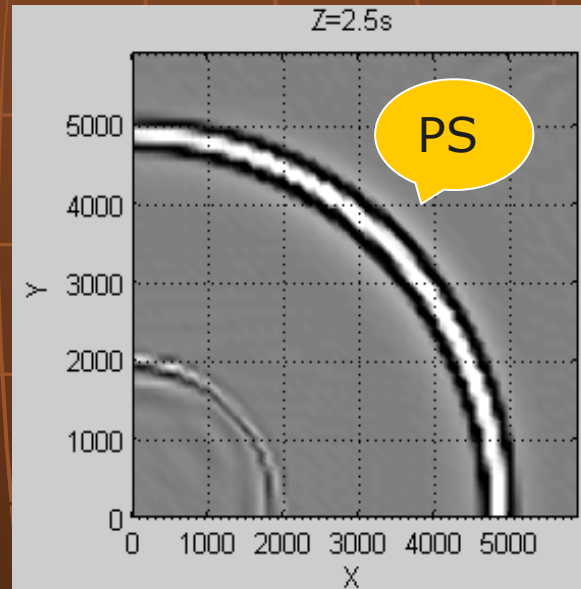
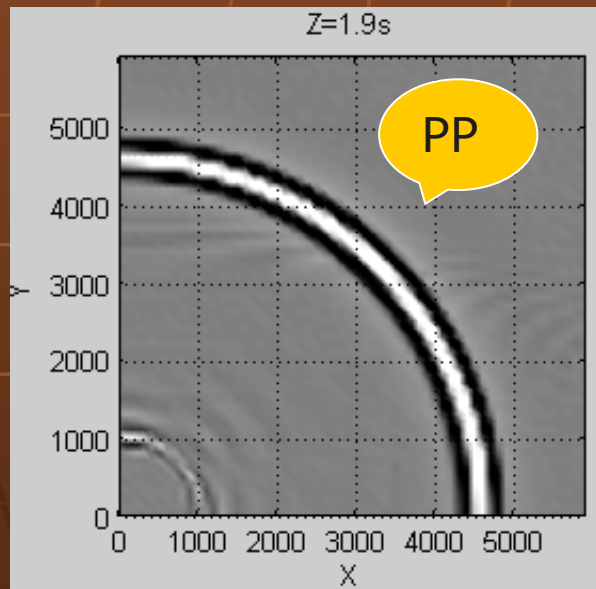


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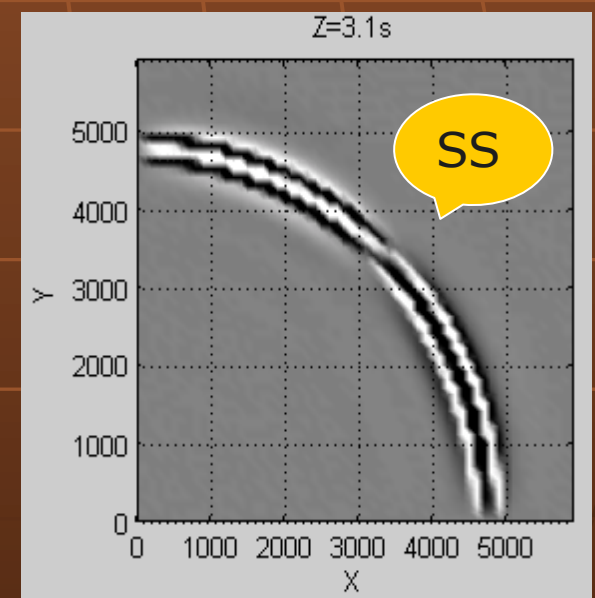
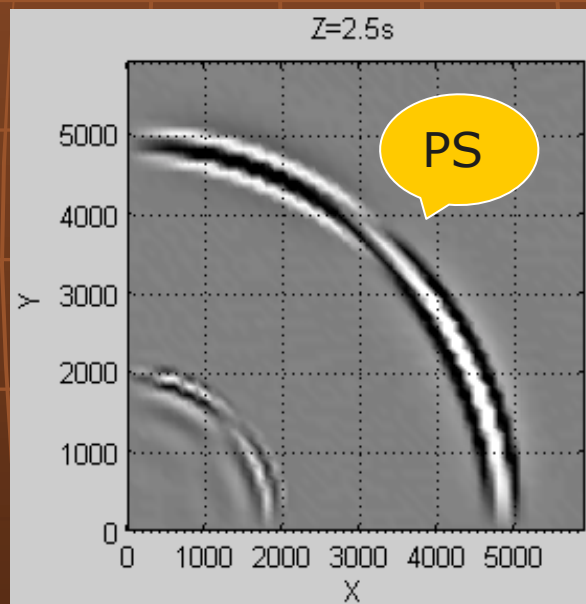
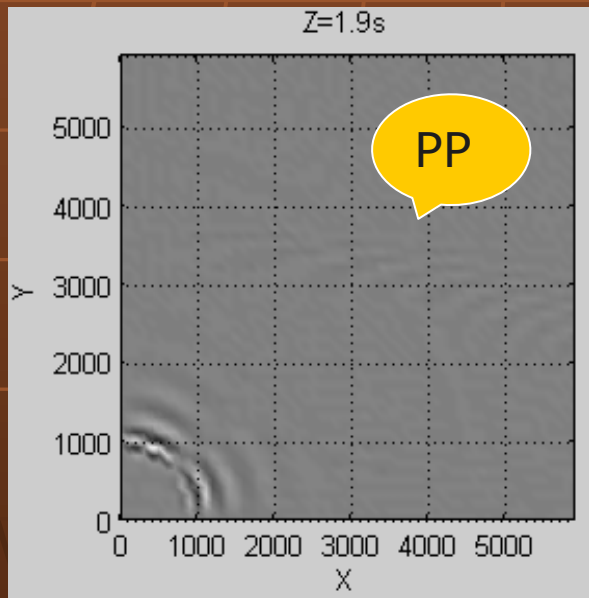
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## Orthorhombic - Isotropic Radial Component



# Orthorhombic - Isotropic Transverse Component



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# Outline

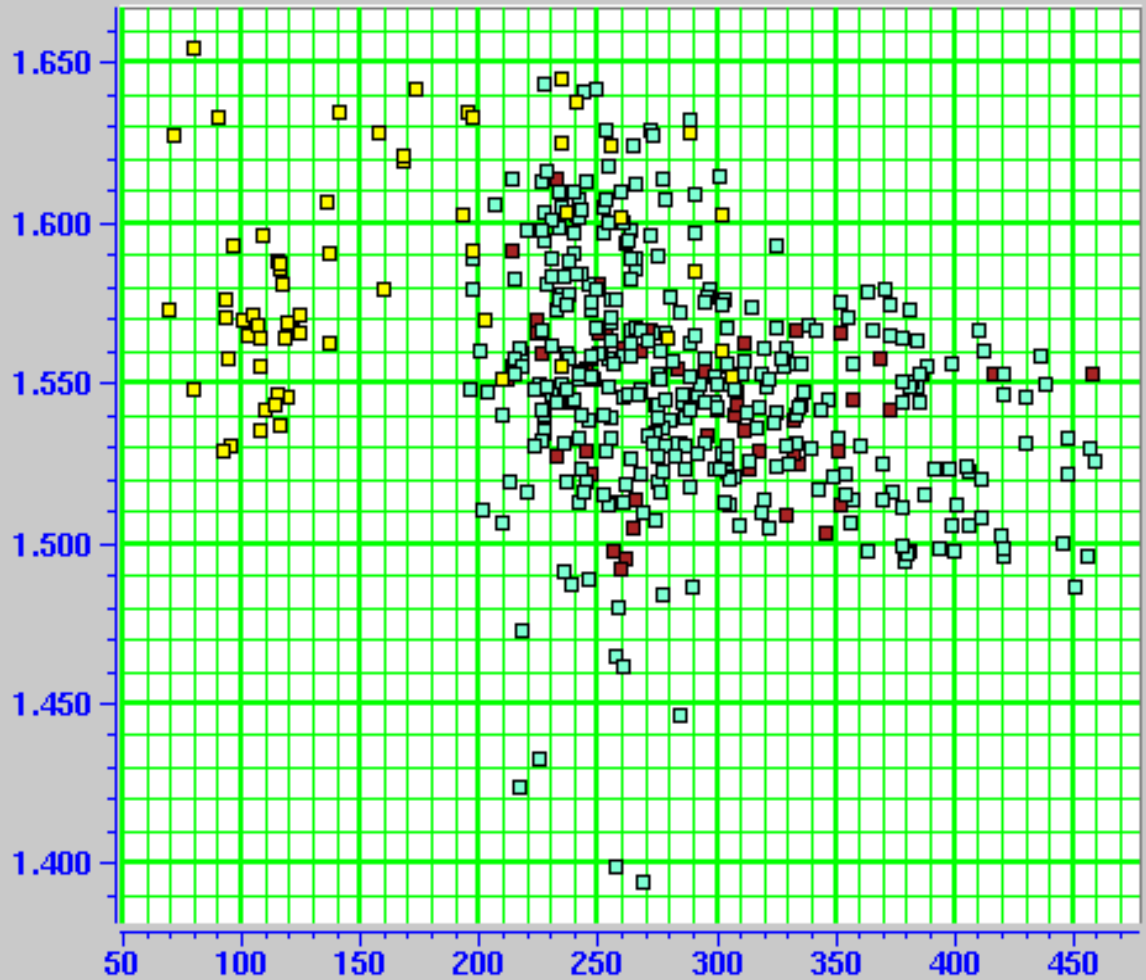
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- Conclusion

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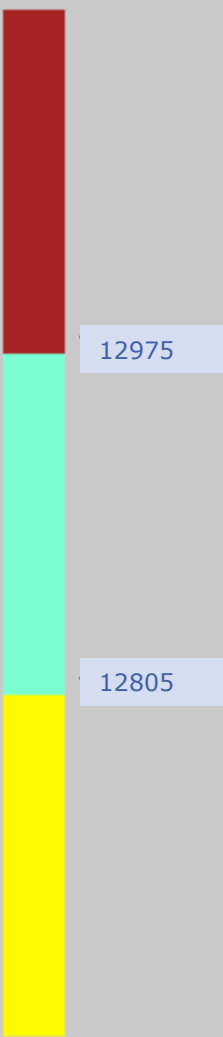
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VpVs\_Ratio(unitless)



<Measured Depth>(ft)



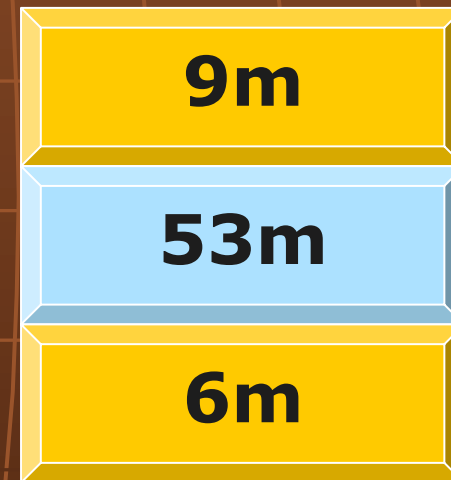
Gamma Ray(gapi)

# Vary Vp/Vs In the Middle Layer

## Isotropic Model



Tuning Effect

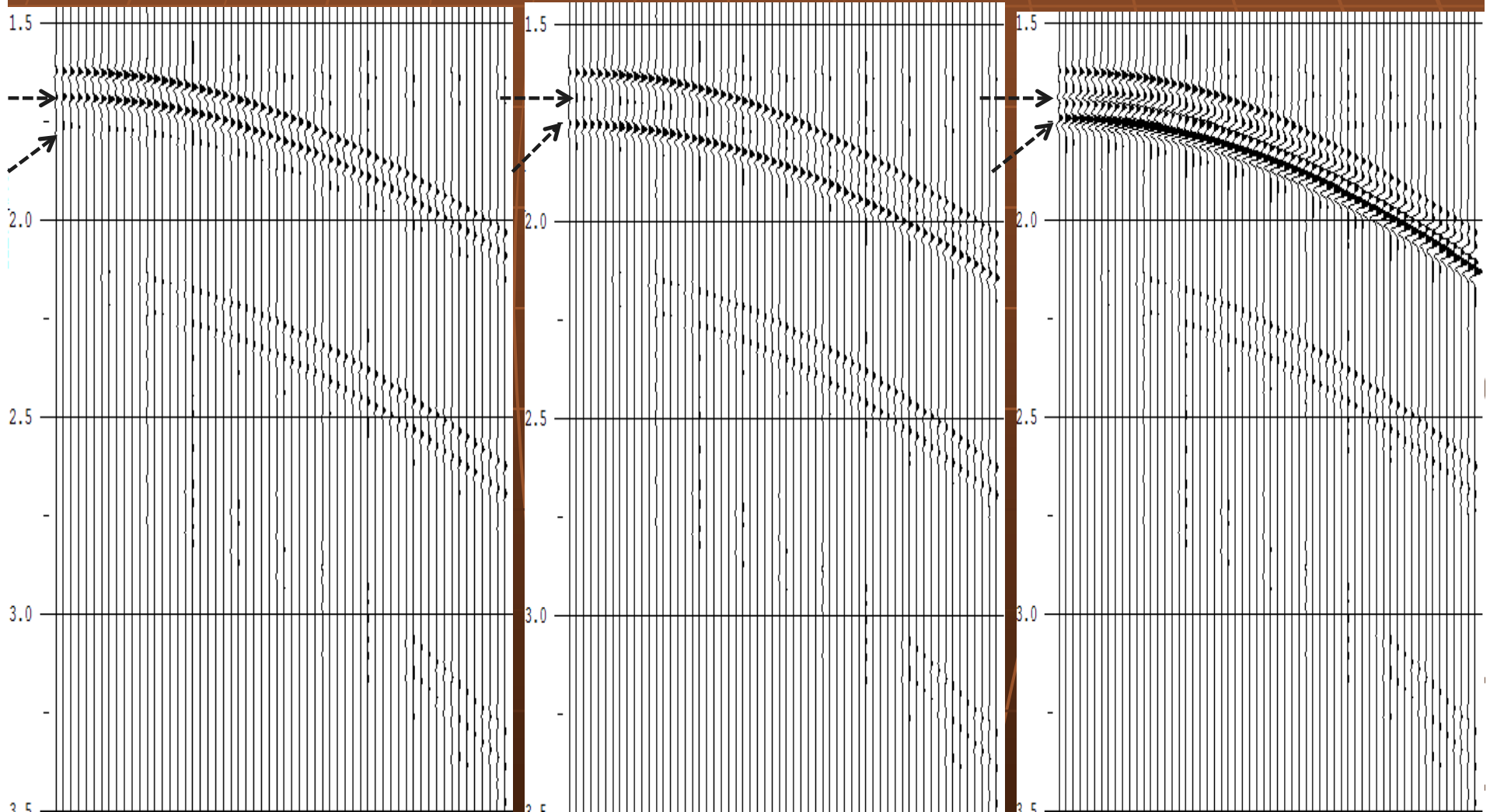


# Z component (150m)

$V_p/V_s=1.54$

$V_p/V_s=1.7$

$V_p/V_s=2$

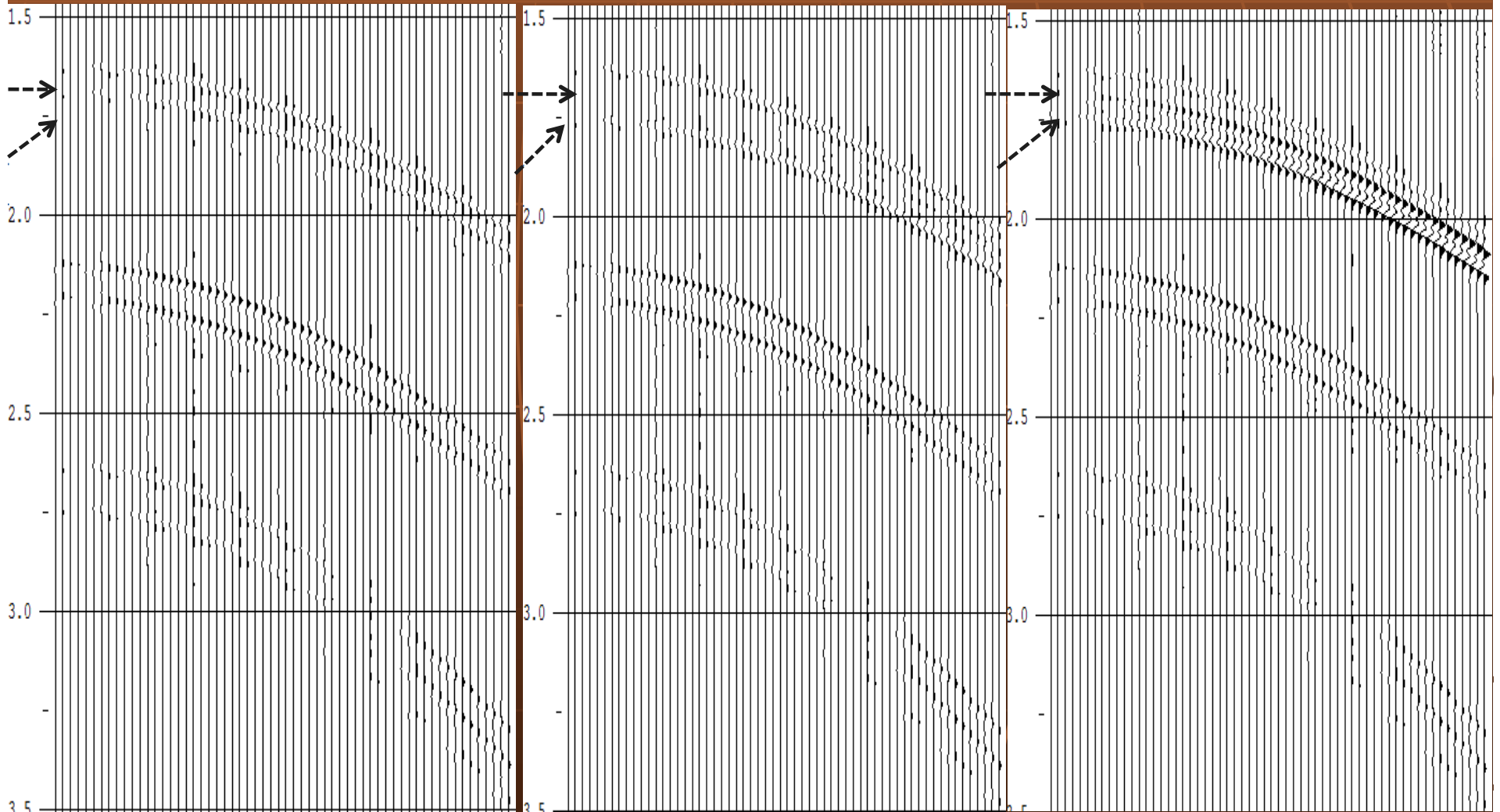


# X component (150m)

$V_p/V_s=1.54$

$V_p/V_s=1.7$

$V_p/V_s=2$

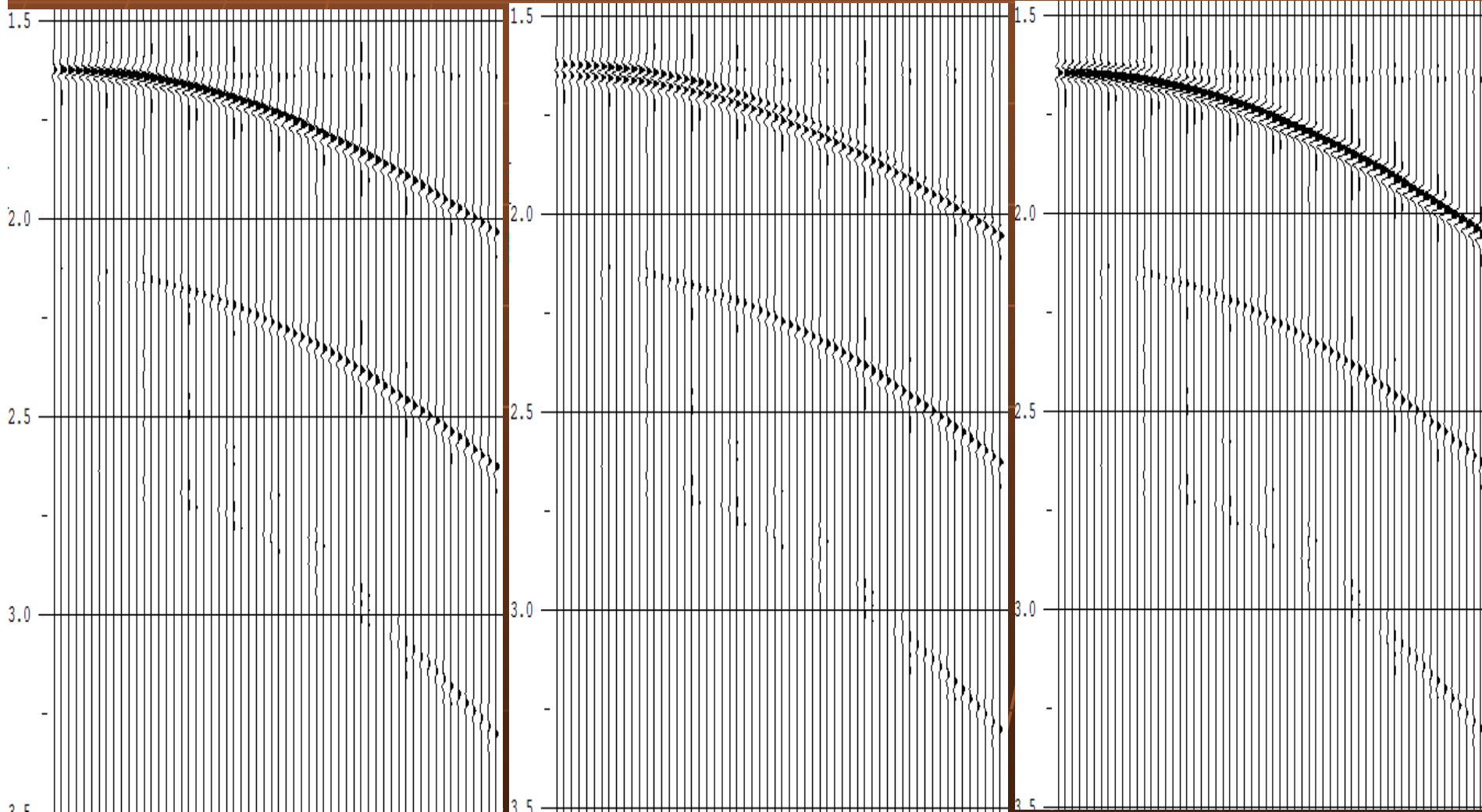


# Z component (Real thickness)

$V_p/V_s=1.54$

$V_p/V_s=1.7$

$V_p/V_s=2$

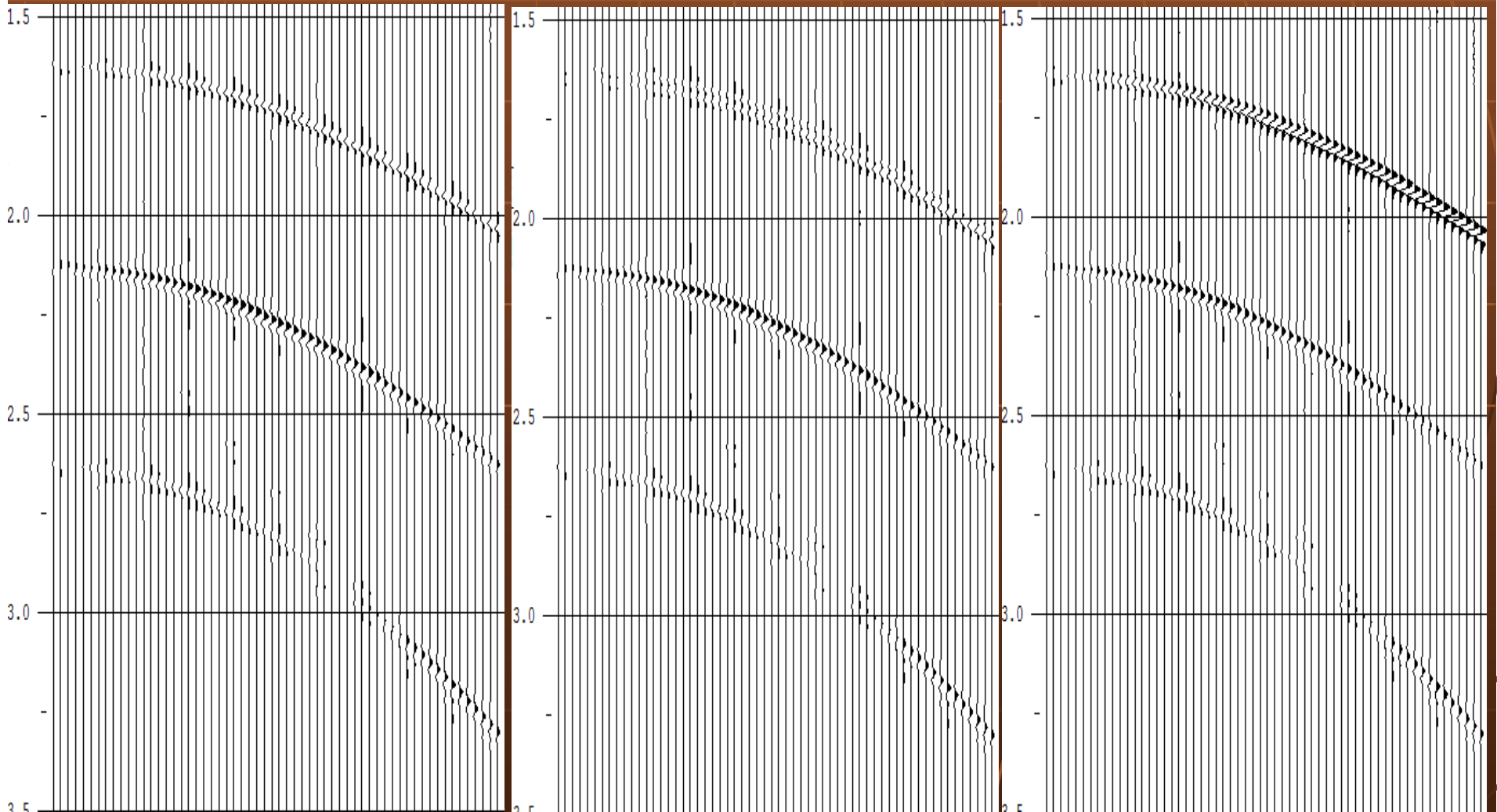


# X component (Real thickness)

$V_p/V_s=1.54$

$V_p/V_s=1.7$

$V_p/V_s=2$



# Vary $V_p/V_s$ In the HTI Layer

## HTI Model

Isotropic

HTI

- (1) Half Space
- (2) Vary  $V_p/V_s$  in the HTI layer
- (3) Use Hudson Model
- (4) Use different  $S_w$  or  $S_g$
- (5) Change aspect ratio

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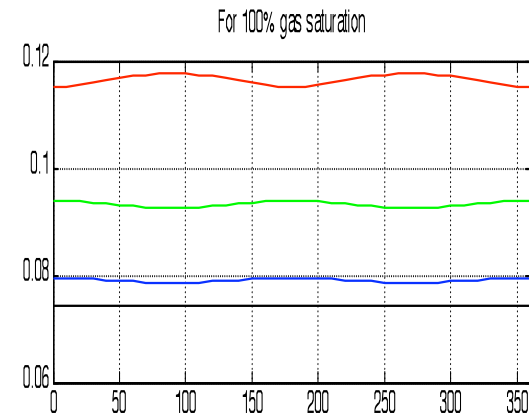
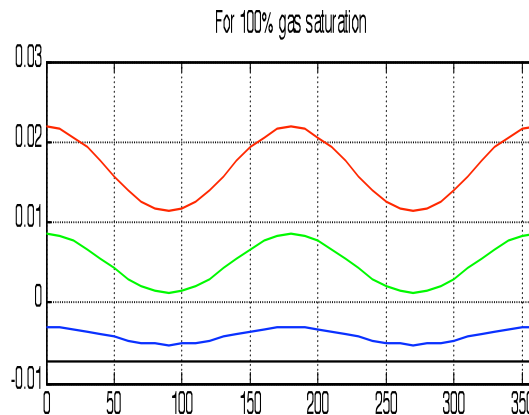
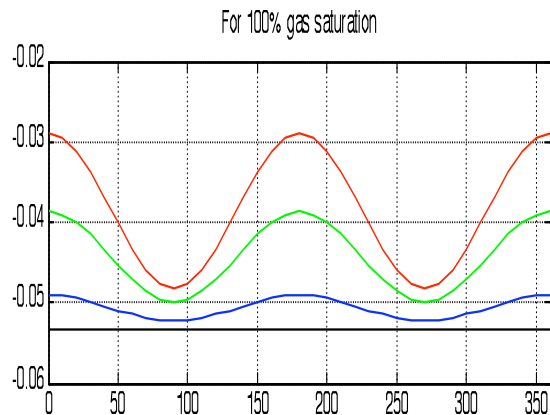
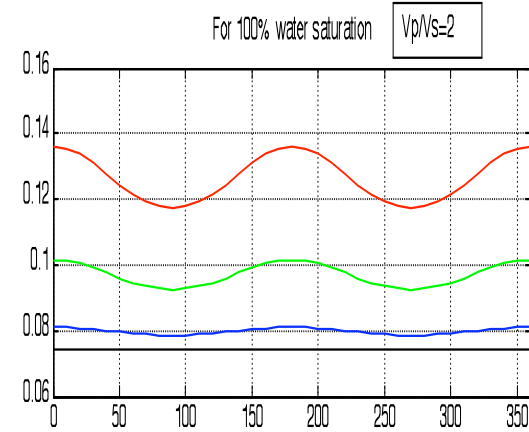
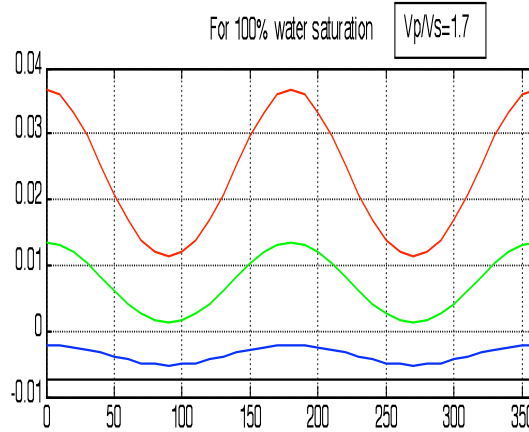
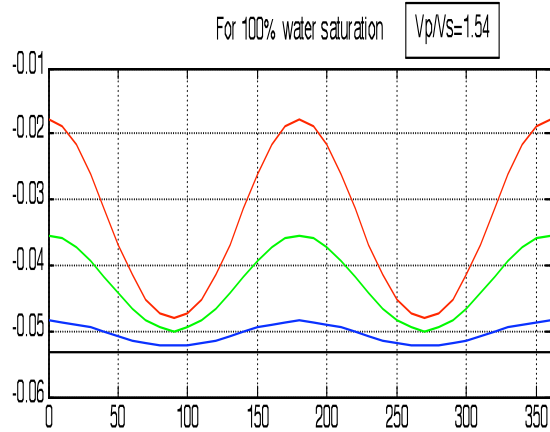
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$V_p/V_s=1.54$

$V_p/V_s=1.7$

$V_p/V_s=2.0$

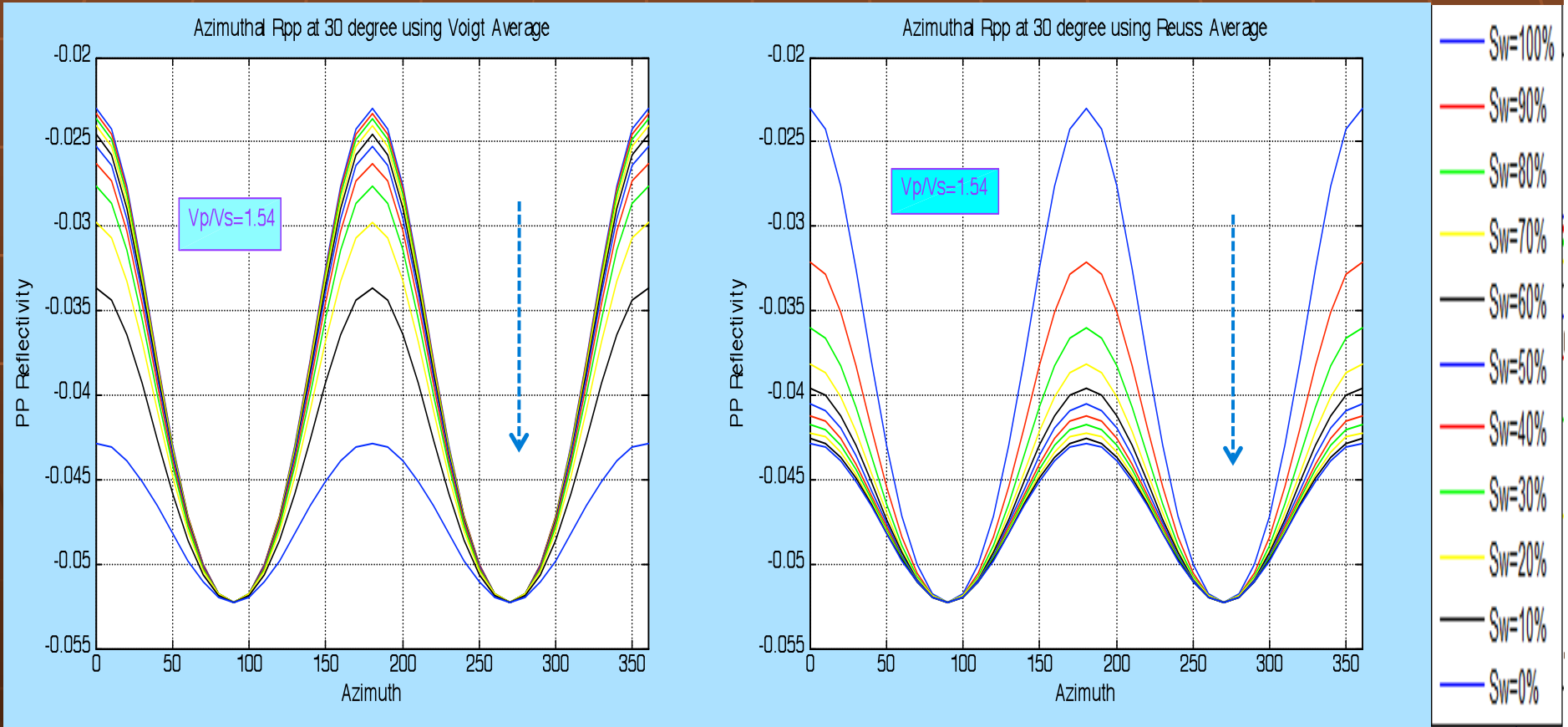


— theta at 0 degree  
— theta at 10 degree  
— theta at 20 degree  
— theta at 30 degree

# Fluid in the Fractures

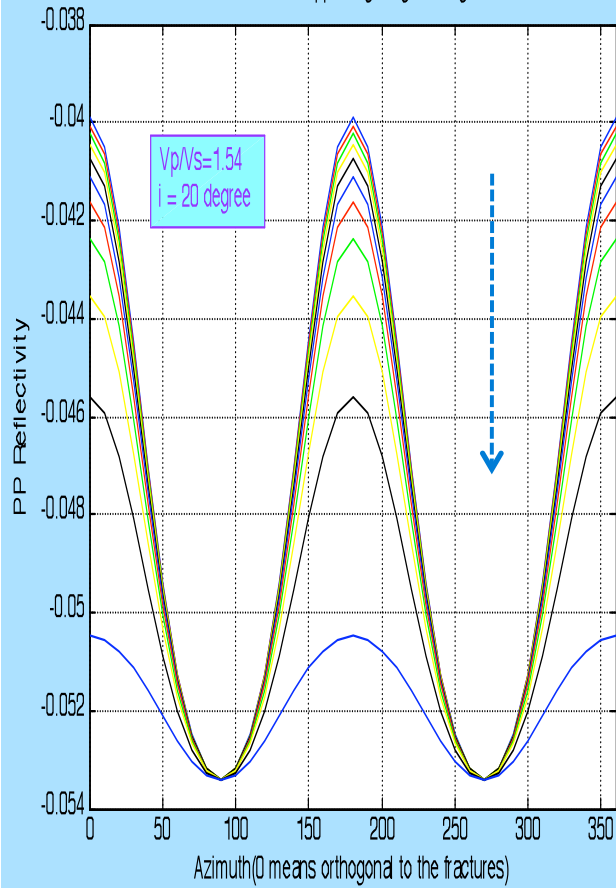
## Voigt Average

## Reuss Average

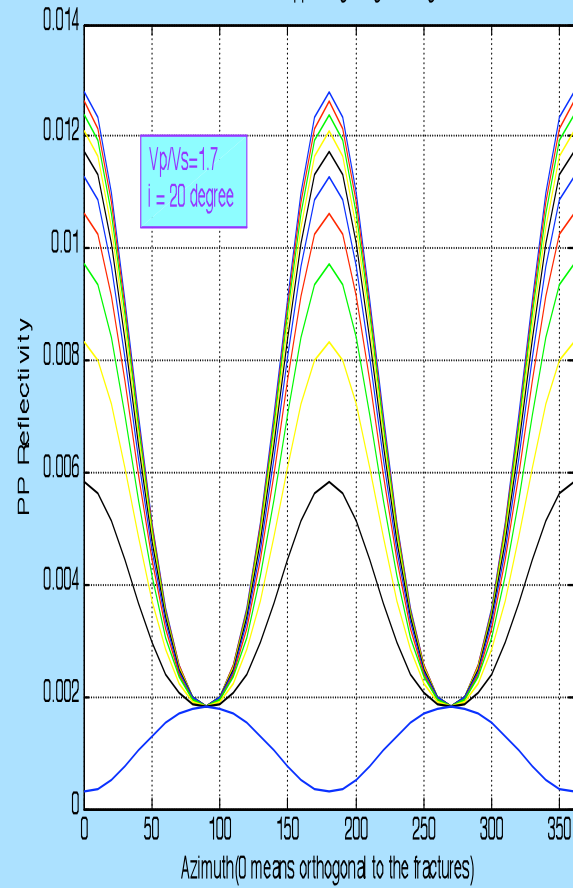


Aspect Ratio=0.01

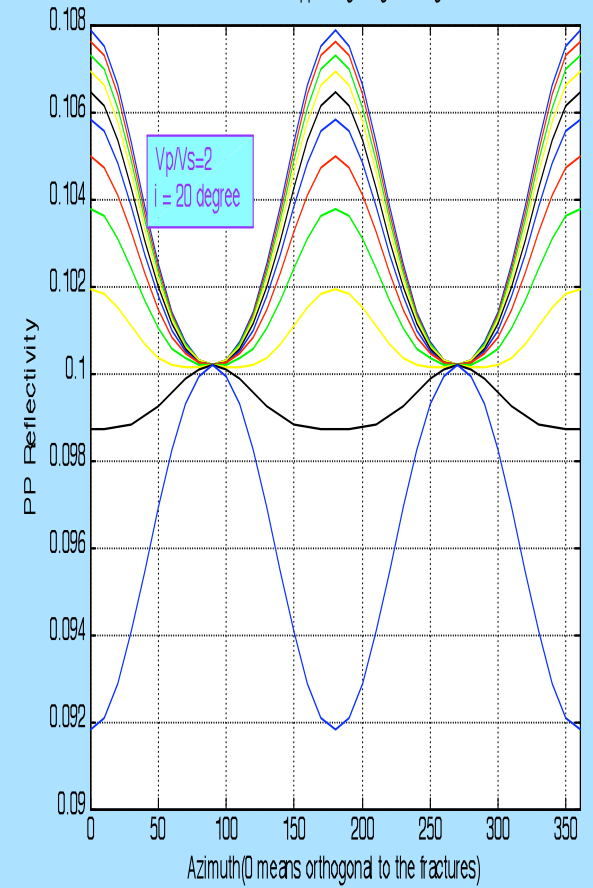
Azimuthal Ppp using Voigt Average

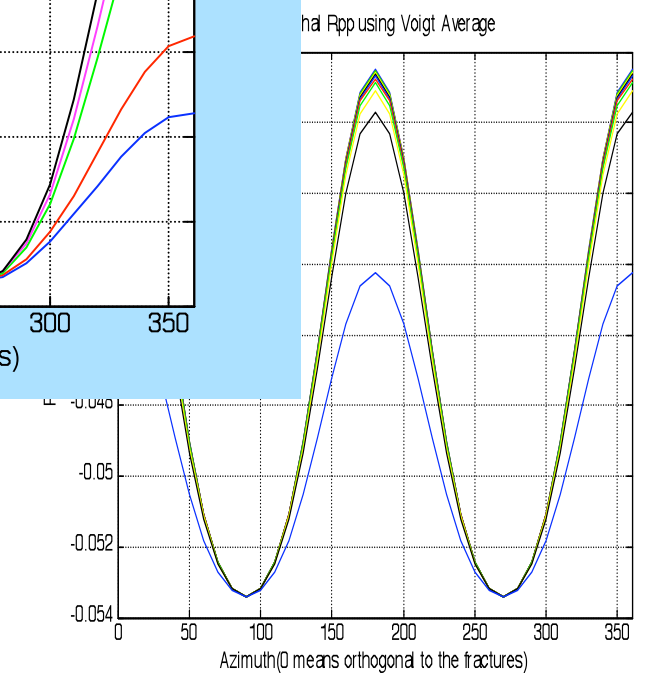
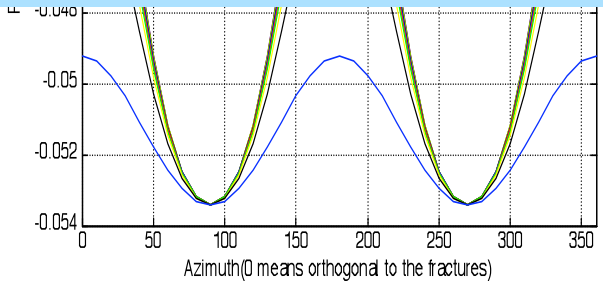
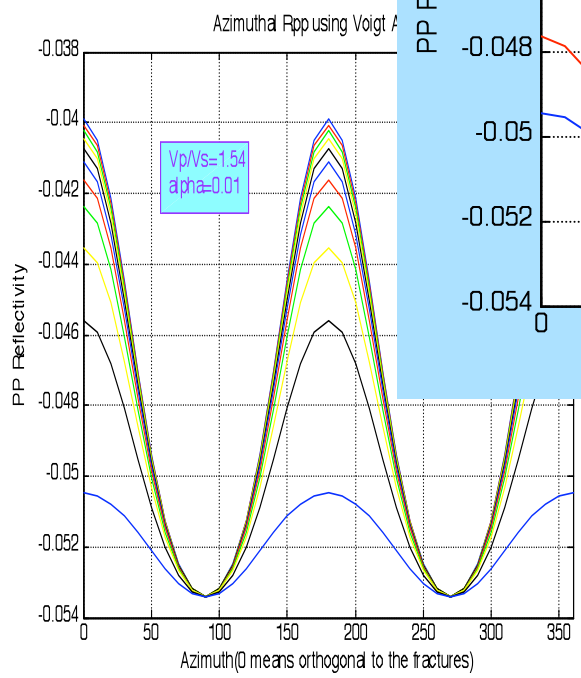
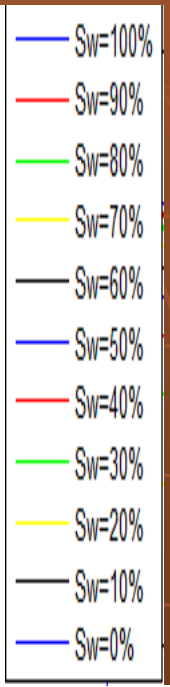
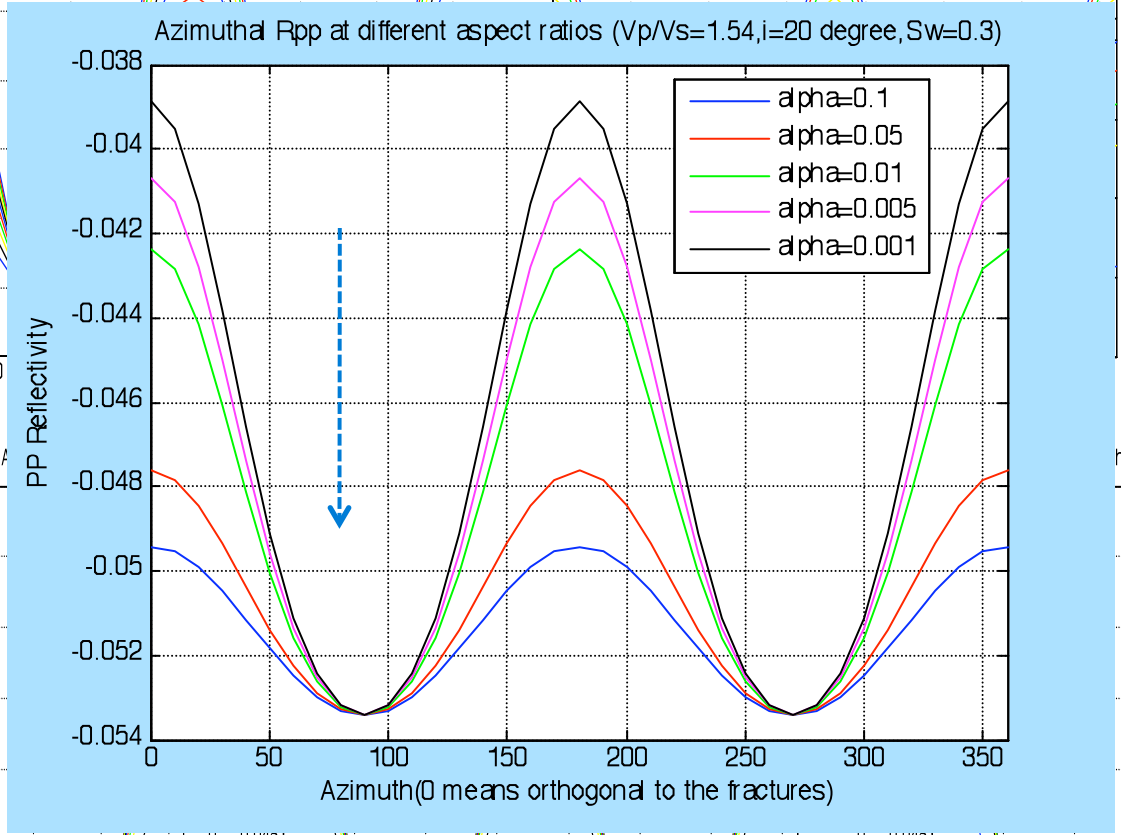
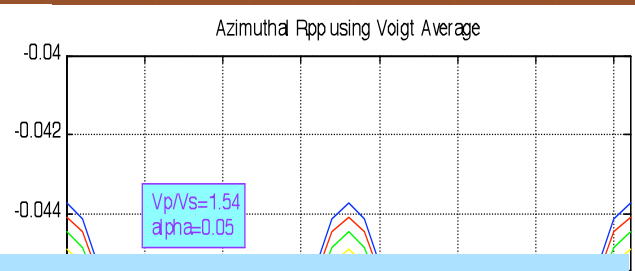
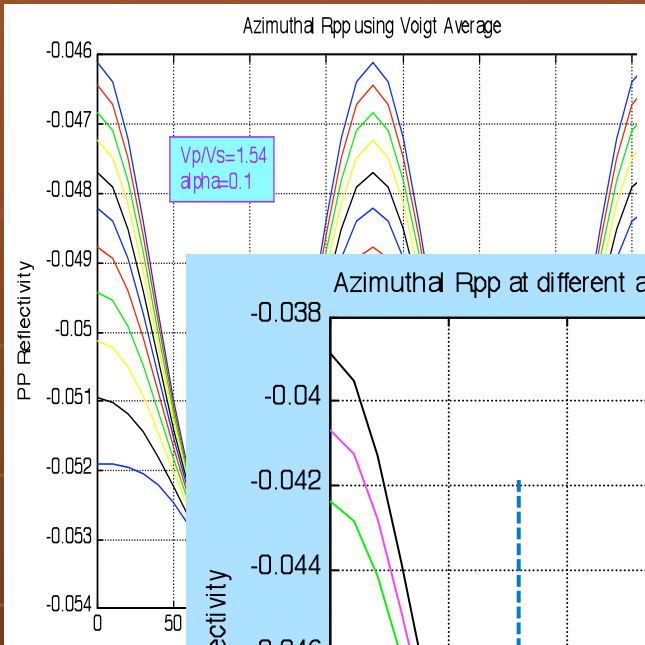


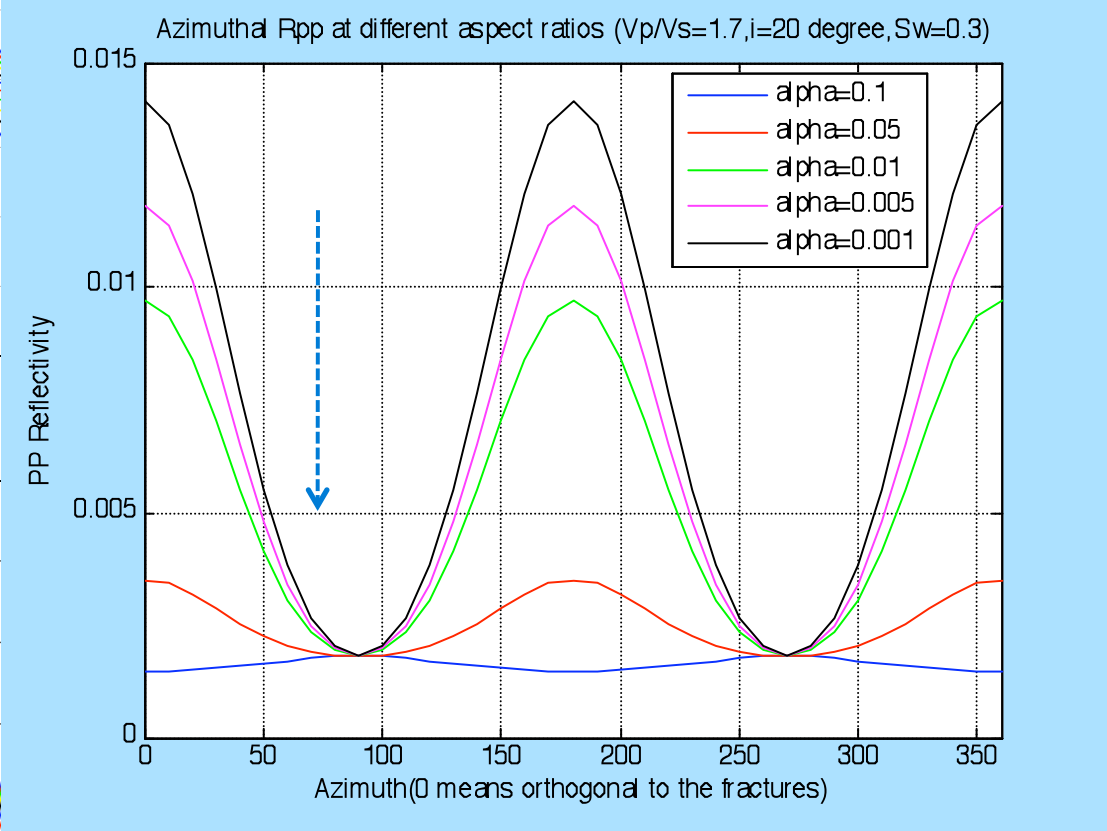
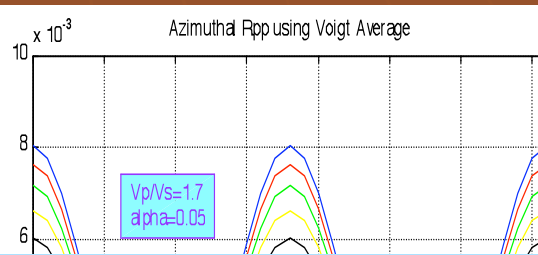
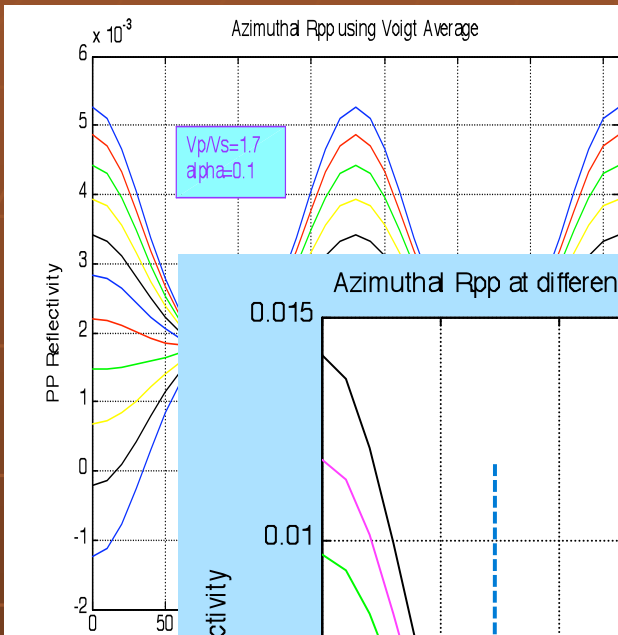
Azimuthal Ppp using Voigt Average



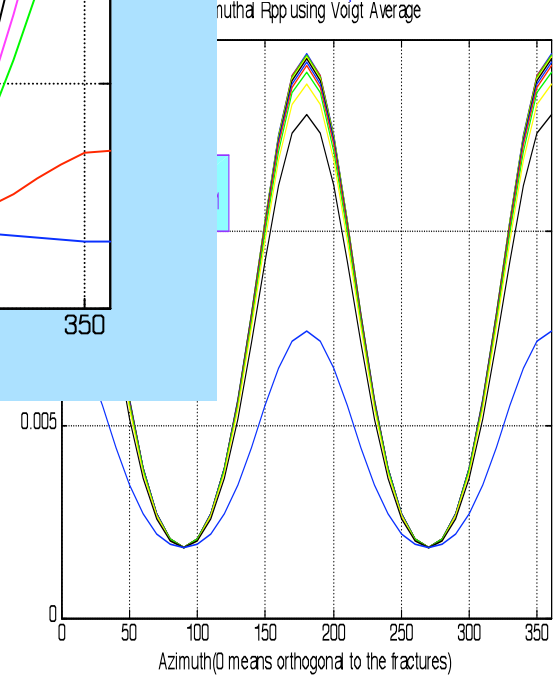
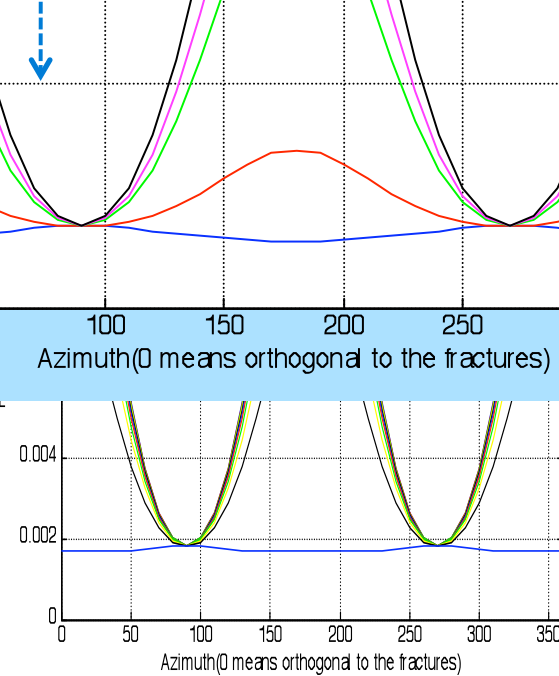
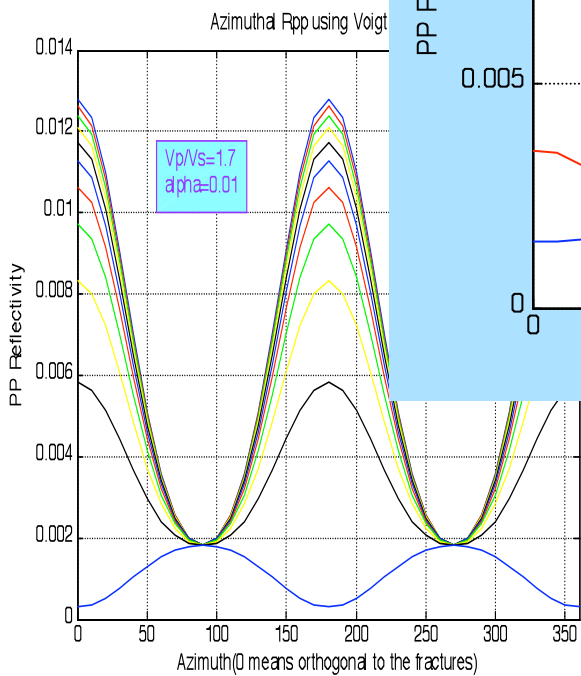
Azimuthal Ppp using Voigt Average

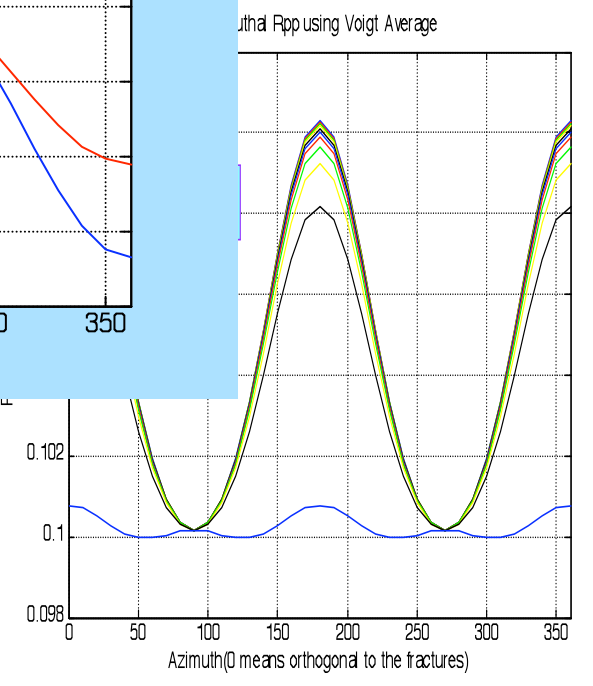
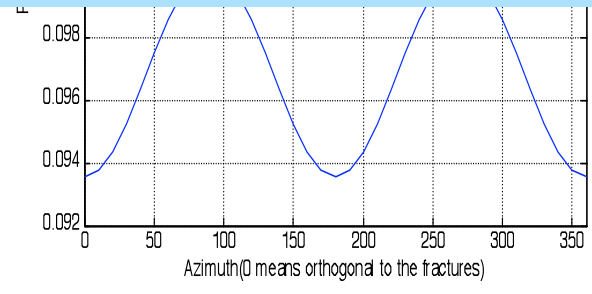
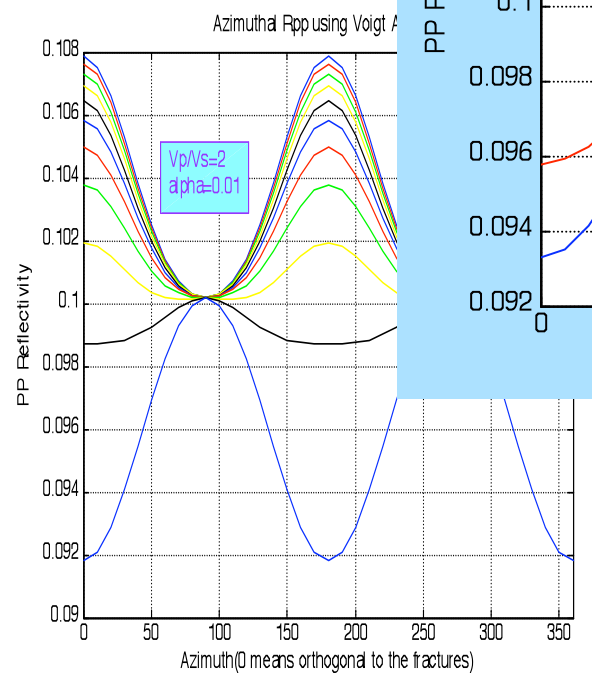
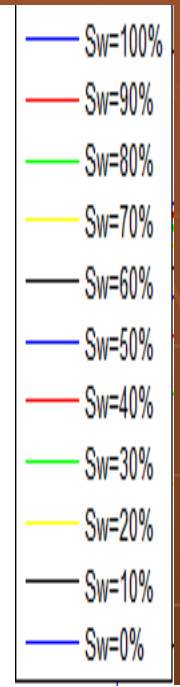
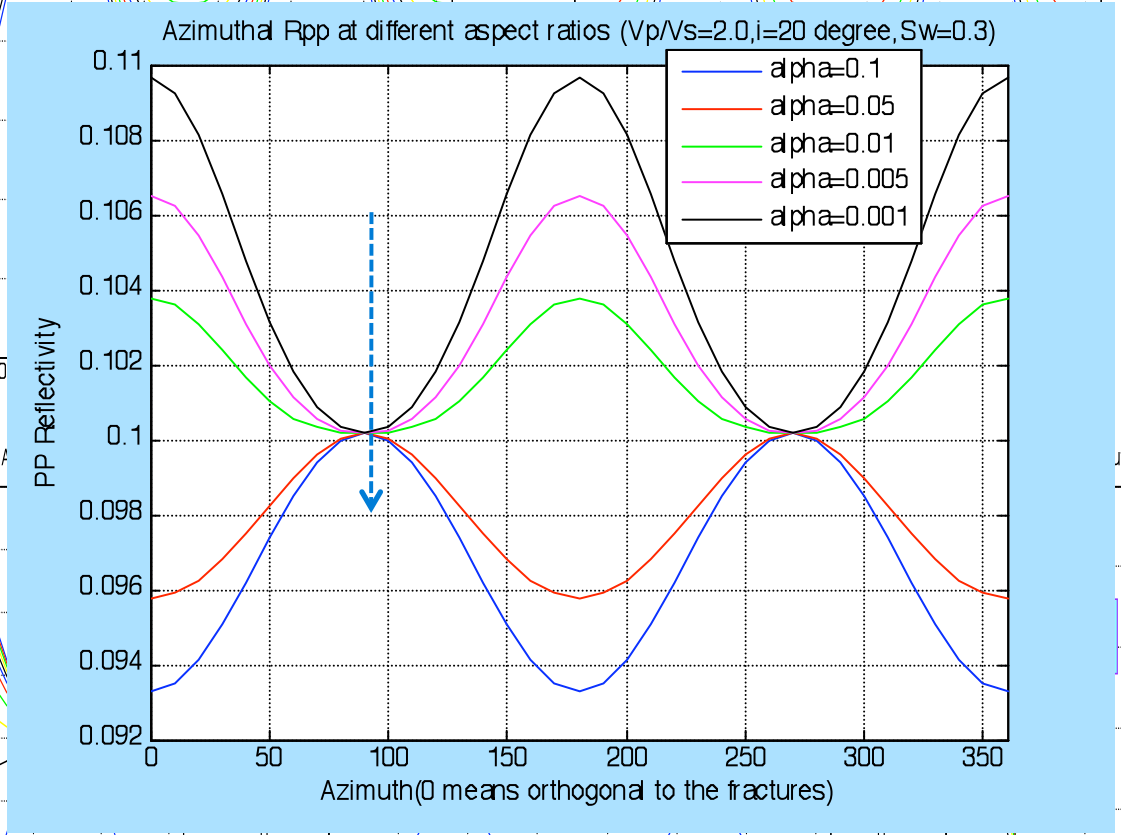
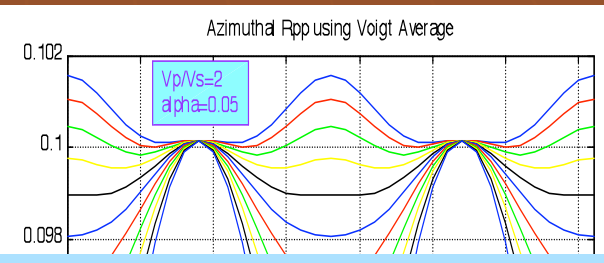
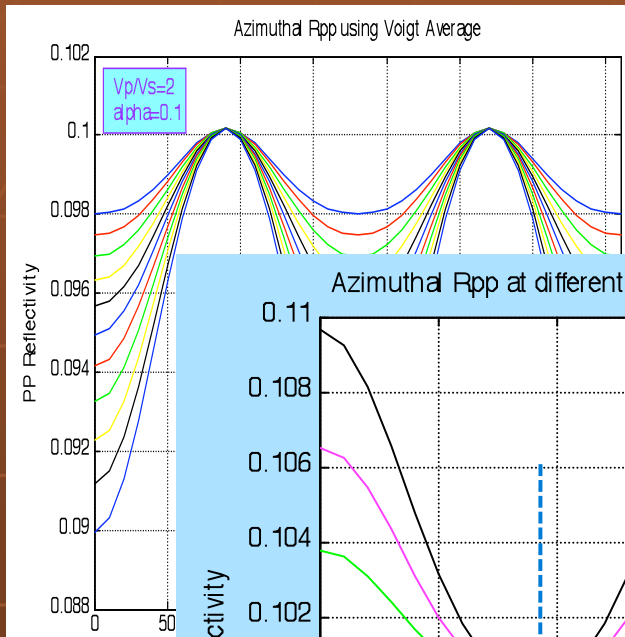






- $Sw=100\%$
- $Sw=90\%$
- $Sw=80\%$
- $Sw=70\%$
- $Sw=60\%$
- $Sw=50\%$
- $Sw=40\%$
- $Sw=30\%$
- $Sw=20\%$
- $Sw=10\%$
- $Sw=0\%$





# Outline

- Overview
- Well log Observation
- Seismic Modeling and Sensitivity Study
  - VTI Model and Sensitivity Study
  - HTI Model and Sensitivity Study
  - Orthorhombic Model
  - Vp/Vs, Anisotropy and Gas Saturations
- **Conclusion**

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# Conclusions

- Observable seismic difference between **VTI** and Isotropic Model, between **HTI** and Isotropic Model and between **Orthorhombic** and Isotropic Model.
- Crack density could cause changes in seismic response for HTI model.  $\epsilon$  and  $\delta$  might also cause different seismic response for VTI model.
- For **HTI** and **Orthorhombic** Model, we could observe the amplitude change with azimuth.

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# Conclusions

- Different  $V_p/V_s$  ratio may cause variations in the Seismic Response to Woodford Shale.
- **Aspect ratio** plays an important role in HTI medium, also the **fluid** saturated in the fractures could change the seismic response.
- Understand background data ( **$V_p/V_s$ , Anisotropy, fluid and lithology etc**) could help predict the seismic response and its variations using reasonable rock physics model.

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