



# Anisotropy of the Bakken Formation, East Williston Basin, North Dakota

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Robert H. Tatham  
February 22, 2010

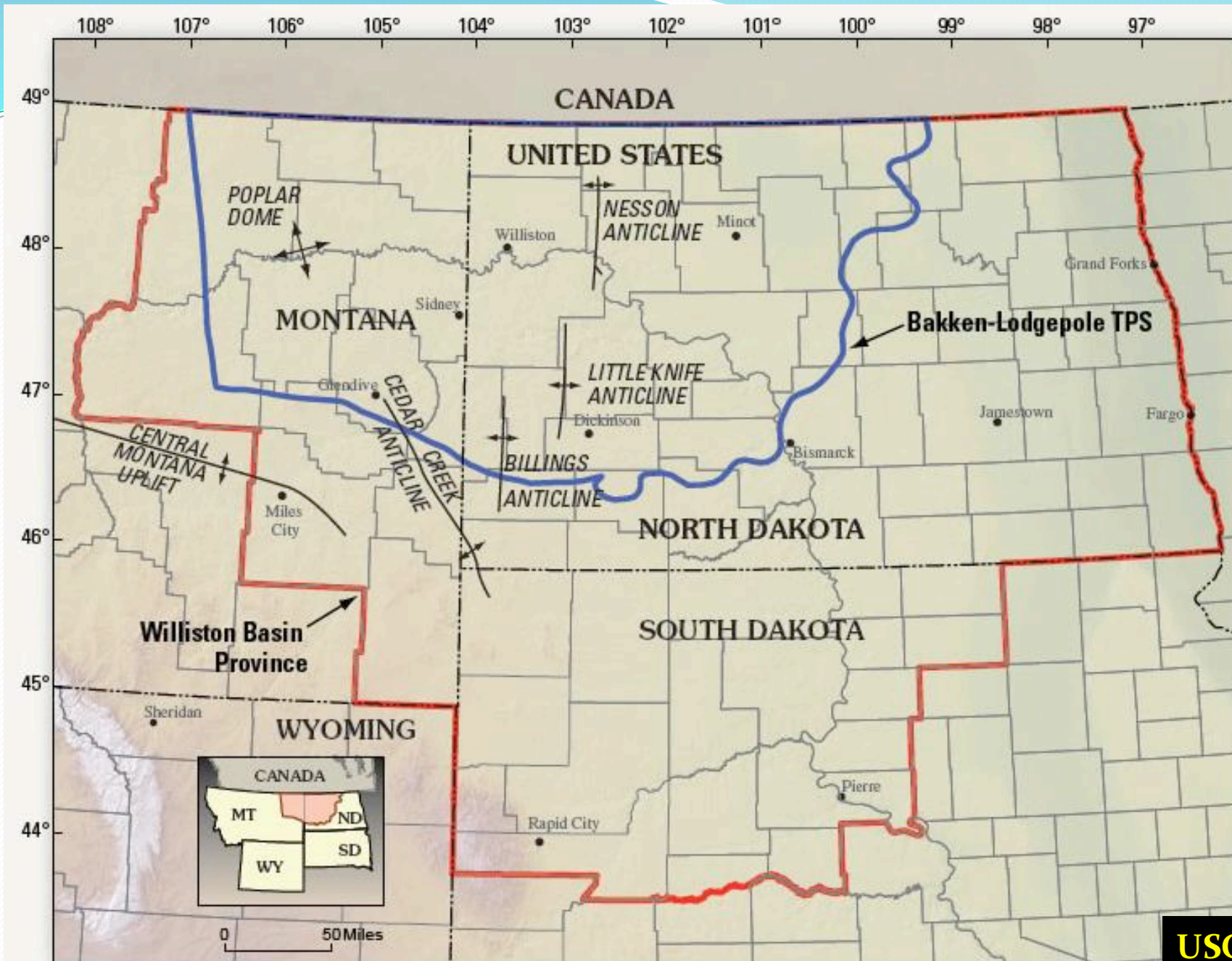
THE UNIVERSITY OF TEXAS AT AUSTIN

**JACKSON**

SCHOOL OF GEOSCIENCES

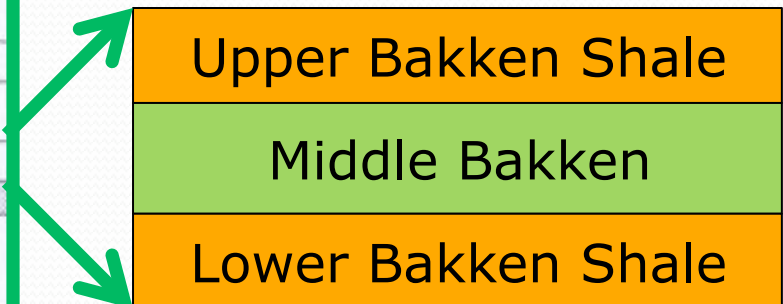
# Outline

- ❖ Introduction
- ❖ Well log analysis
- ❖ Seismic modeling
- ❖ Field data analysis
- ❖ Mechanical properties
- ❖ Summary

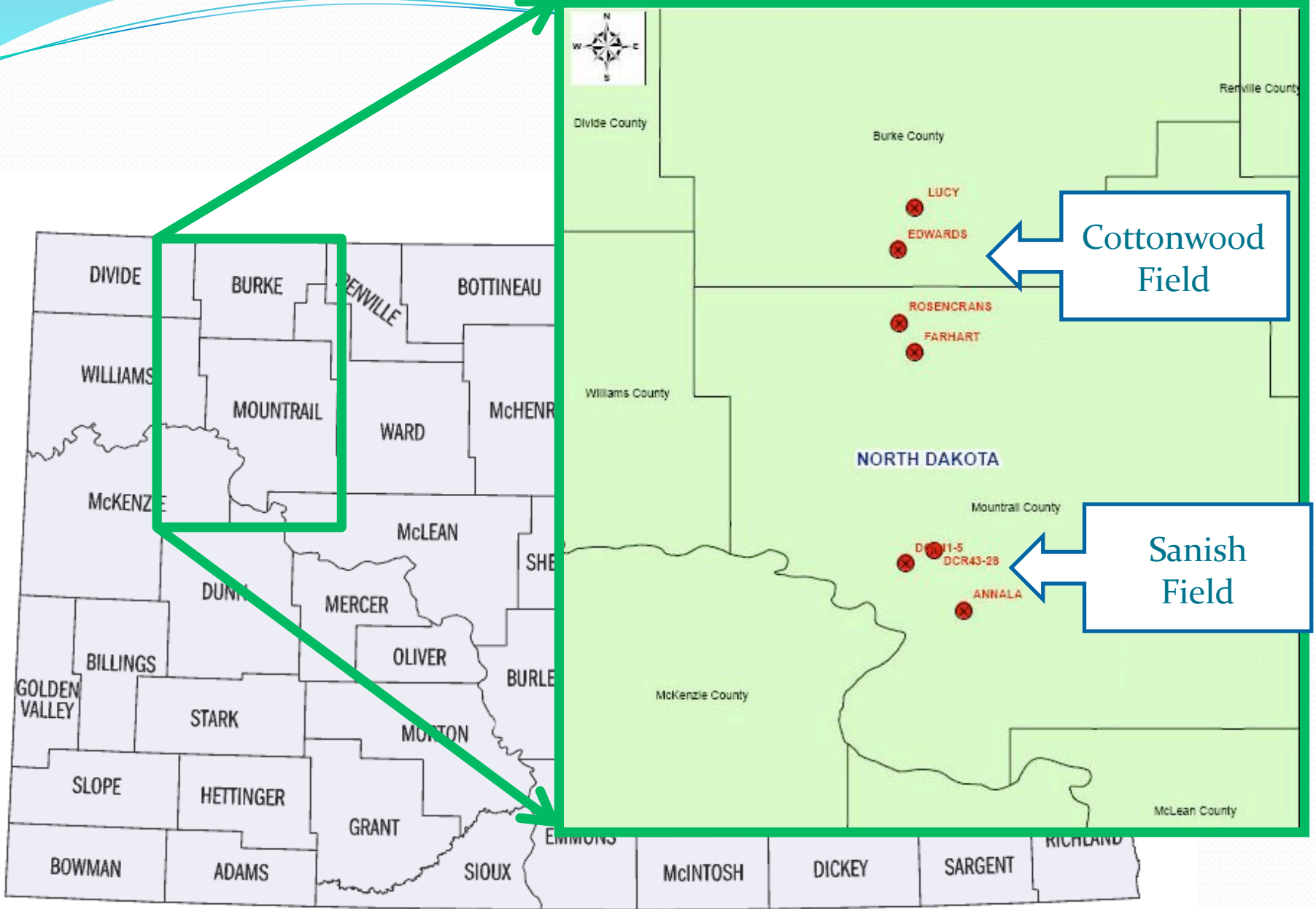


# Stratigraphy

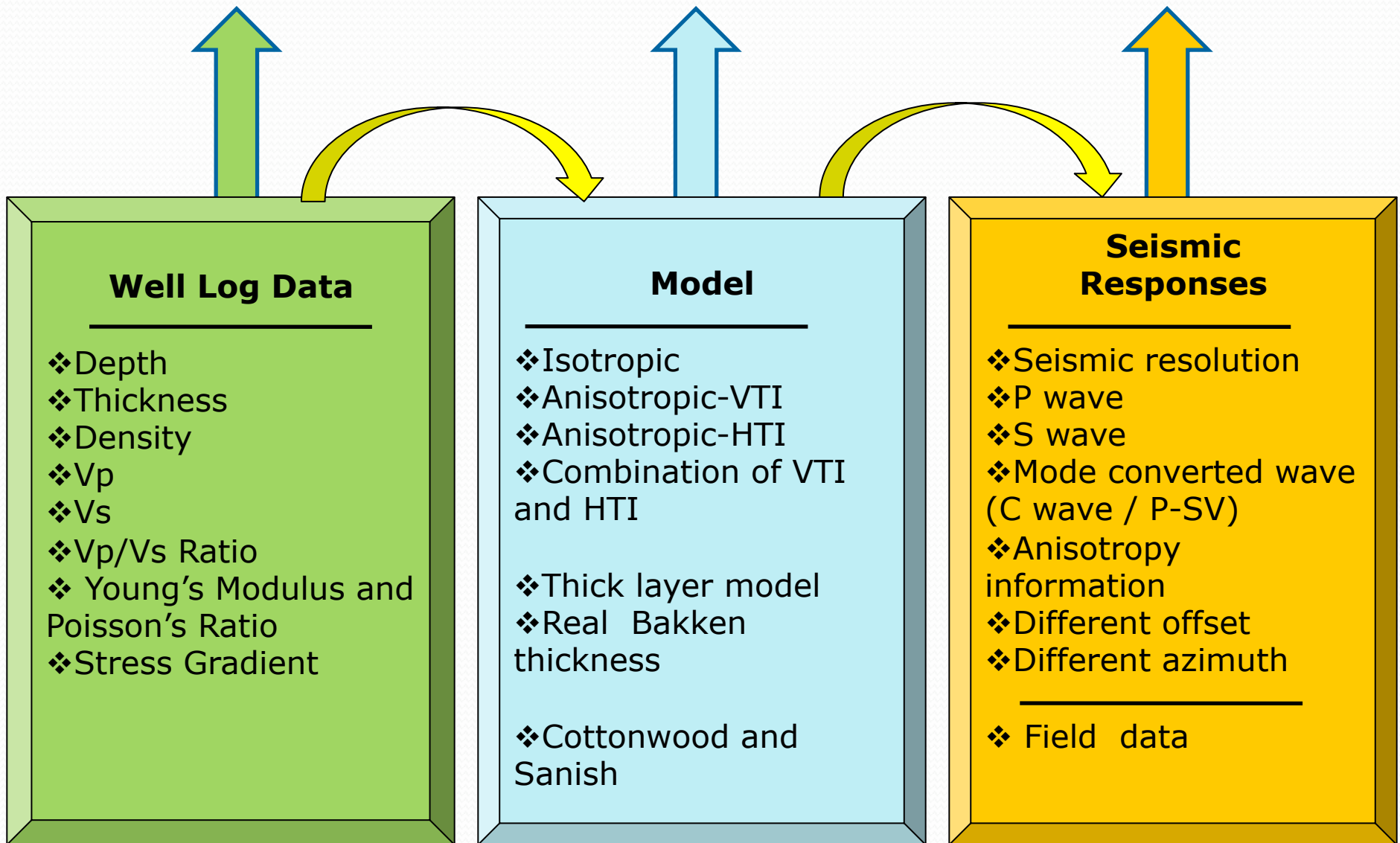
ERA	PERIOD	WILLISTON BASIN
PALEOZOIC	MISSISSIPPIAN	HEATH FM
		OTTER FM
		KIBBEY FM
		MADISON GP
		CHARLES FM
		MISSION CANYON LS
	DEVONIAN	LODGEPOLE LS
		BAKKEN FM
		THREE FORKS FM
		JEFFERSON GP
		BIRDBEAR (NISKU) FM
		DUPEROW FM
		SOURIS RIVER FM
		DAWSON BAY FM
		ELK POINT GP
PRAIRIE EVAPORITE		
WINNIPEGOSIS FM		
ASHERN		



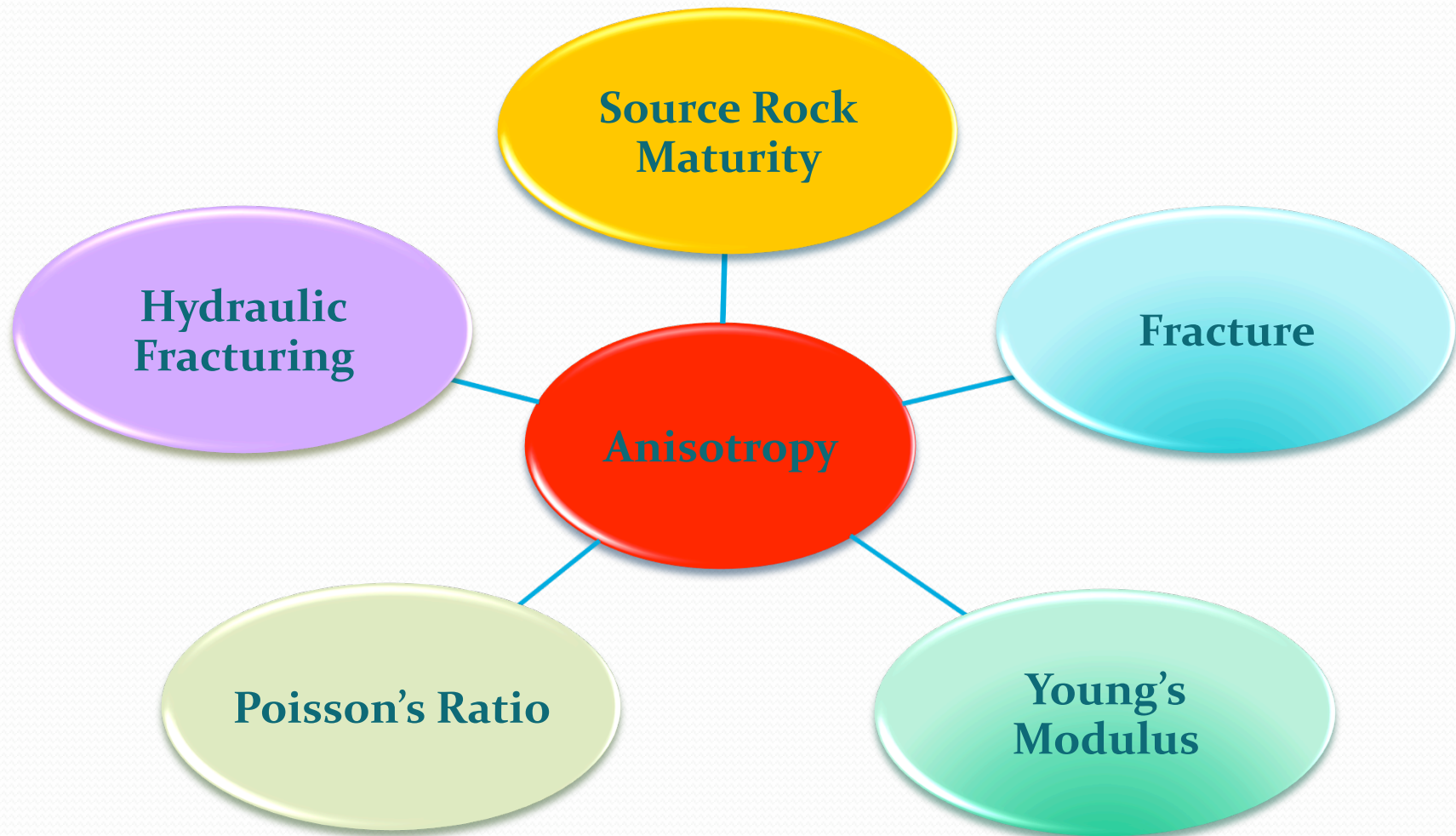
Modified from Montana Board of Oil and Gas



# Identify seismically observable characteristics of the Bakken Shale associated with the productivity

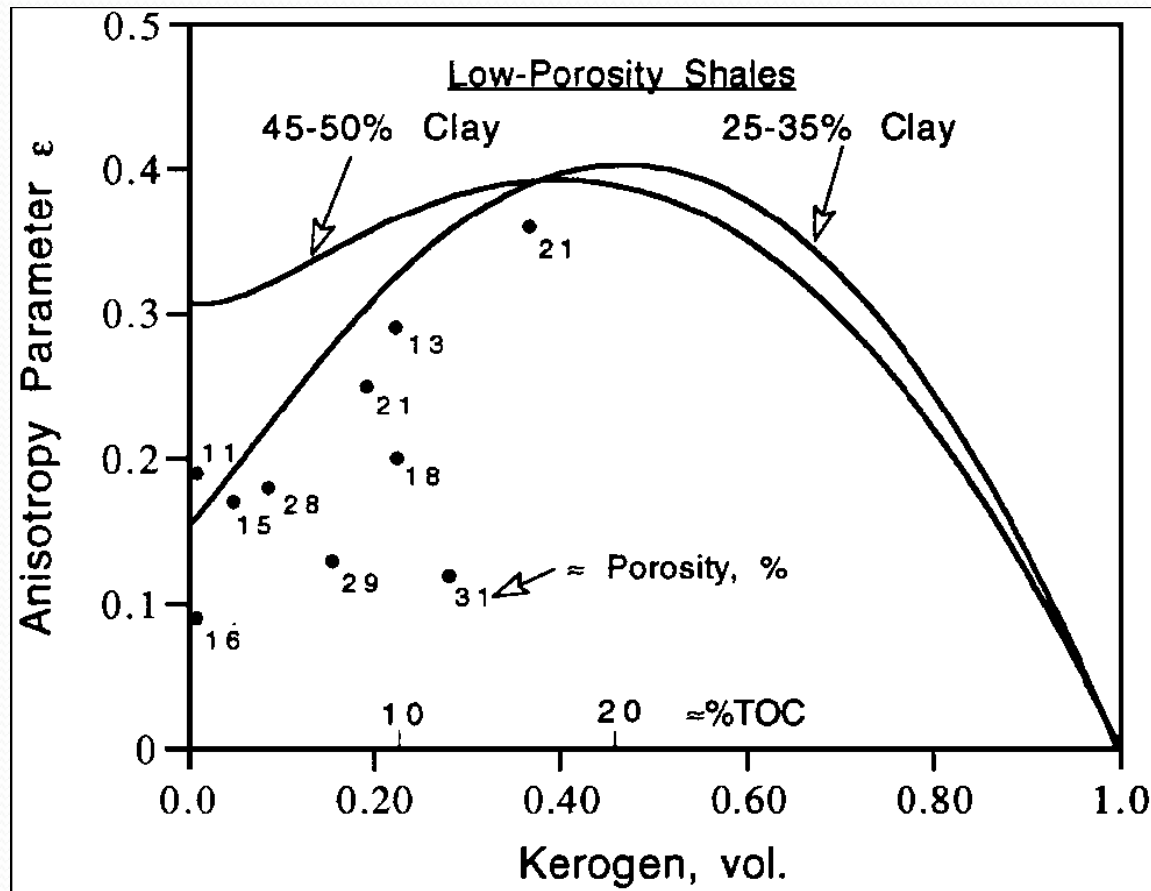


# Why do we care about anisotropy?



## Productivity

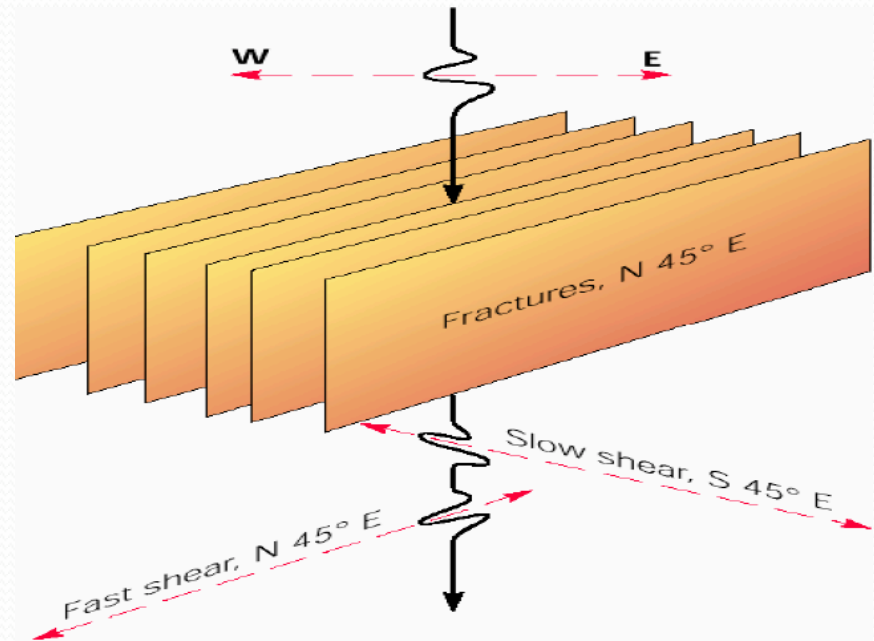
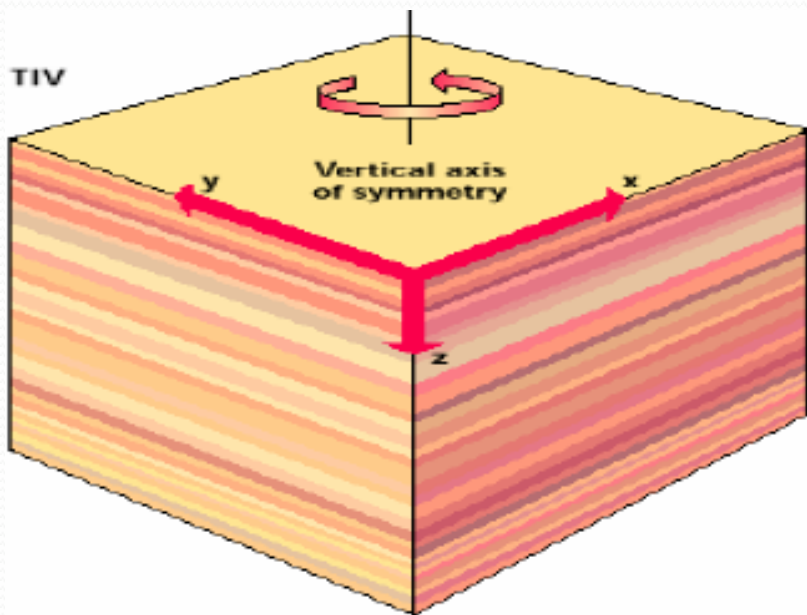
# Anisotropy and Kerogen Content



Vernik & Liu, 1997: "Anisotropy of shales dramatically increases with kerogen reaching the maximum values of about 0.4 at total organic carbon (TOC) = 15-20%."



# Transversely Isotropic – VTI & HTI

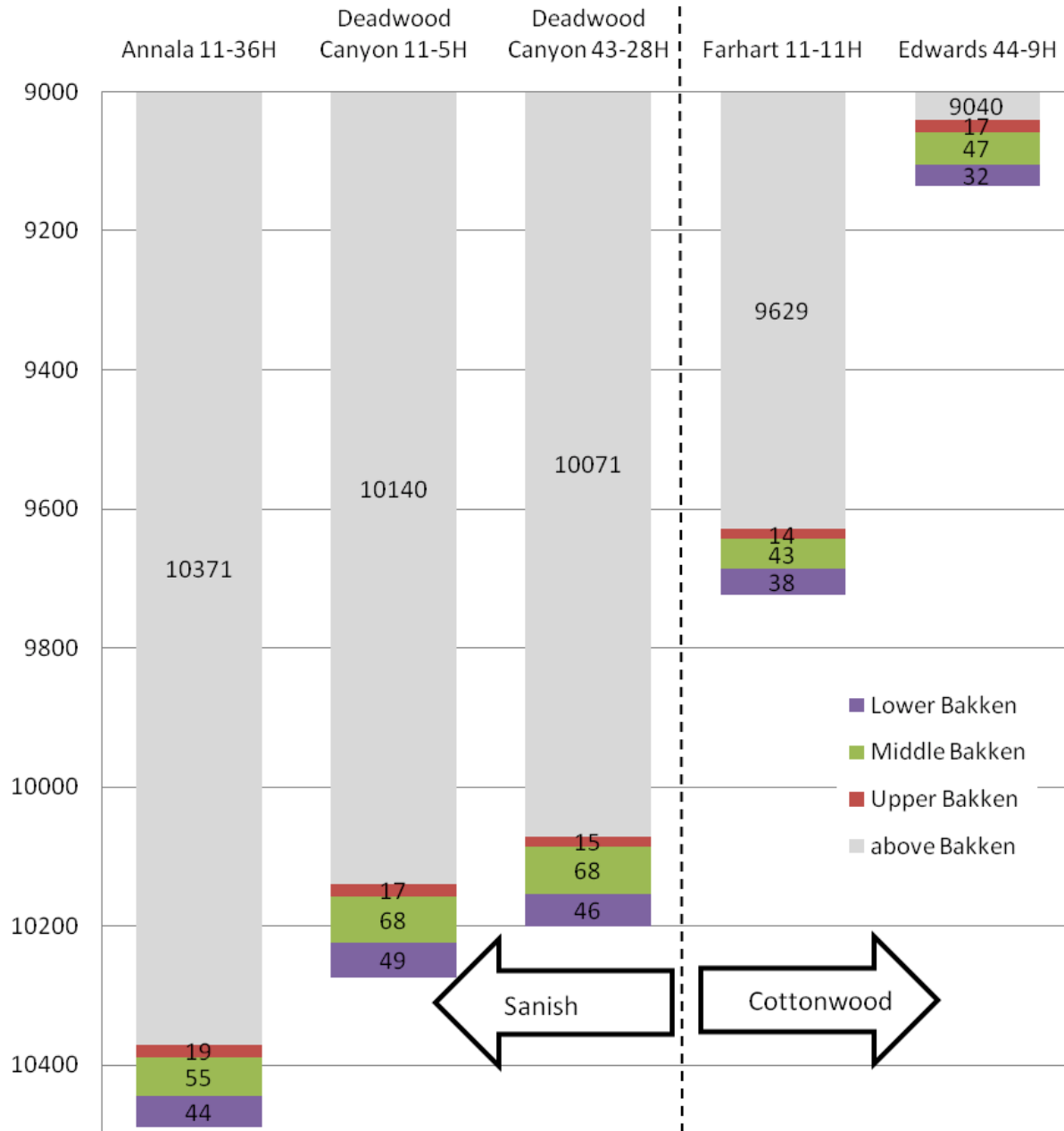


Schlumberger

# Outline

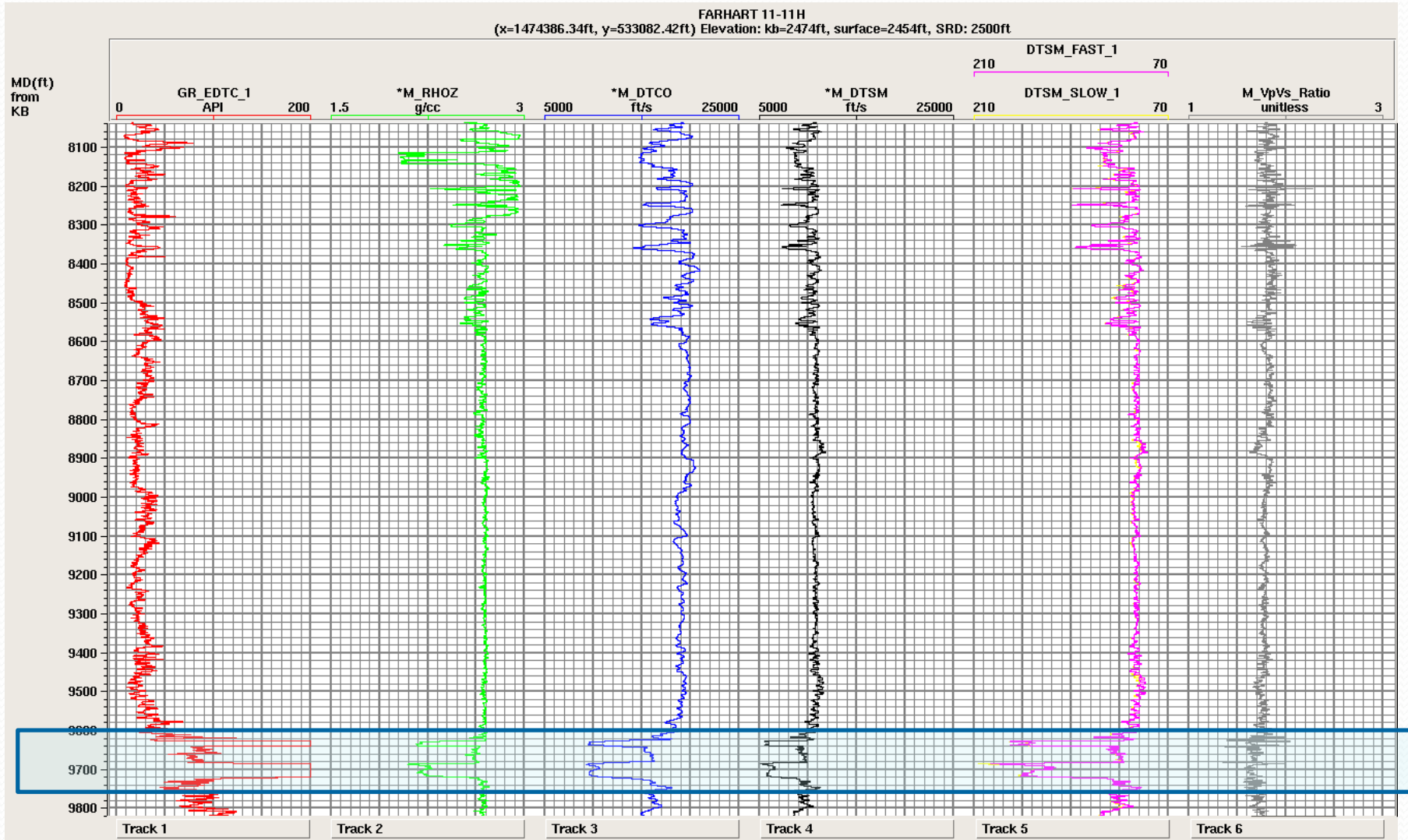
- ❖ Introduction
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## Depth and Thickness of the Bakken

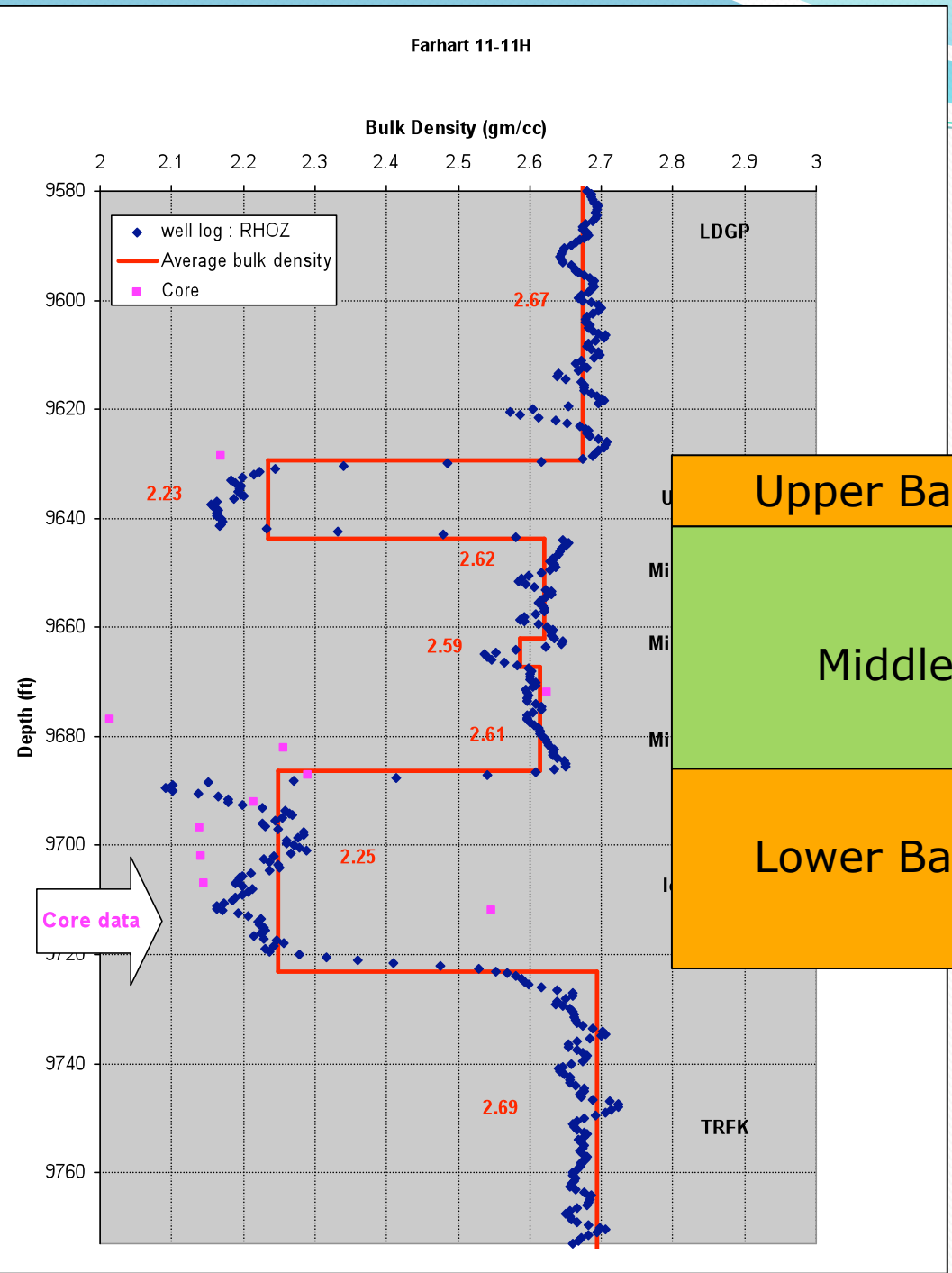


## Depth and thickness

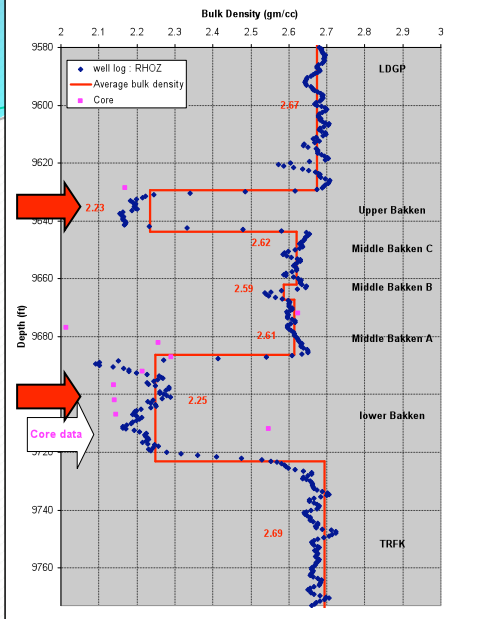
Well	Depth (ft)	Bakken Thickness (ft)
Annala 11-36H	10371	119
DCR 11-5H	10140	134
DCR 43-28H	10071	129
Farhart 11-11H	9629	95
Edwards 44-9H	9040	96



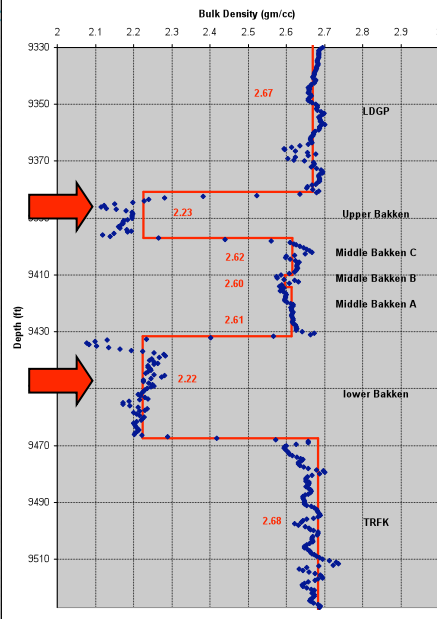
# Density



## Farhart 11-11H



## Rosencrans 44-21H

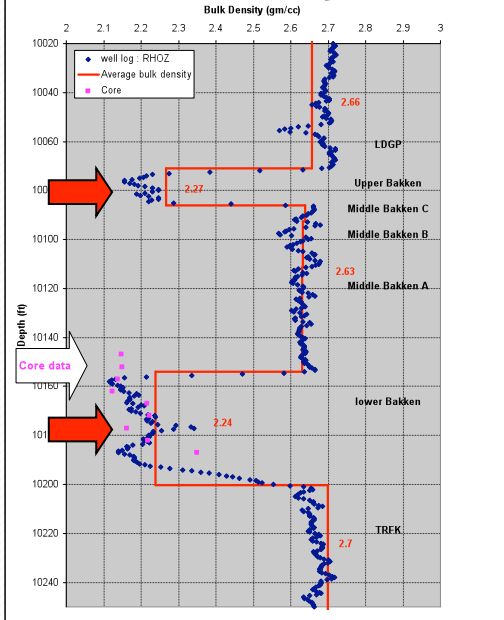


# Density

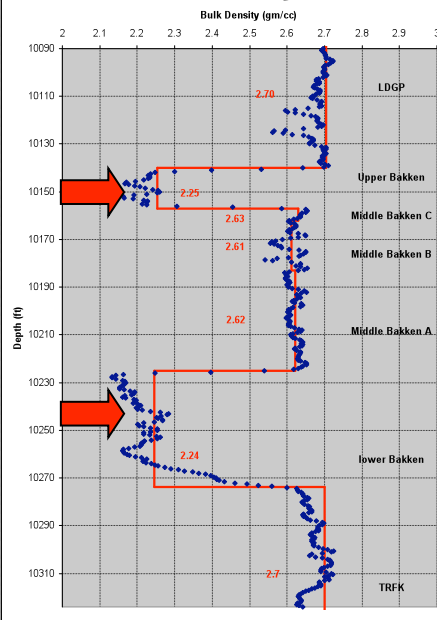
### Average Density (gm/cc)

Upper Bakken Shale: 2.24  
 Middle Bakken: 2.62  
 Lower Bakken Shale: 2.24

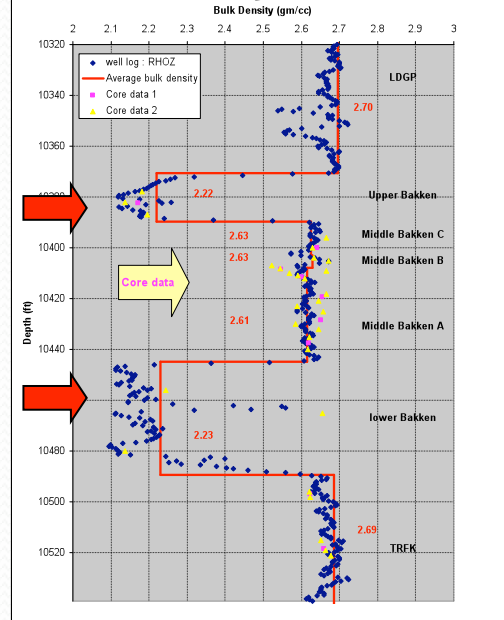
## DCR 43-28H



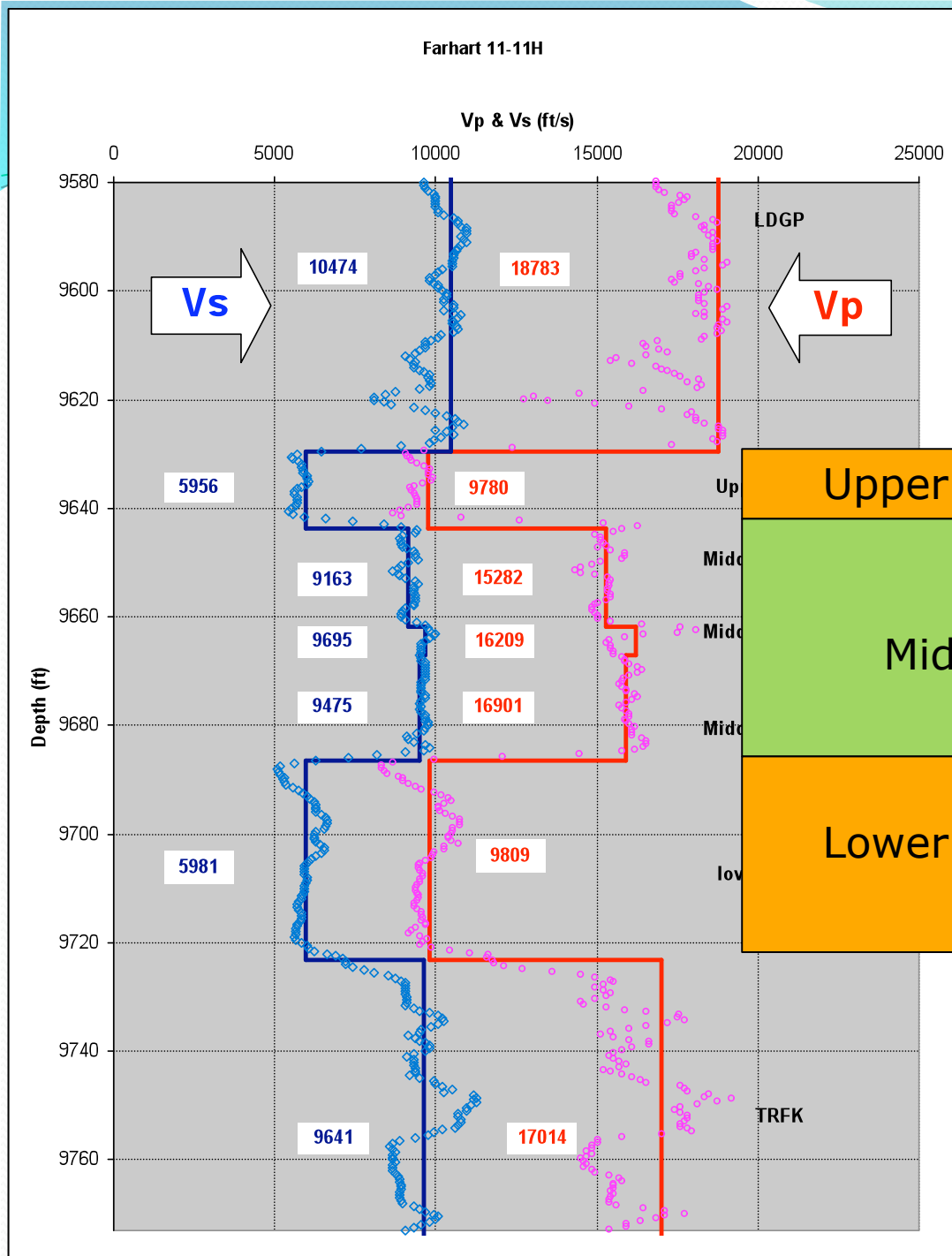
## DCR 11-5H



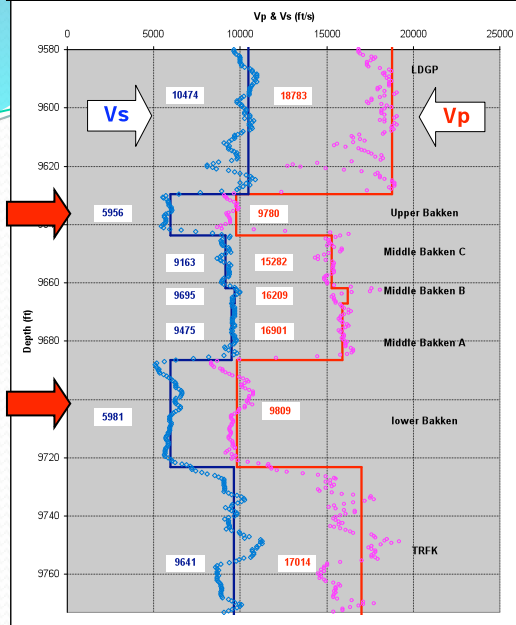
## Annala 11-36H



# P-wave and S-wave Velocity



## Farhart 11-11H



# P-wave and S-wave Velocity

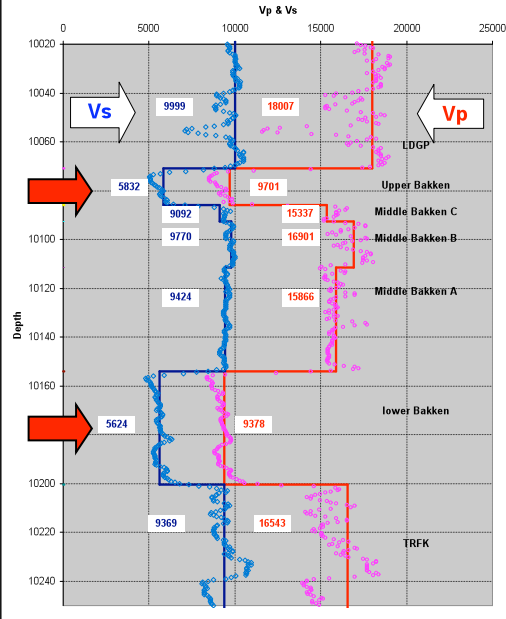
### ❖ Bakken Shales : Low P and S velocity

- Vp: ~9500ft/s
- Vs: ~5700ft/s

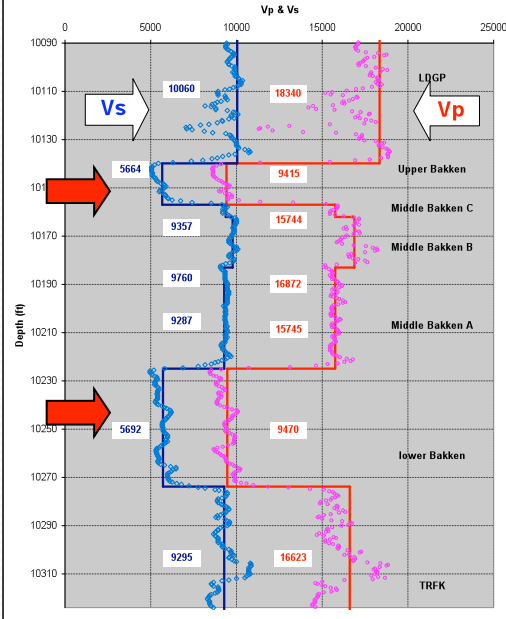
### ❖ Middle Bakken :

- Vp: ~16000ft/s
- Vs: ~9400ft/s

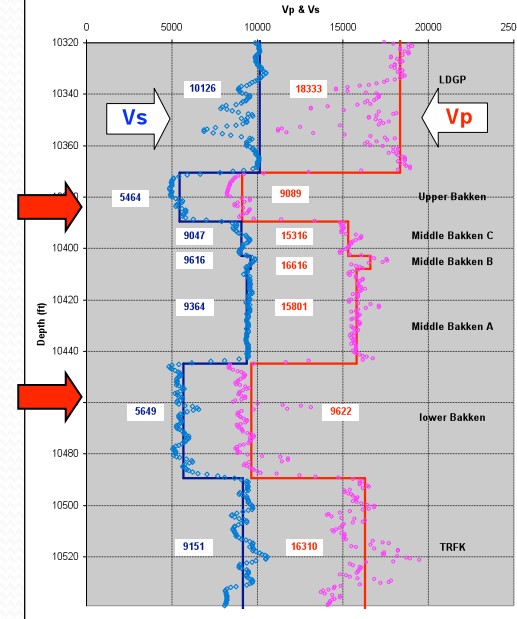
## DCR 43-28H



## DCR 11-5H

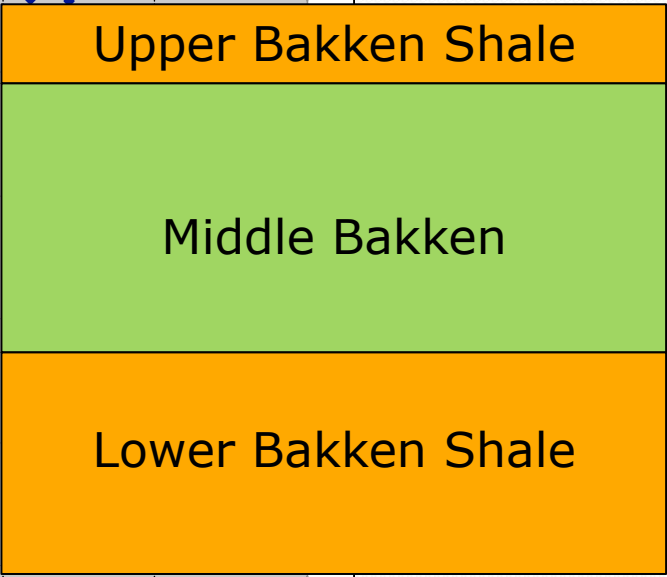
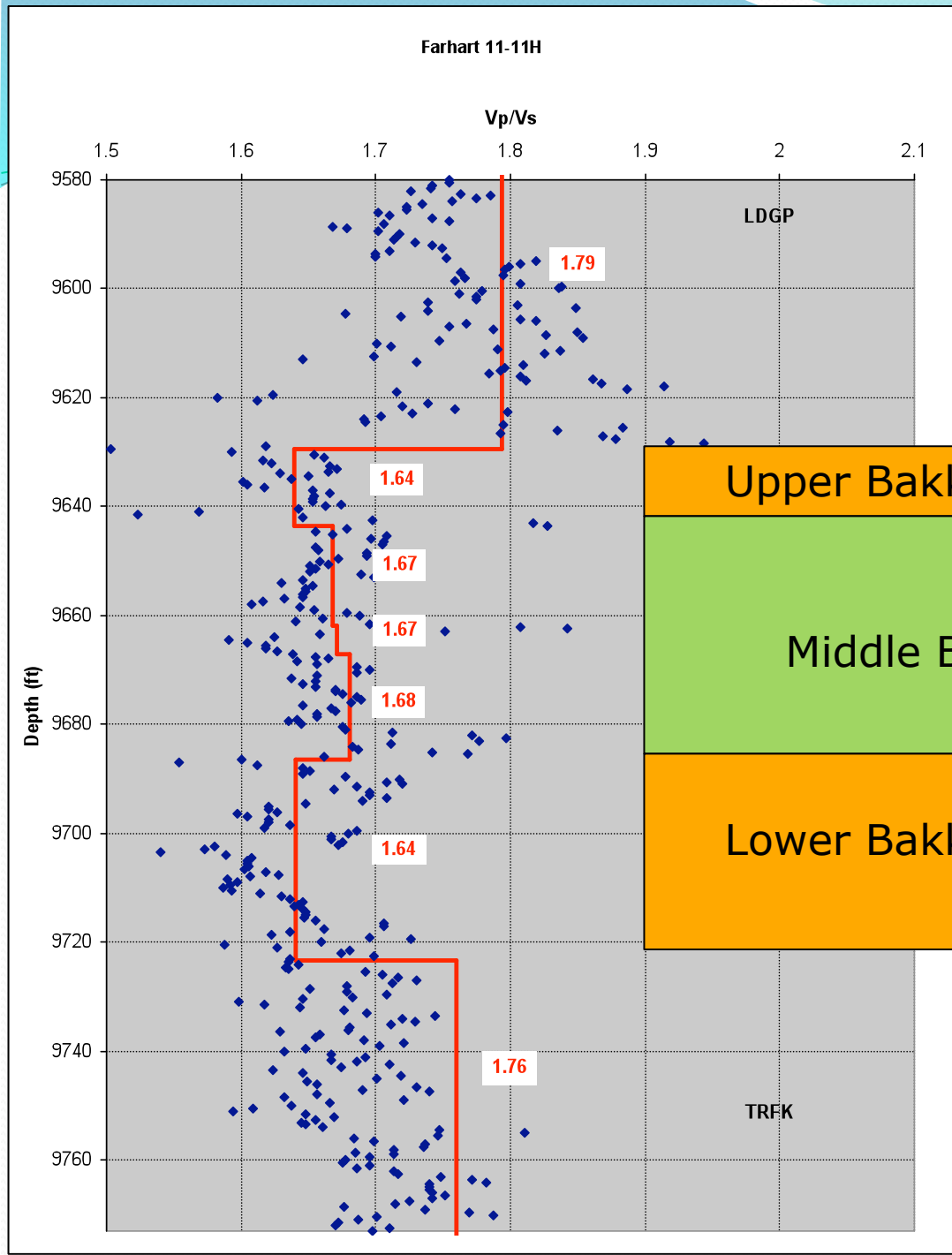


## Annala 11-36H

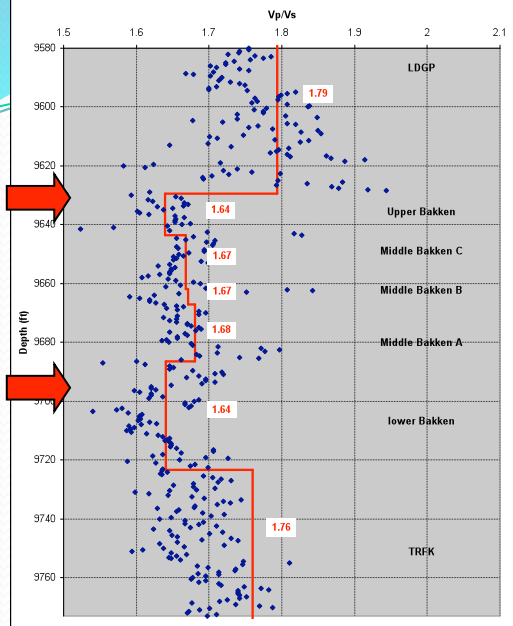




# Vp / Vs



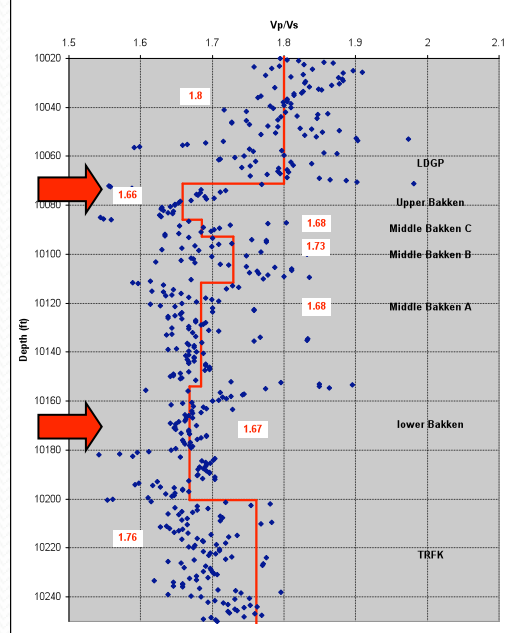
# Farhart 11-11H



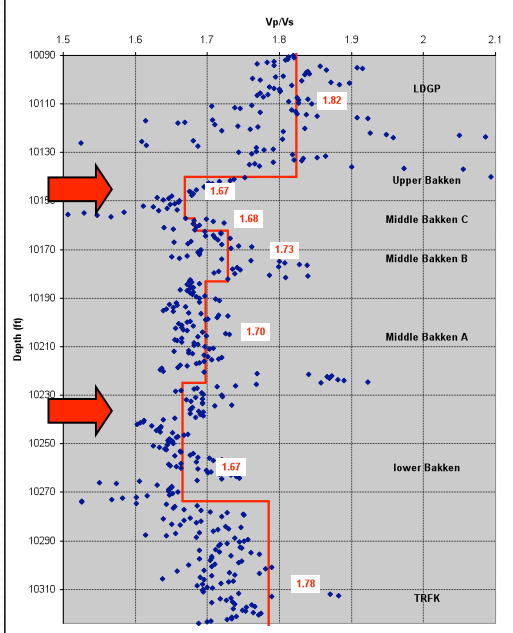
# Vp / Vs

❖ Bakken Shale : Low Vp/Vs

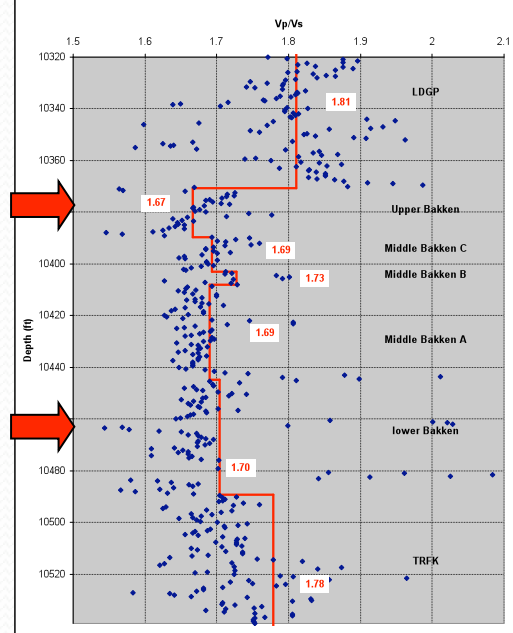
# DCR 43-28H



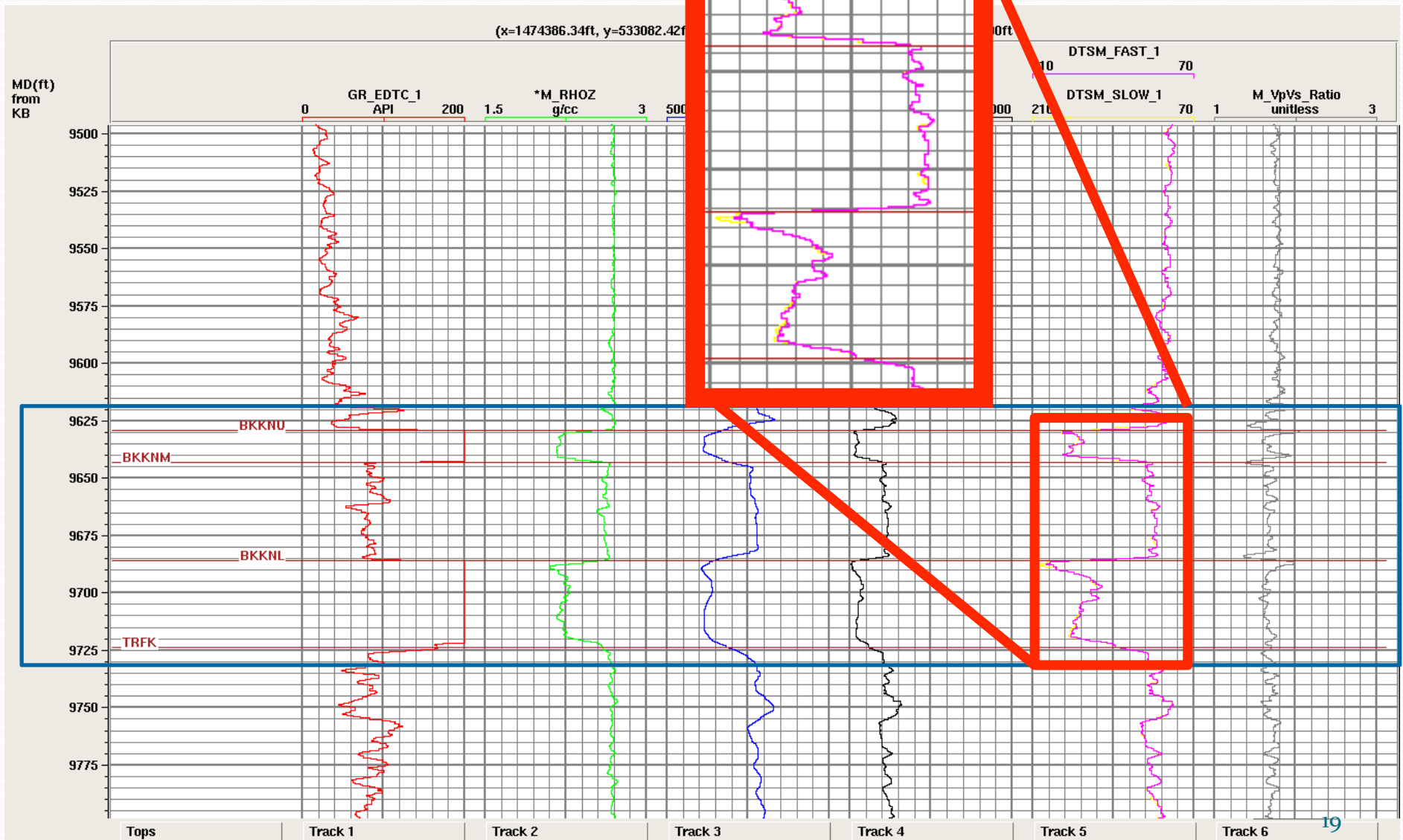
# DCR 11-5H



# Annala 11-36H



# Fast Shear and Slow Shear ?



# Young's Modulus and Poisson's Ratio

		Young's Modulus					Poisson's Ratio				
		Horizontal / Vertical					Horizontal / Vertical				
		Rosencrans 44-21H	Farhart 11-11H	DCR 43-28H	DCR 11-5H	Annala 11-36H	Rosencrans 44-21H	Farhart 11-11H	DCR 43-28H	DCR 11-5H	Annala 11-36H
<b>Upper Bakken Shale</b>		1.62	1.52	1.74	1.47	1.52	0.5	0.59	0.5	0.6	0.58
<b>Middle Bakken</b>	<b>C</b>	1.00	1.04	1.20	1.04	0.98	0.99	0.95	0.79	0.94	1.02
	<b>B</b>	0.93	0.97	1.12	1.05	0.98	1.09	1.04	0.84	0.93	1.03
	<b>A</b>	1.01	1.02	1.08	1.02	1.09	0.94	0.98	0.91	0.97	0.89
<b>Lower Bakken Shale</b>		1.64	1.55	1.67	1.60	1.60	0.52	0.58	0.54	0.55	0.54

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# Thick Model

100 m

100 m

100 m

Isotropic

VTI

HTI

VTI + HTI

Upper Bakken Shale

Middle Bakken

Lower Bakken Shale

# Real Thickness

4.4 m

13.0 m

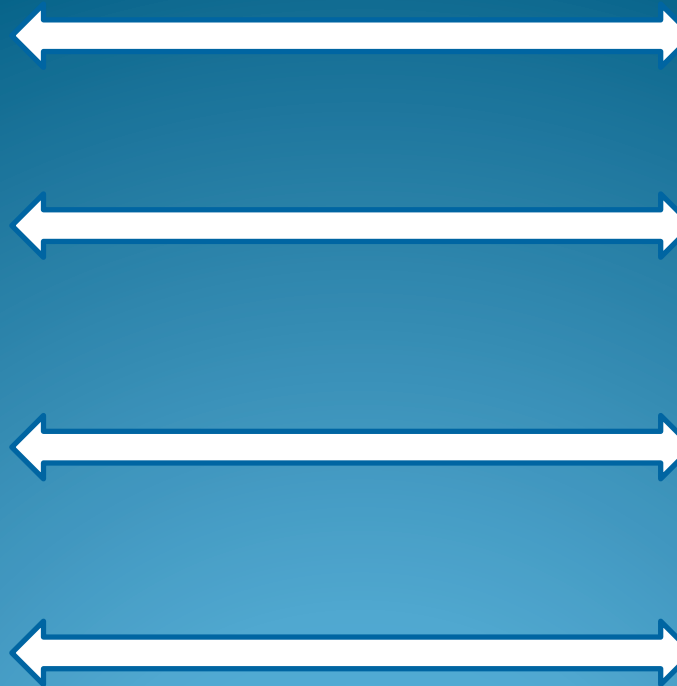
11.2 m

Isotropic

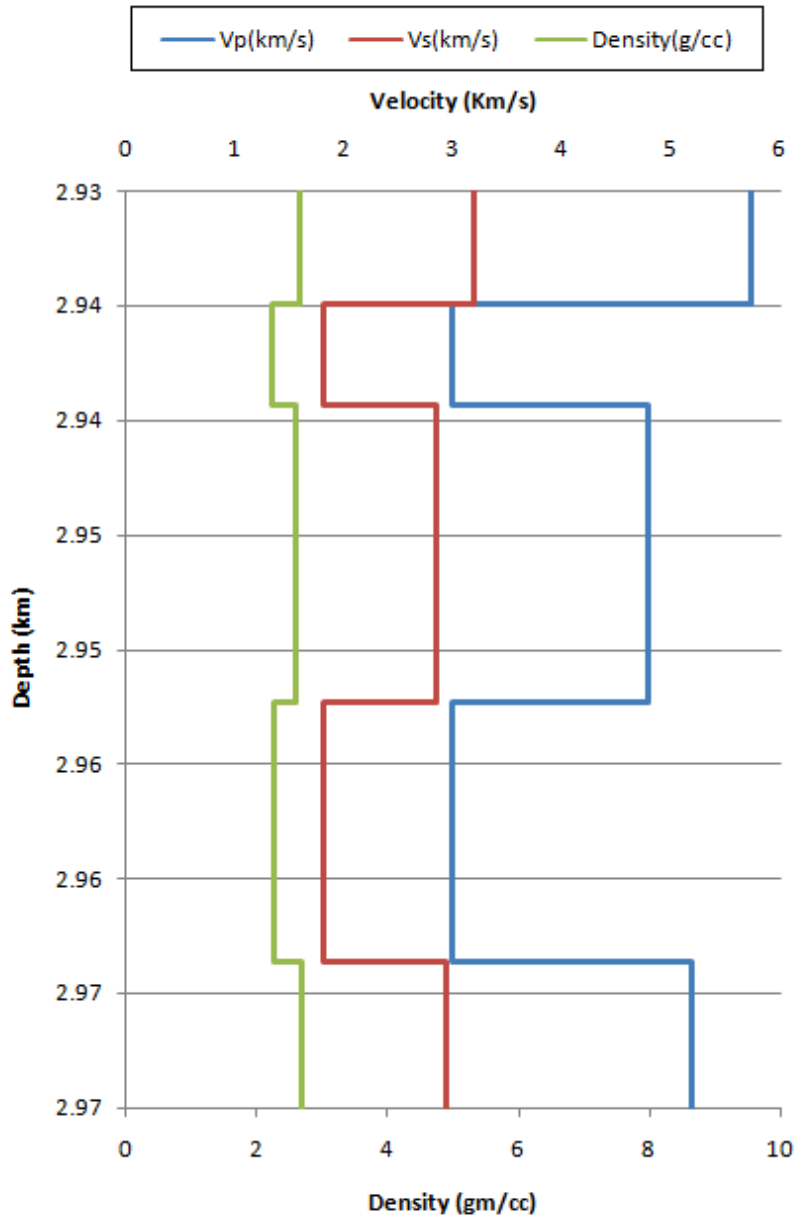
VTI

HTI

VTI + HTI

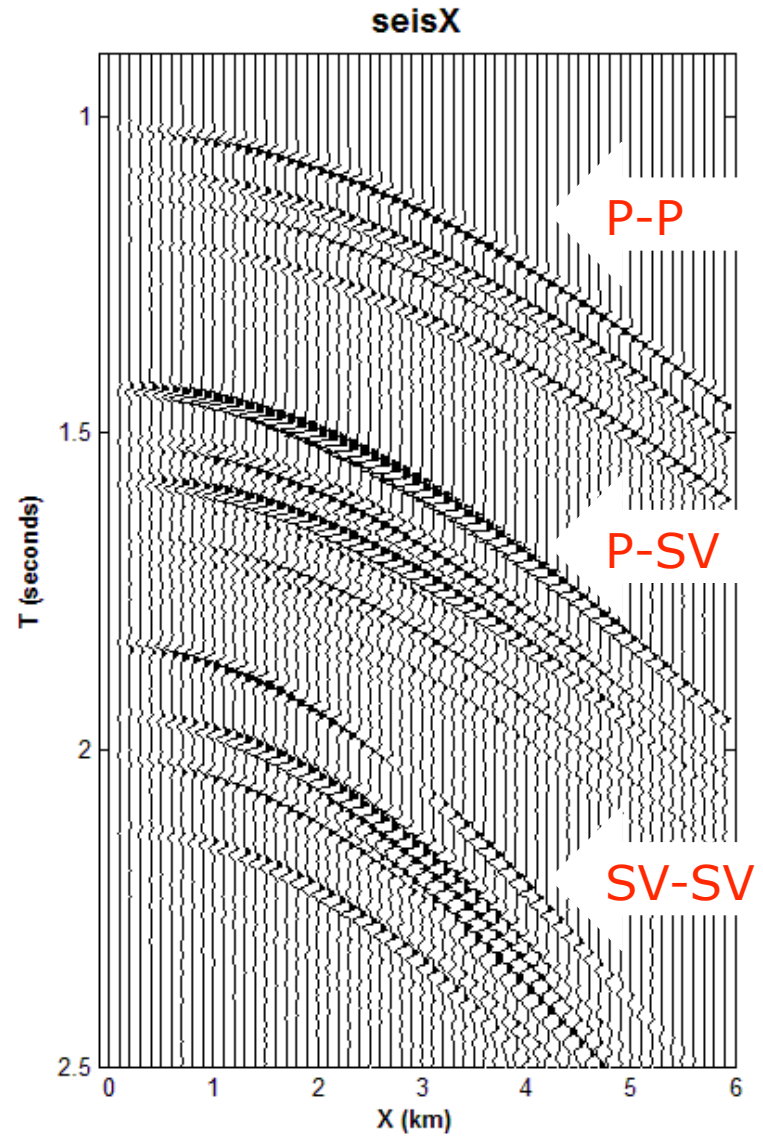
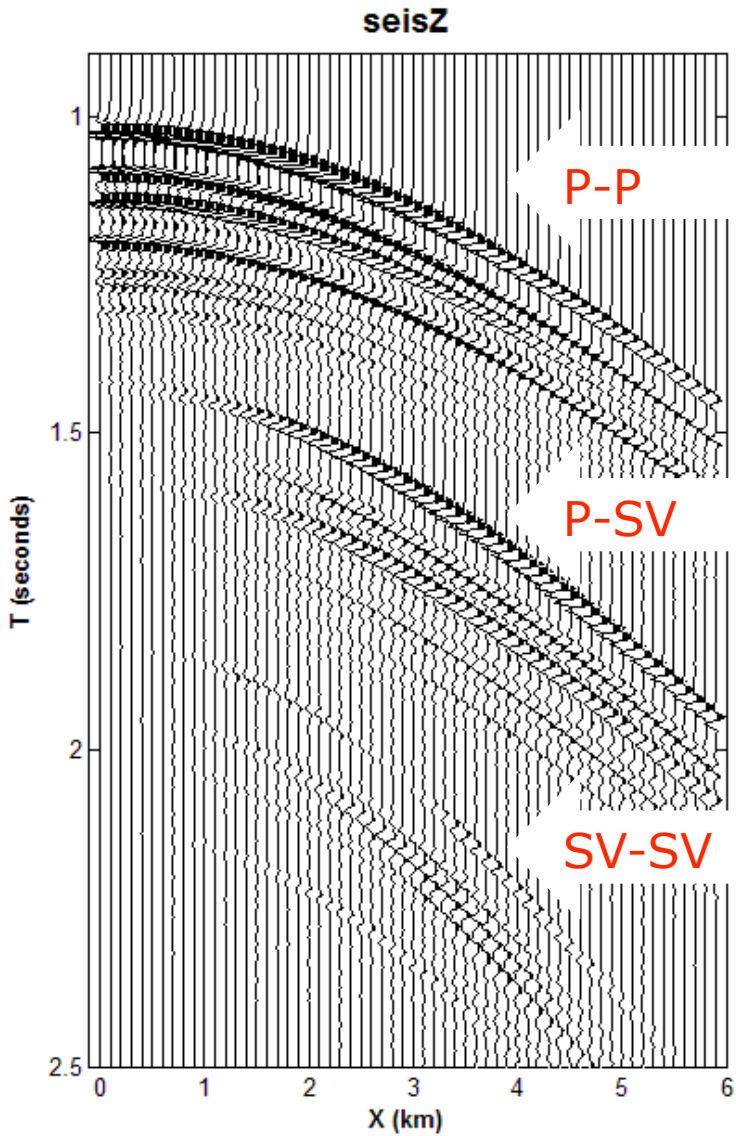


# Modeling Step 1: Isotropic



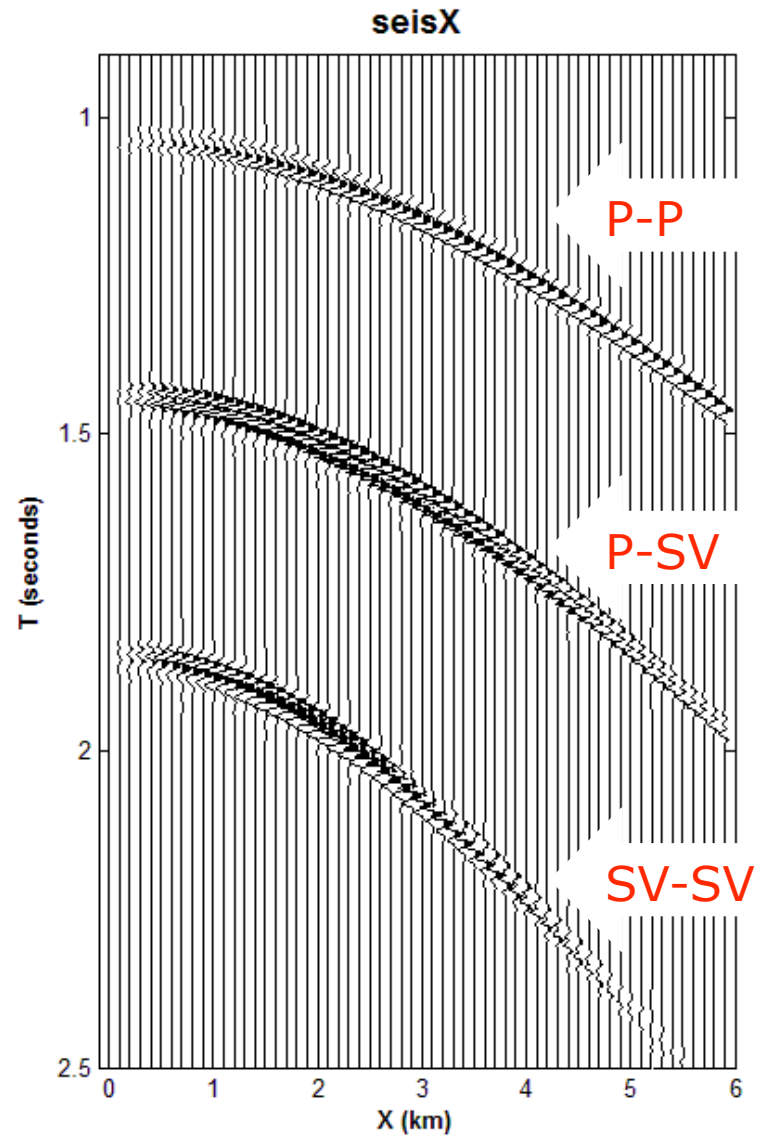
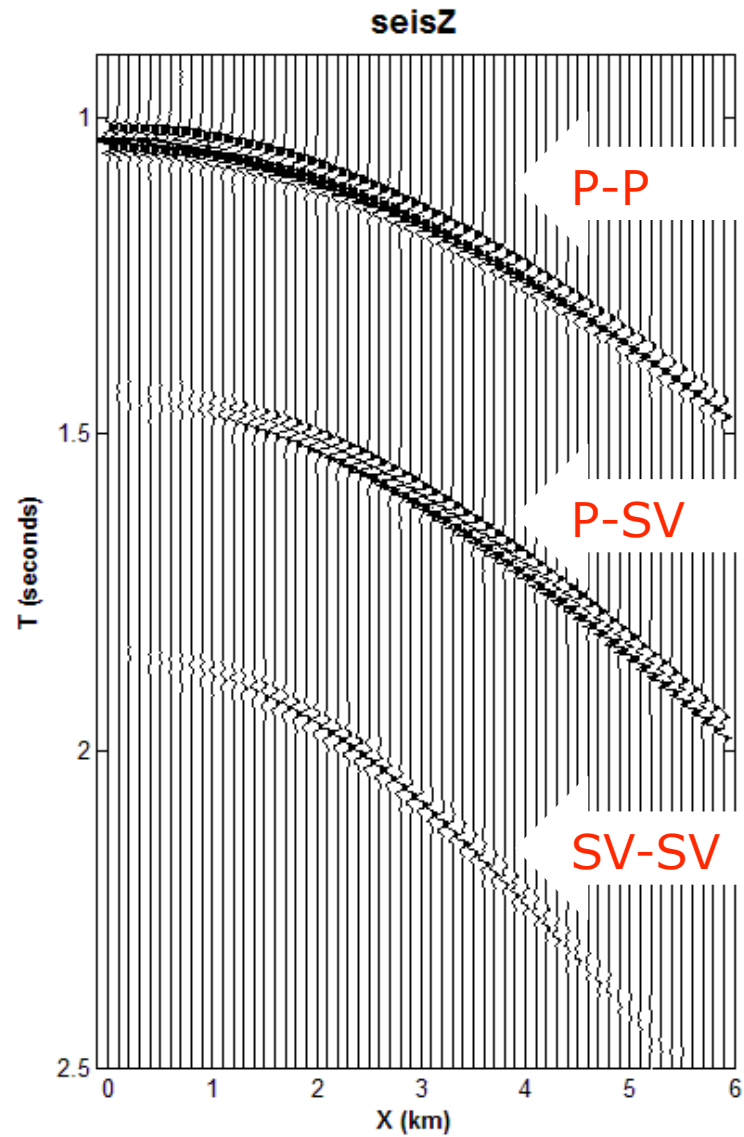
Above	Isotropic
Upper Bakken Shale	Isotropic
Middle Bakken	Isotropic
Lower Bakken Shale	Isotropic
Below	Isotropic

# Thick Model

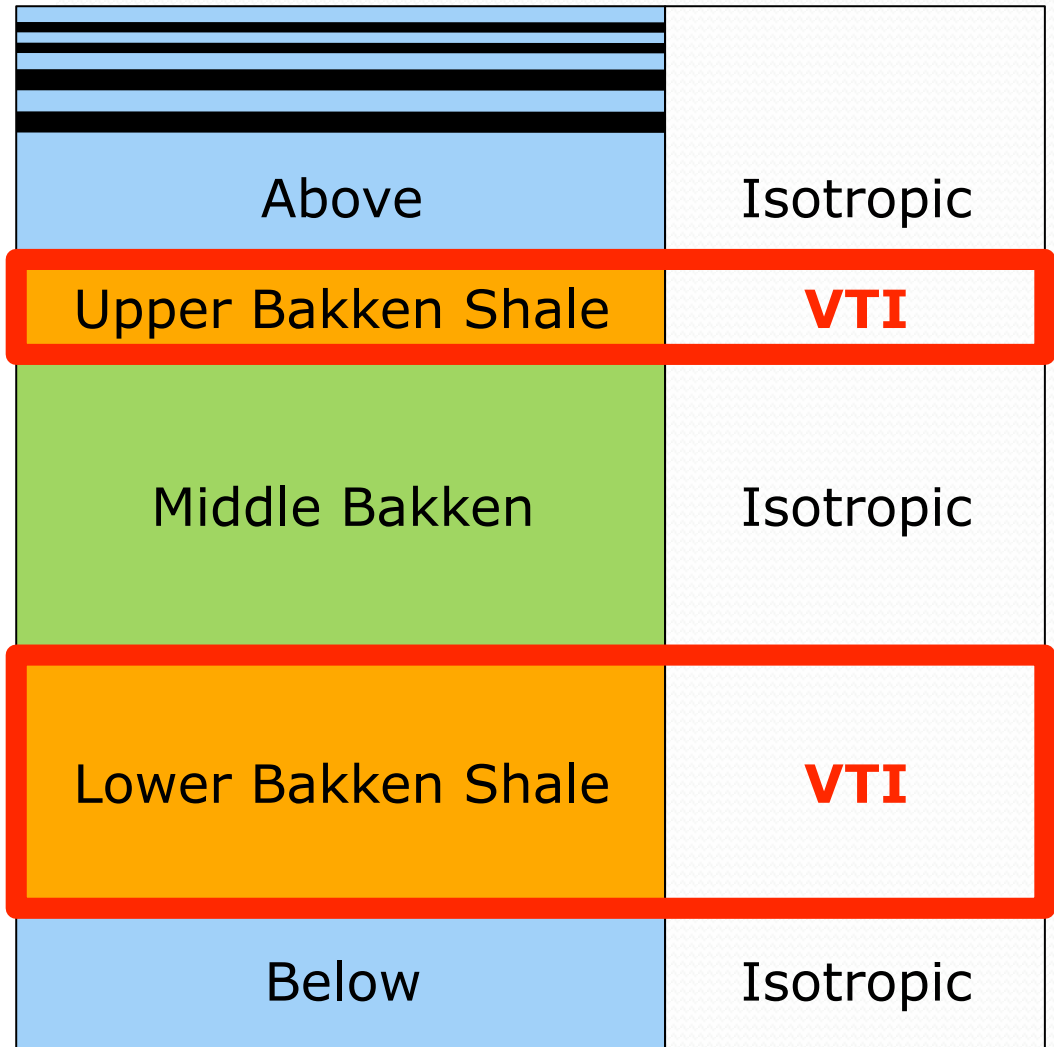
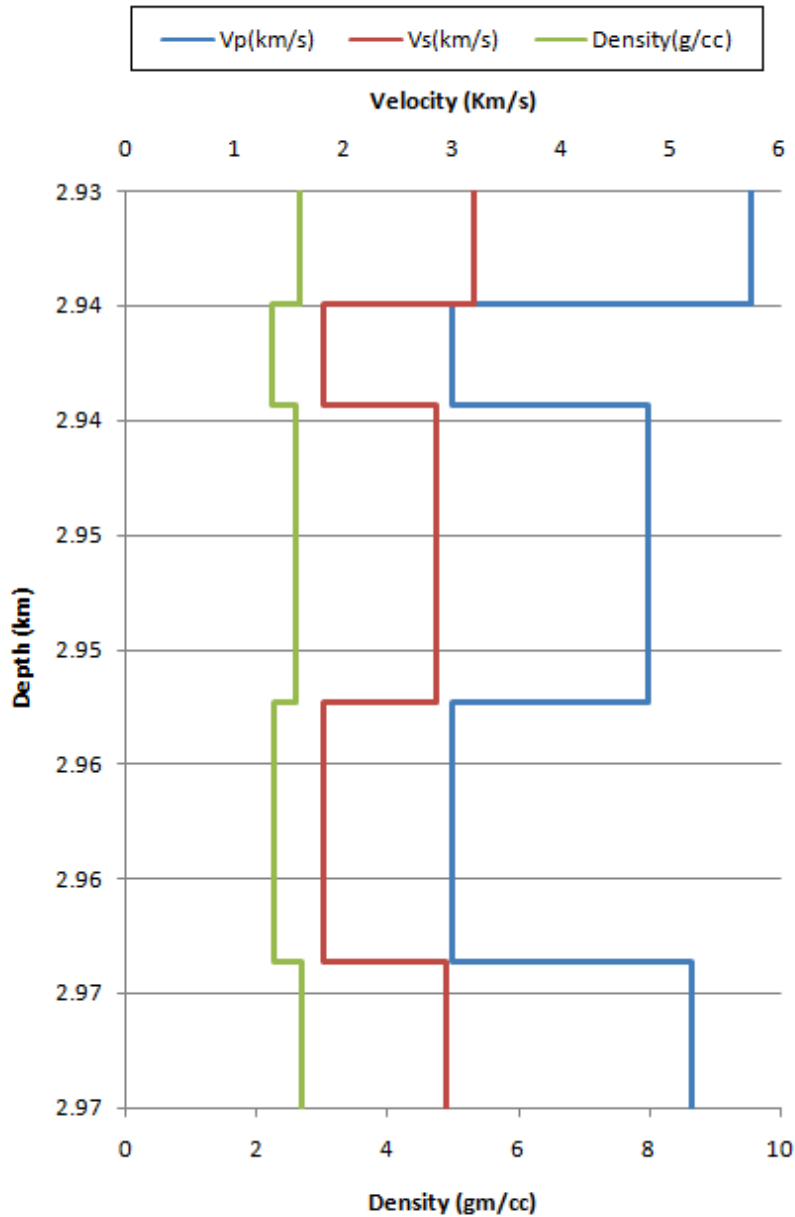




# Real Bakken Thickness



# Modeling Step 2: Anisotropic-VTI



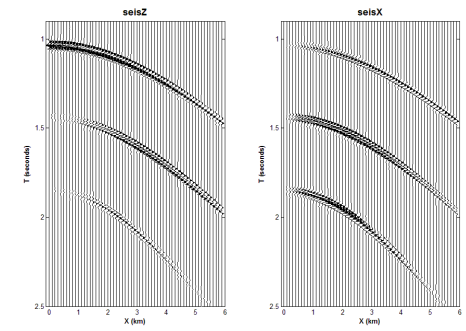
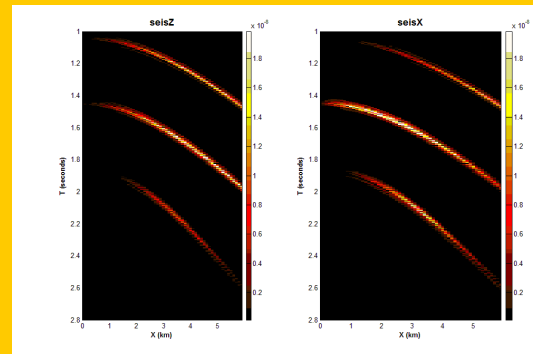
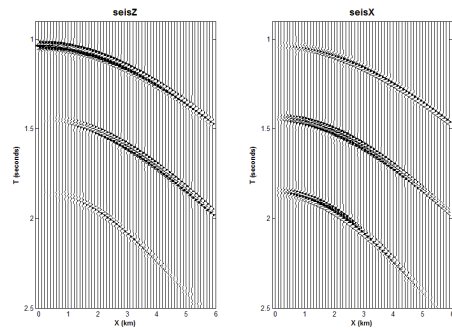
Isotropic  
Response



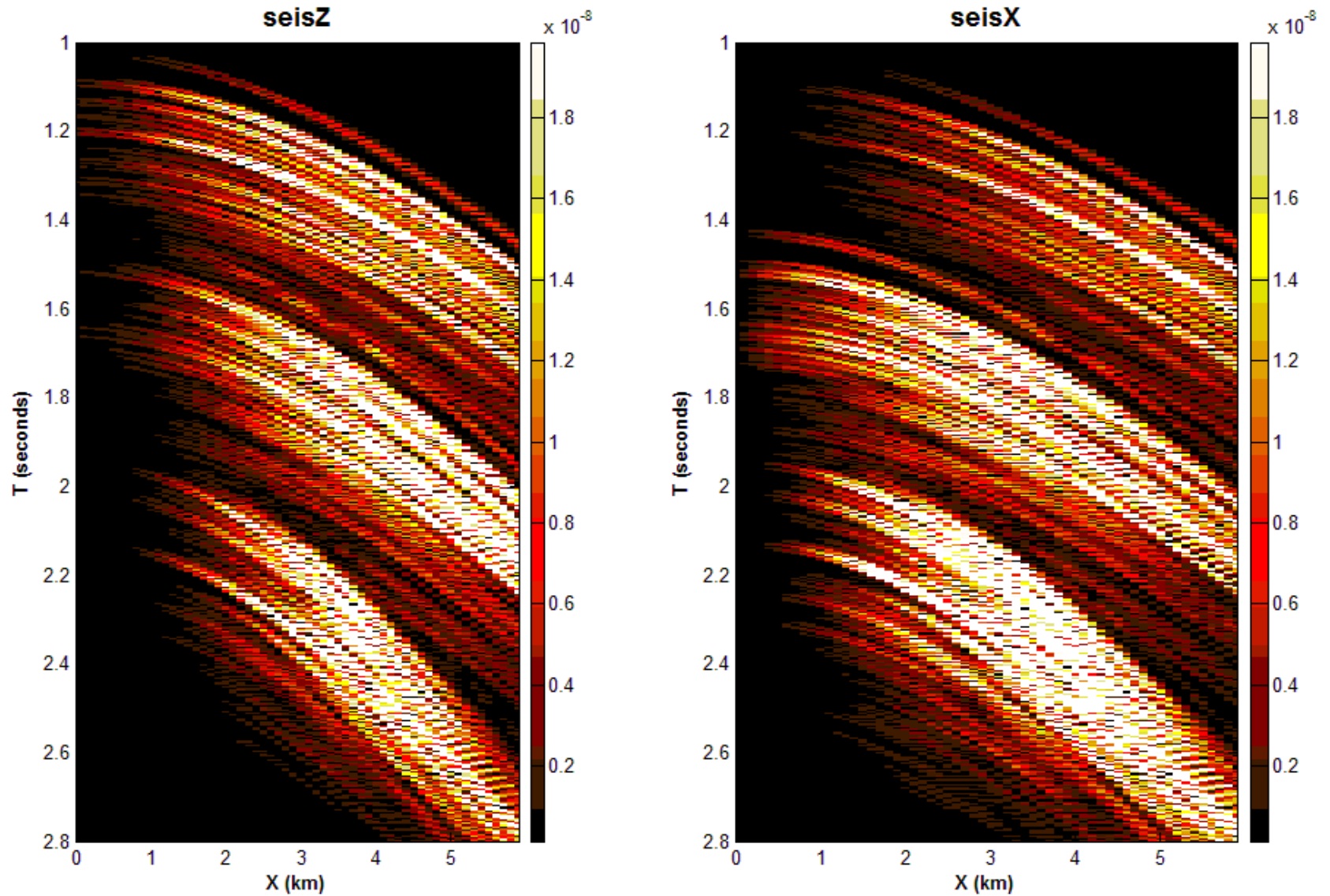
Anisotropy  
Information



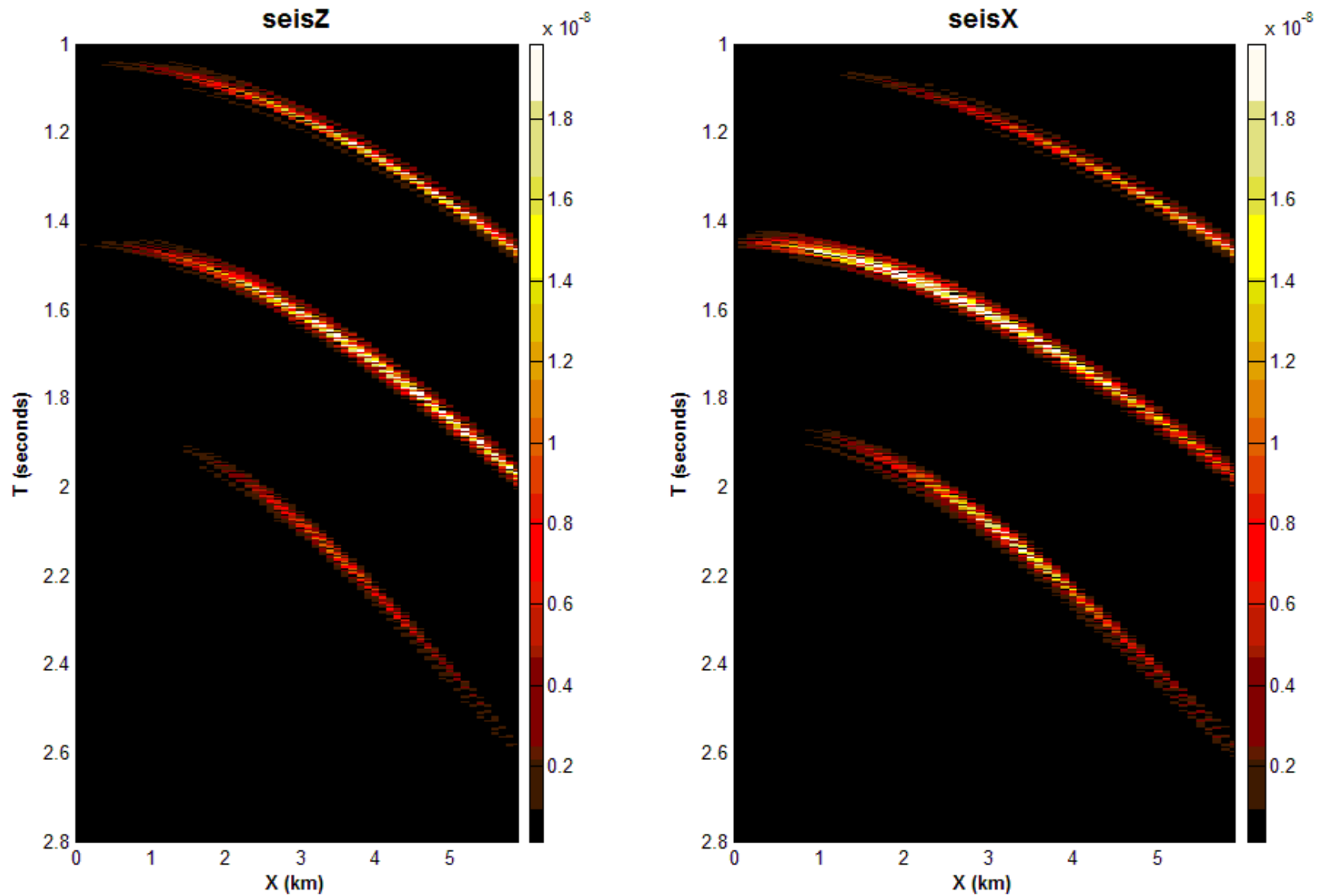
Total  
Anisotropic  
Seismic  
Response



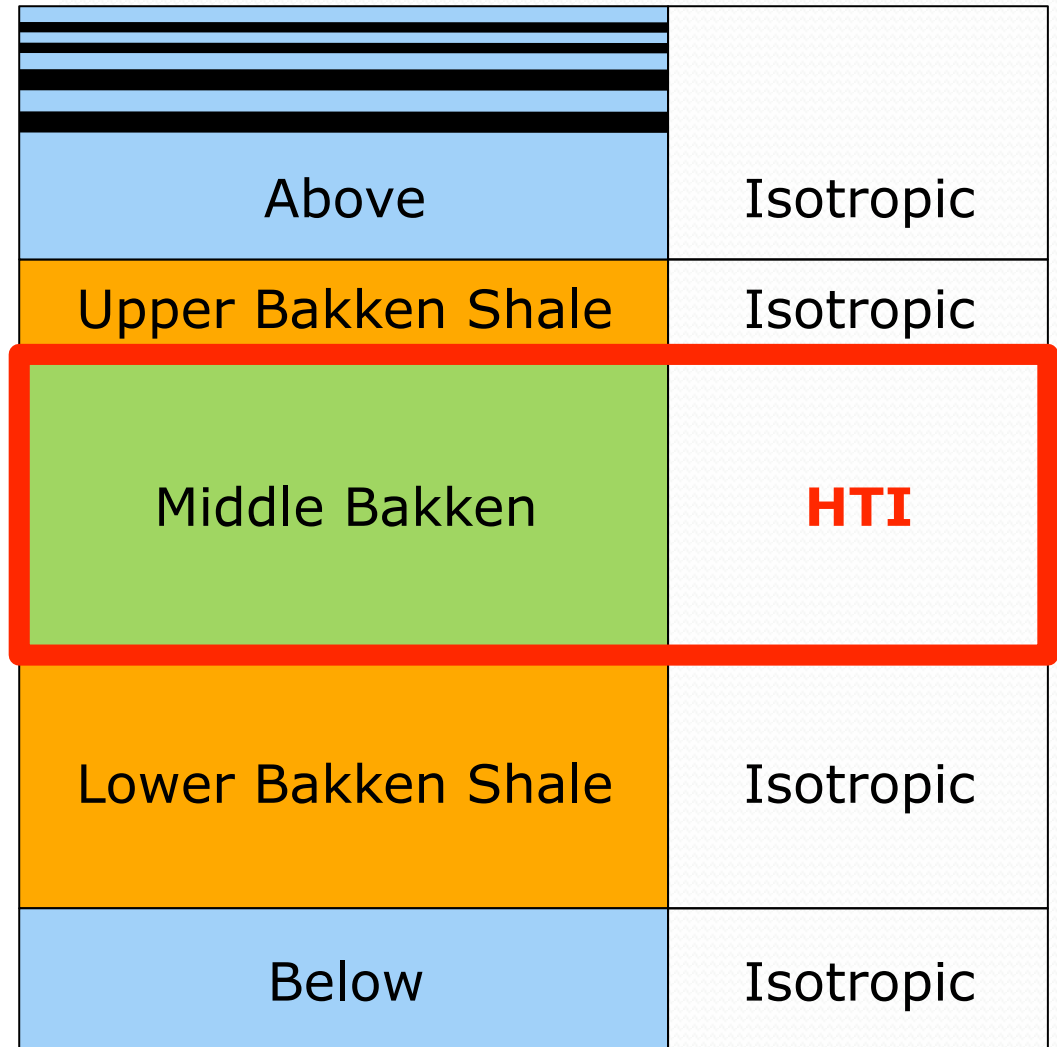
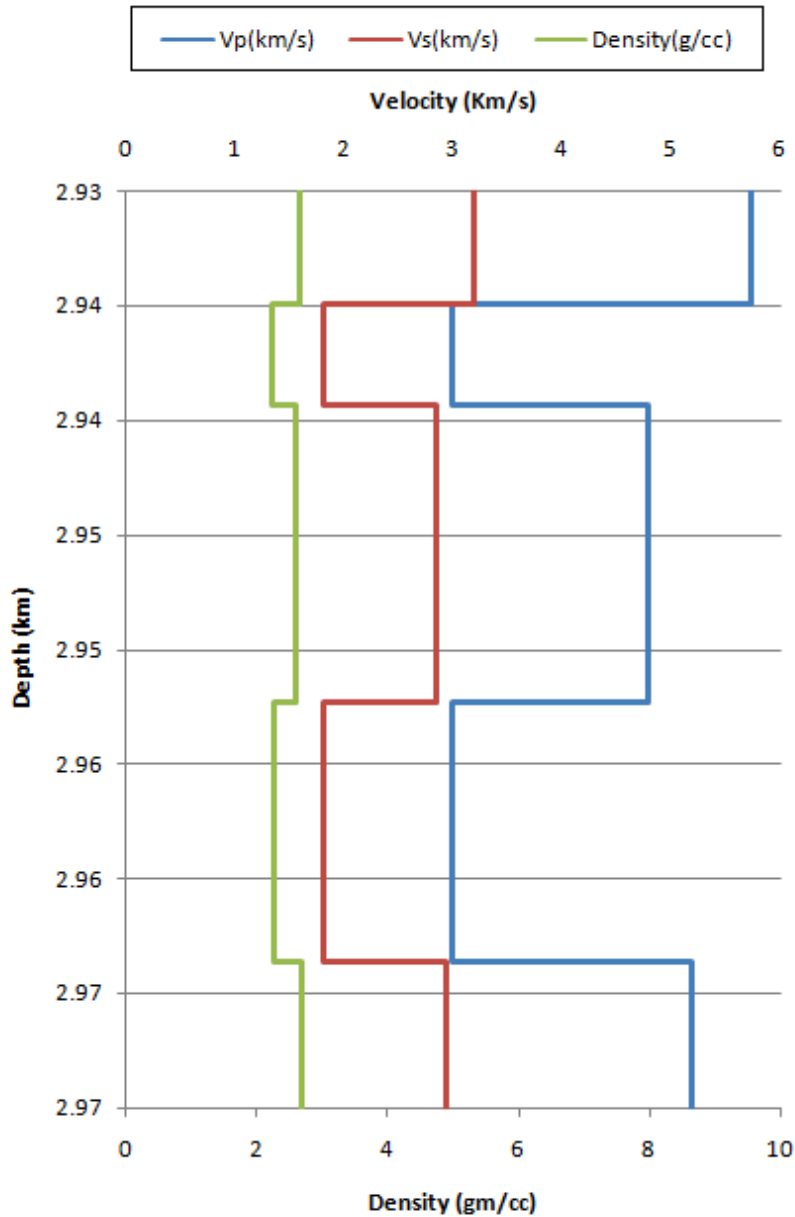
# Thick Model: VTI Anisotropy information



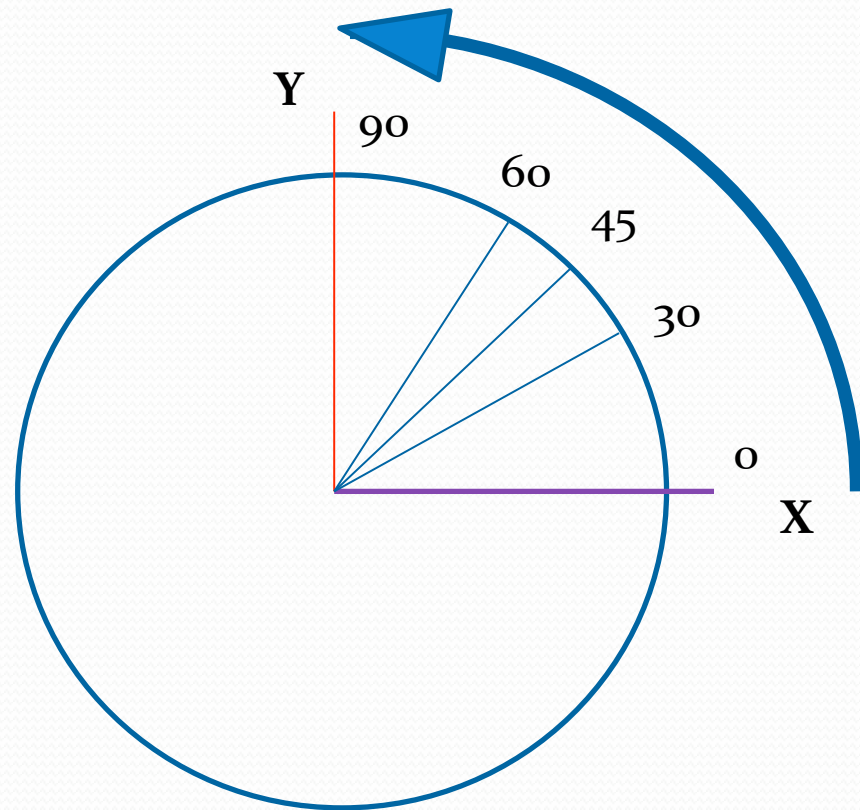
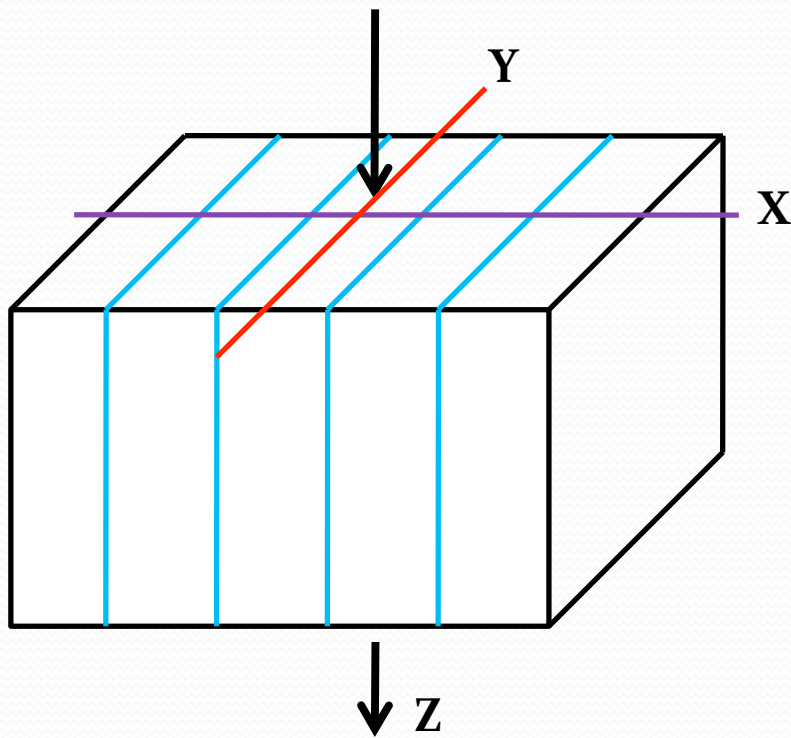
# Real Bakken Thickness: VTI Anisotropy information

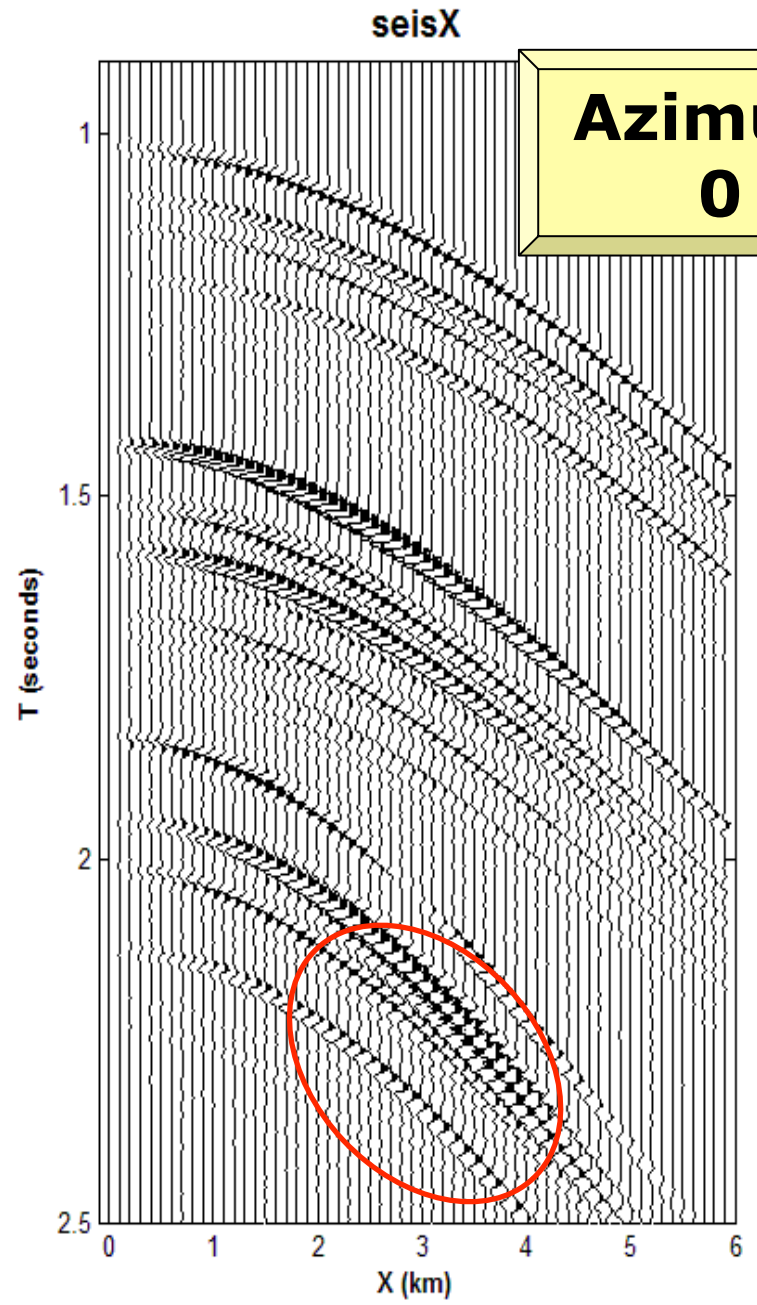
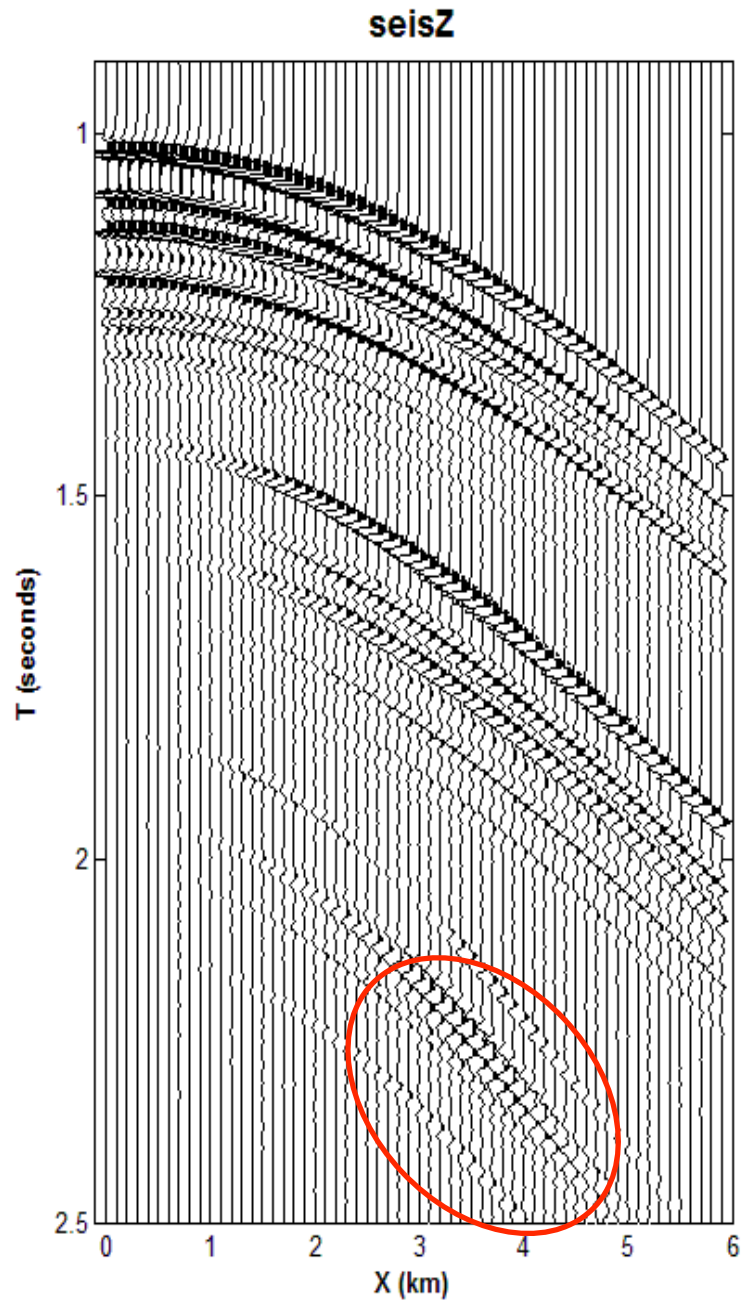


# Modeling Step 3: HTI

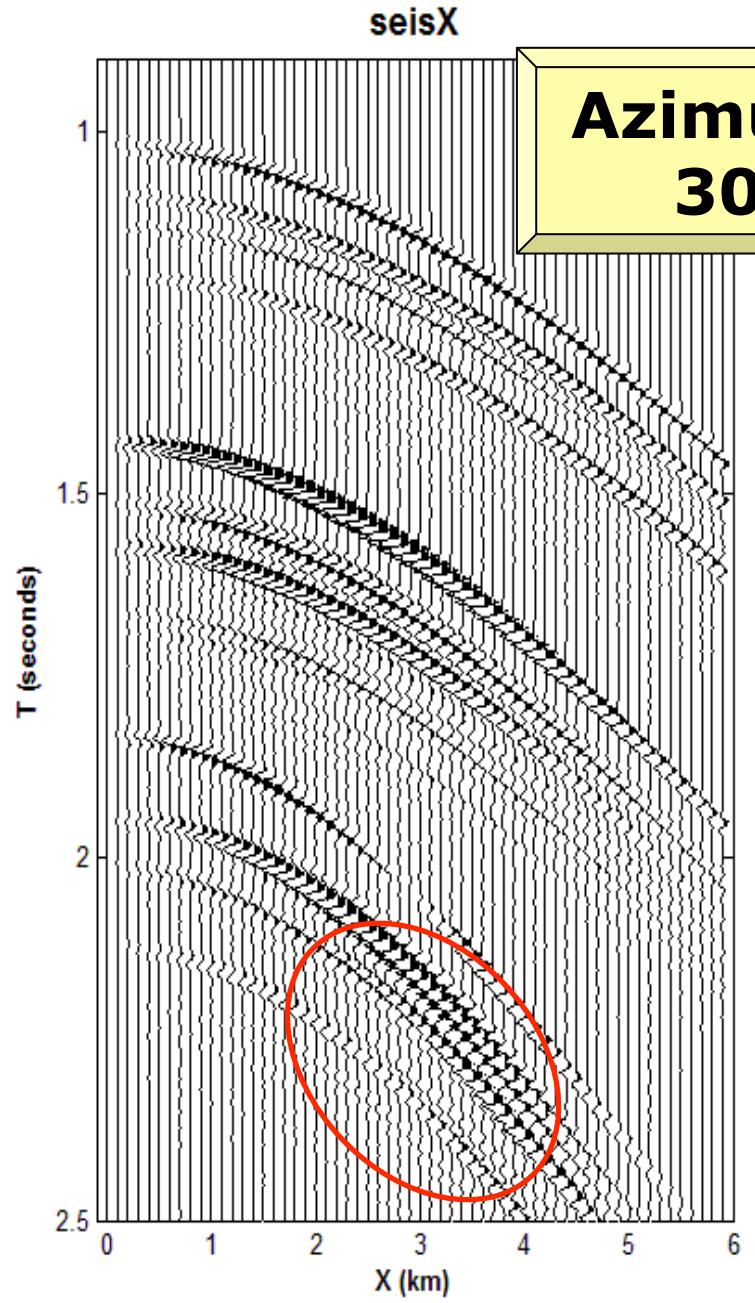
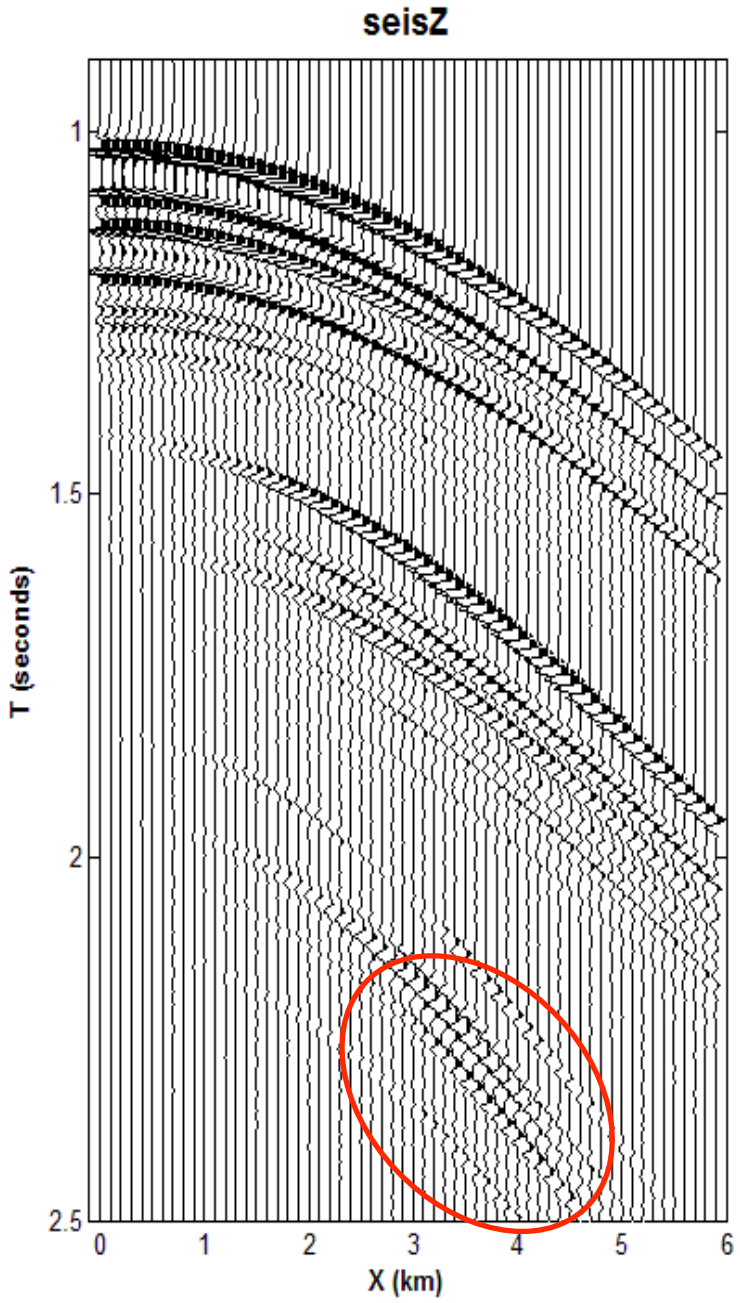


# Azimuthal Anisotropy

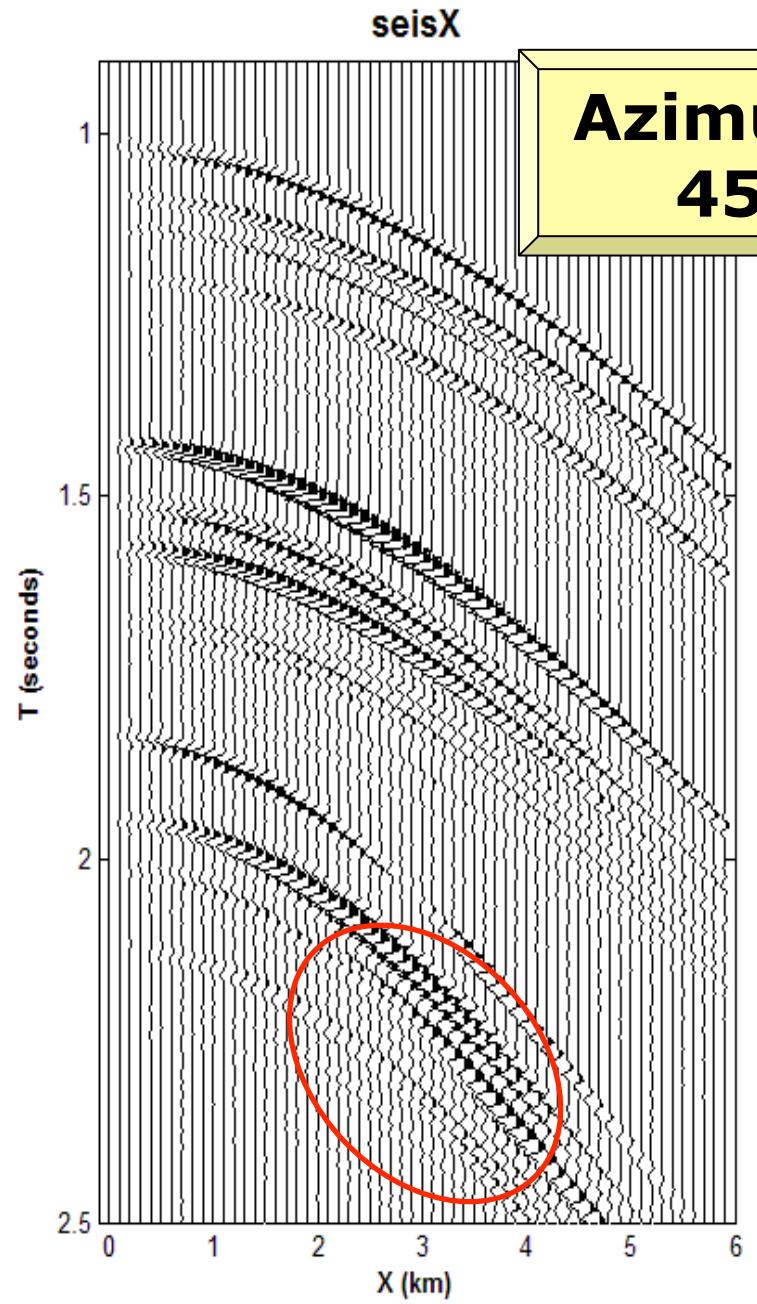
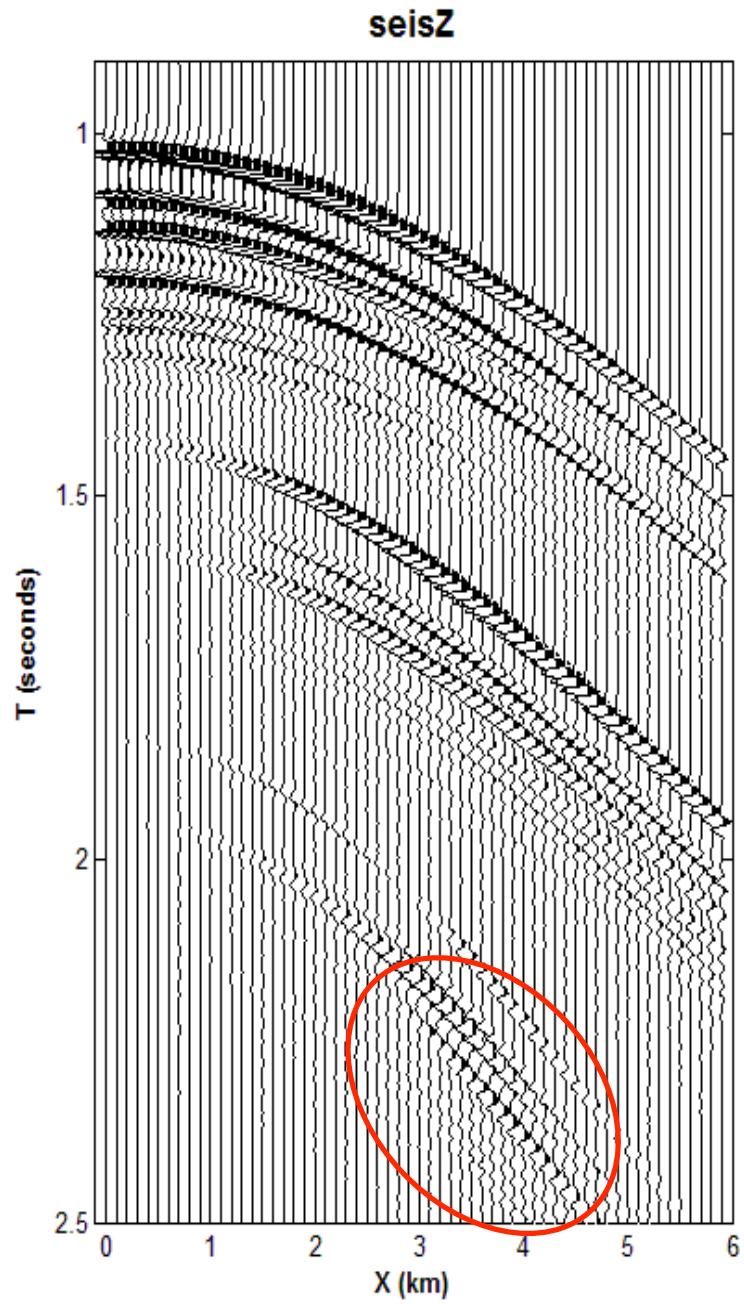




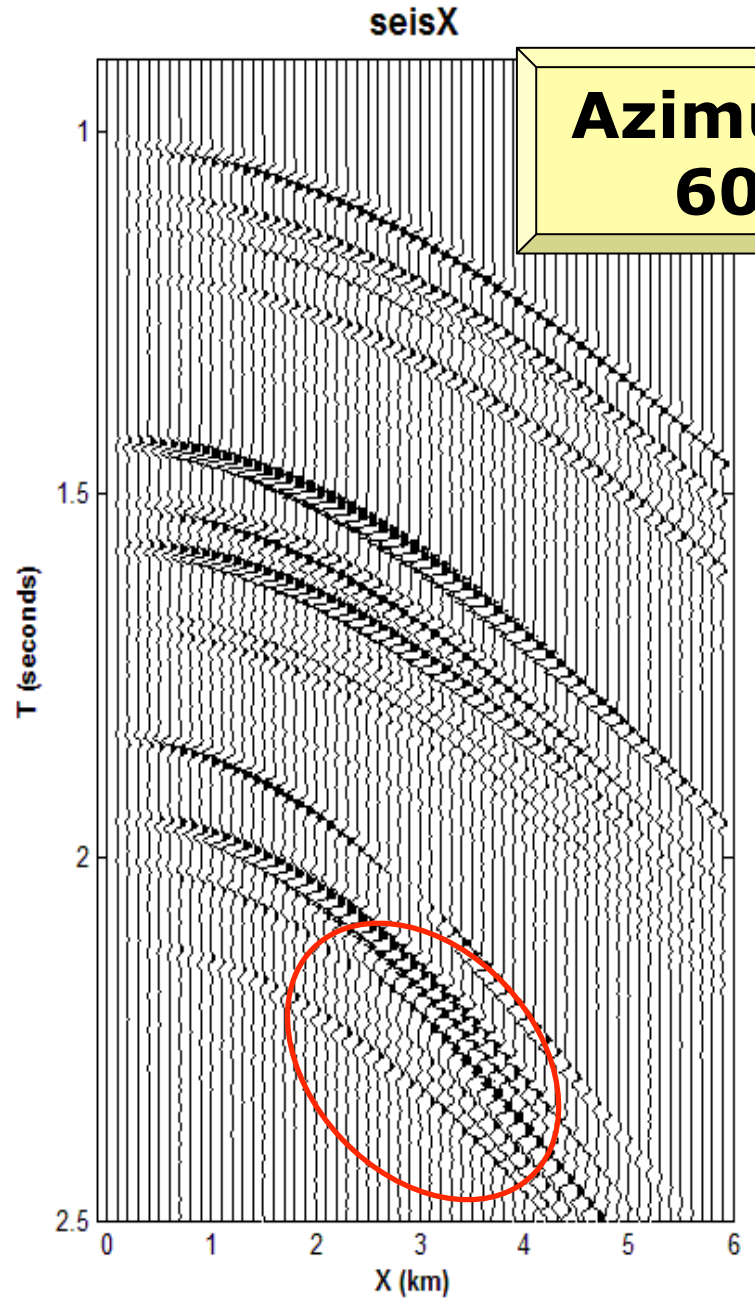
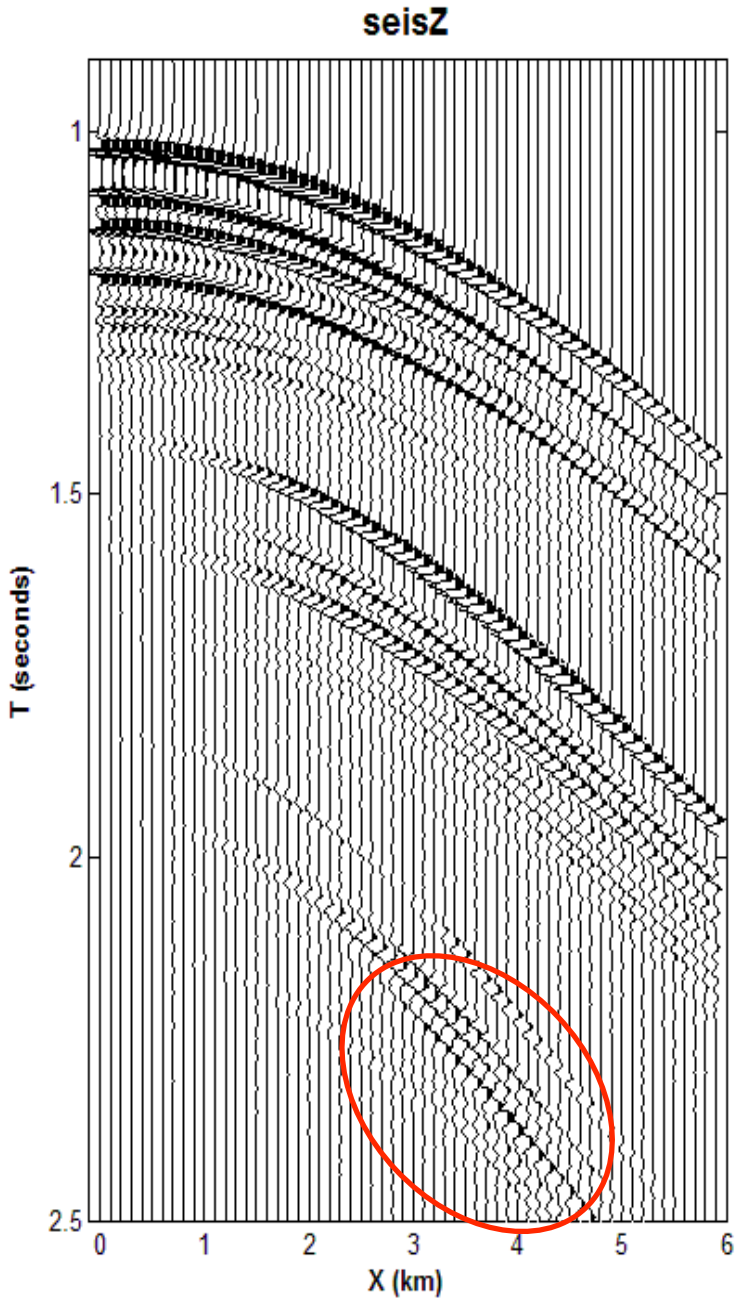




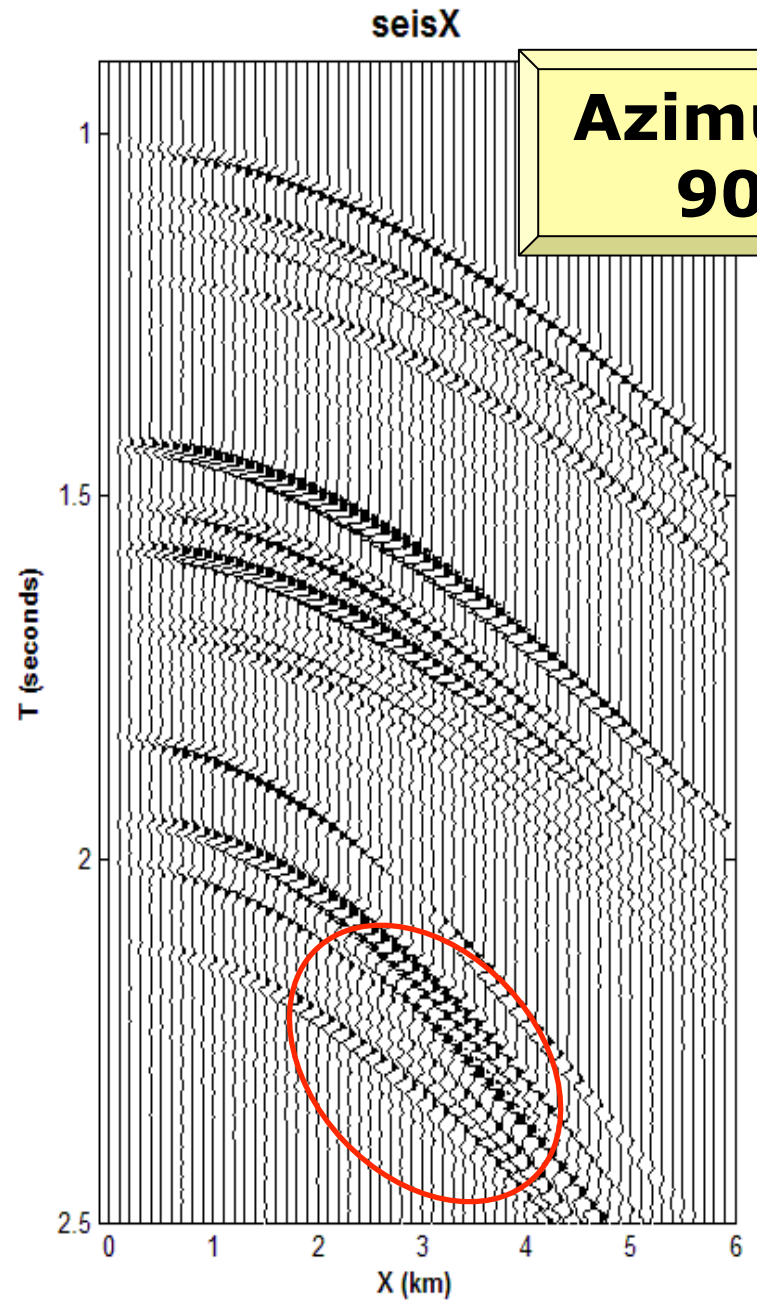
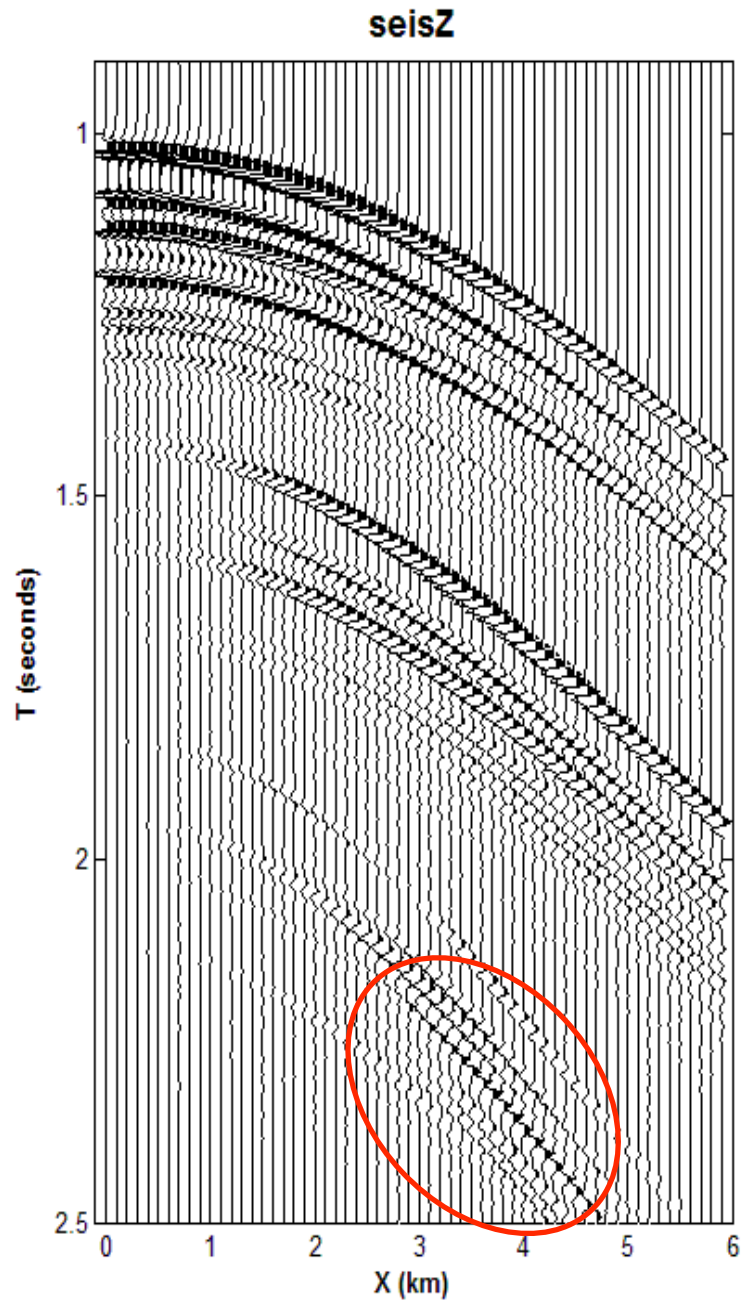
**Azimuth  
30**

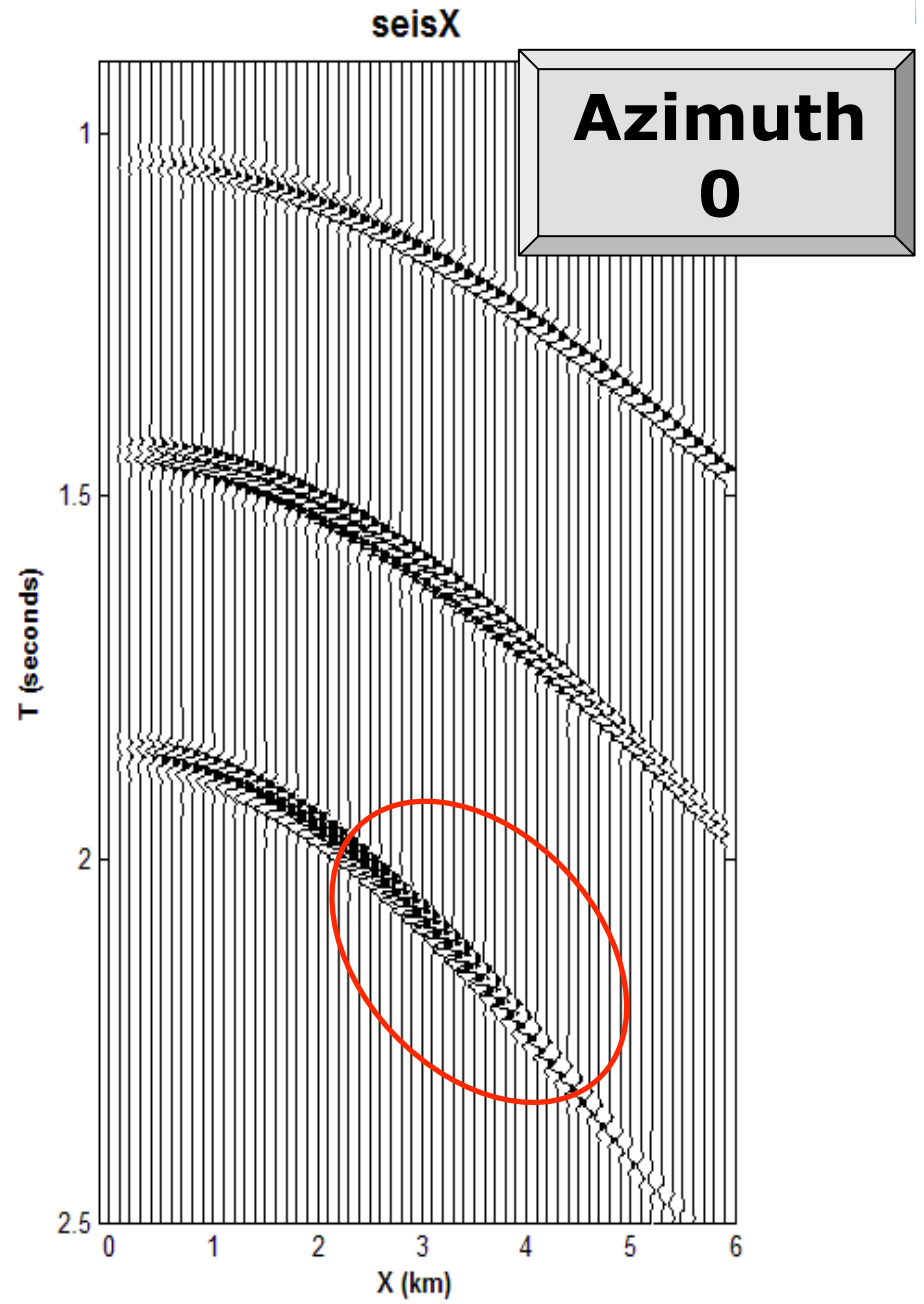
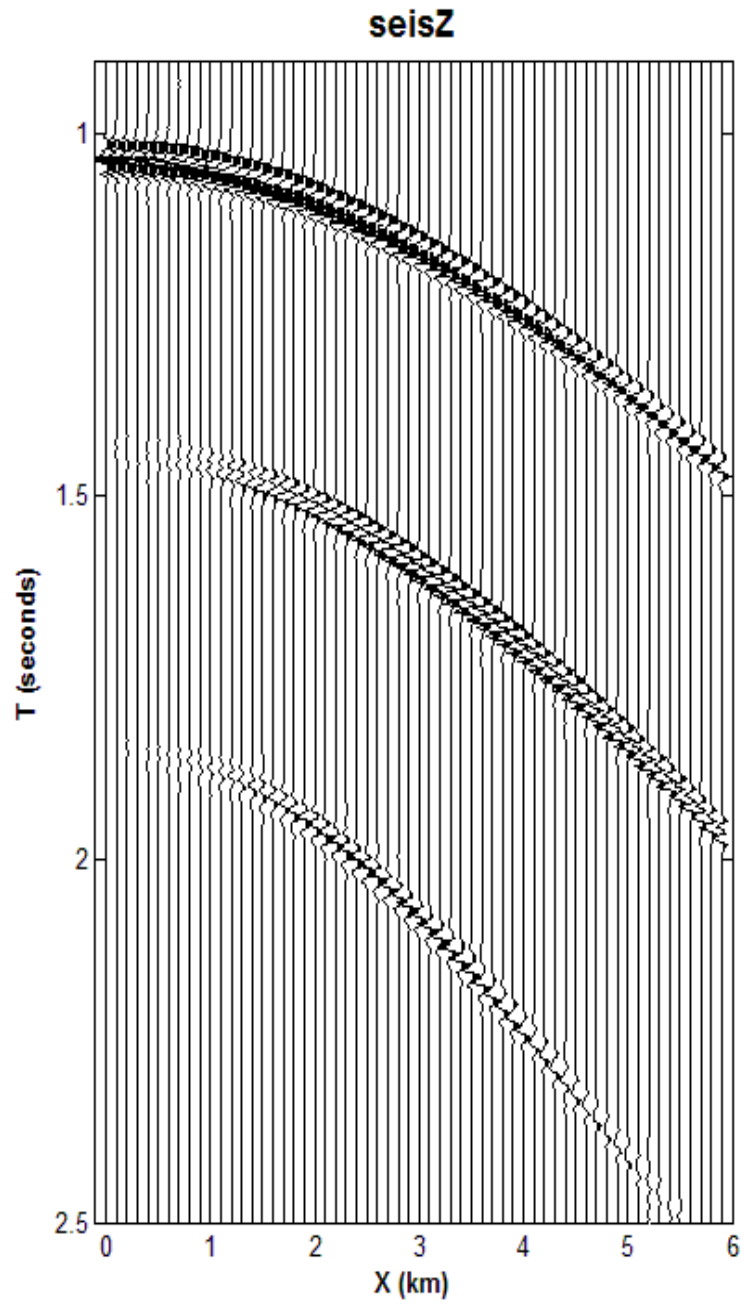


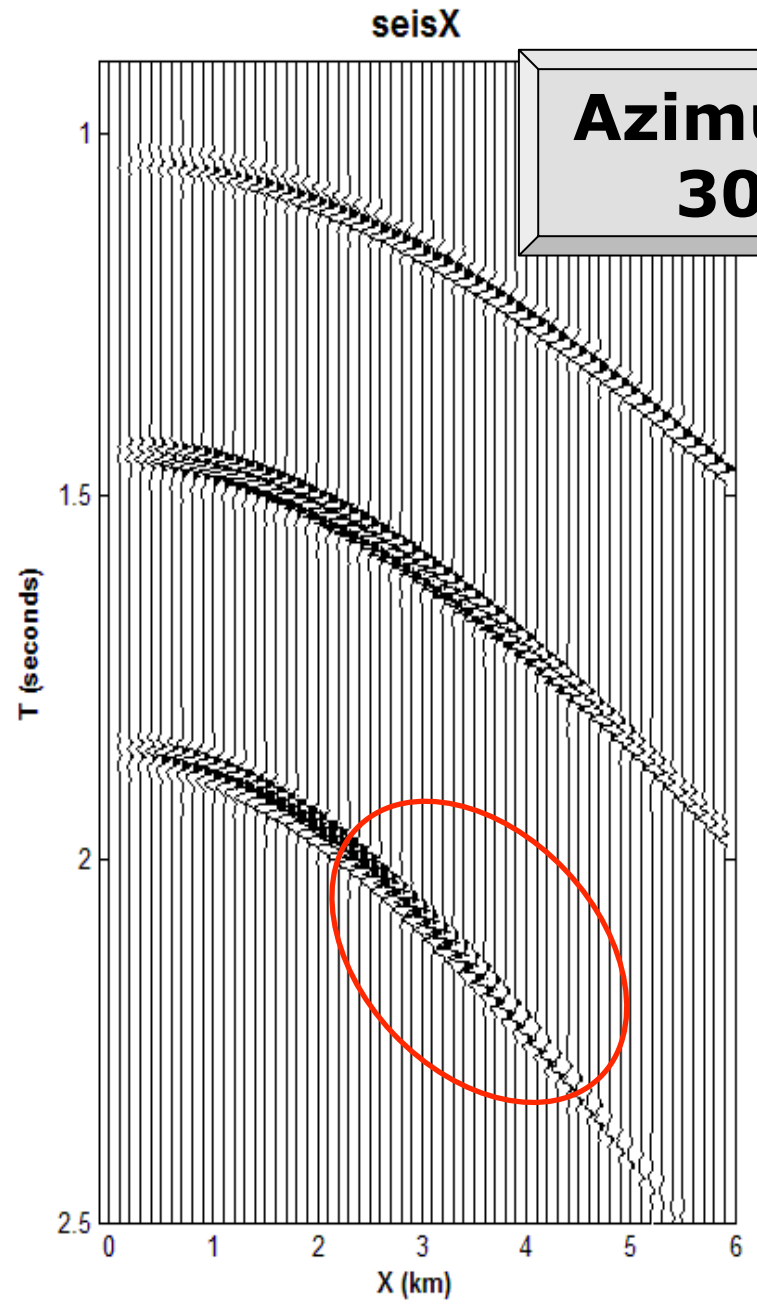
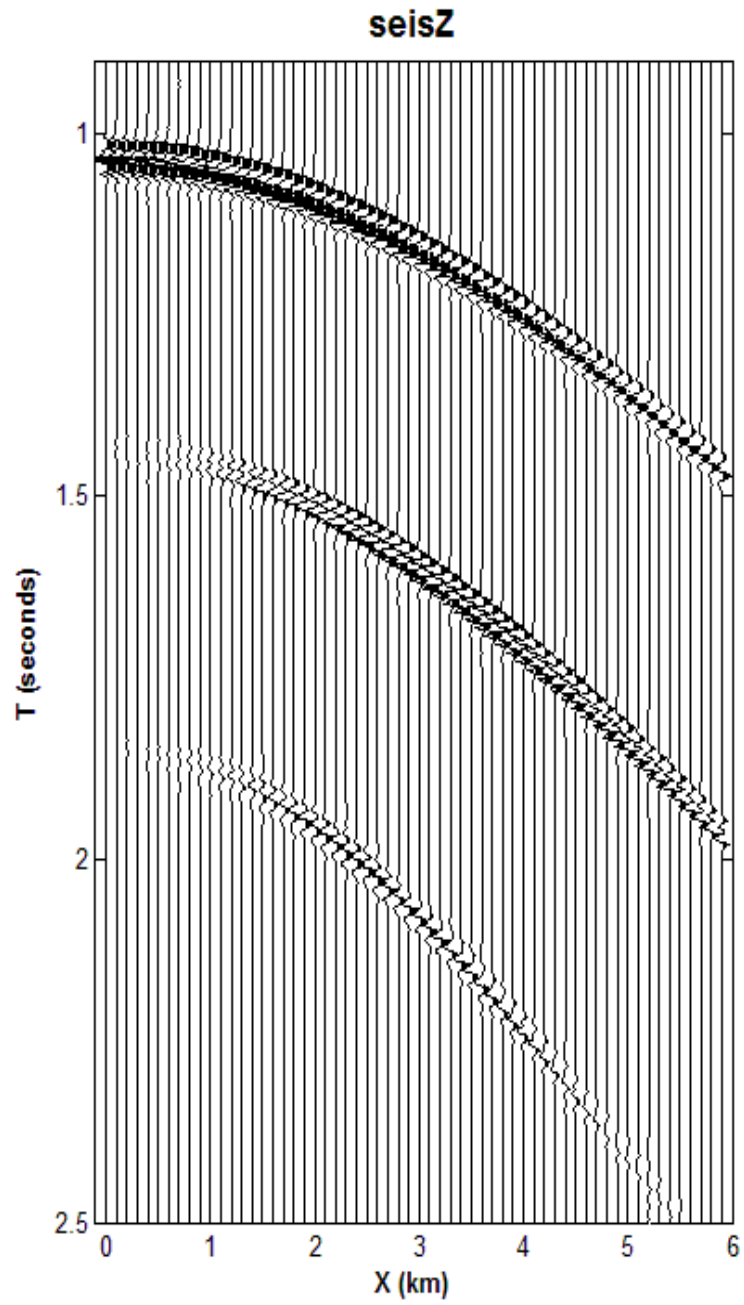
**Azimuth  
45**



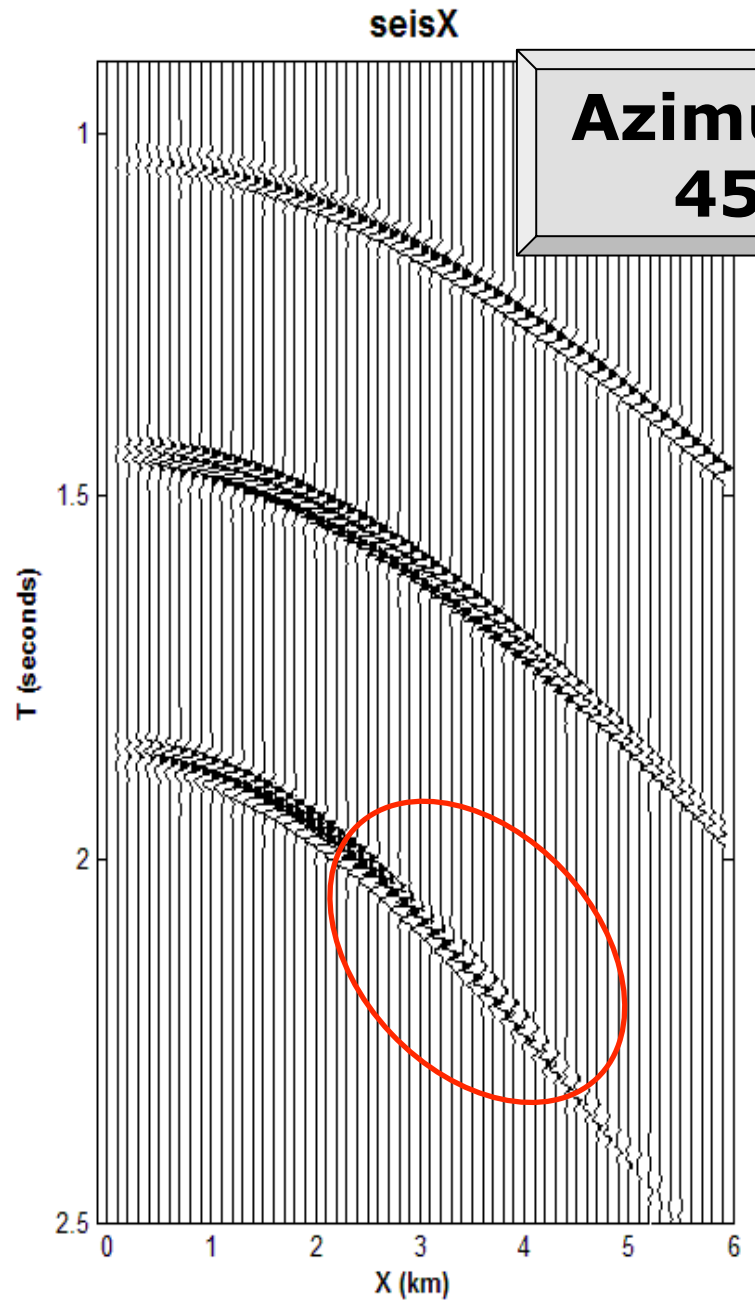
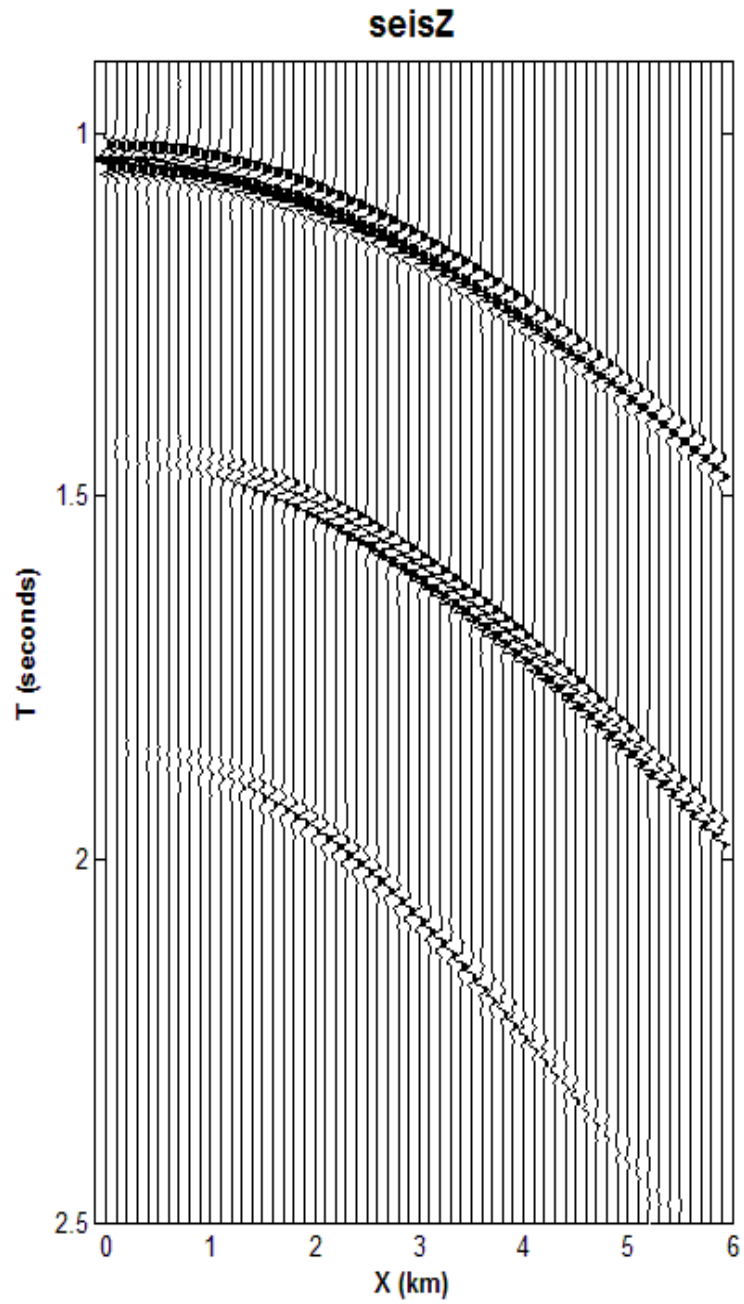
**Azimuth  
60**



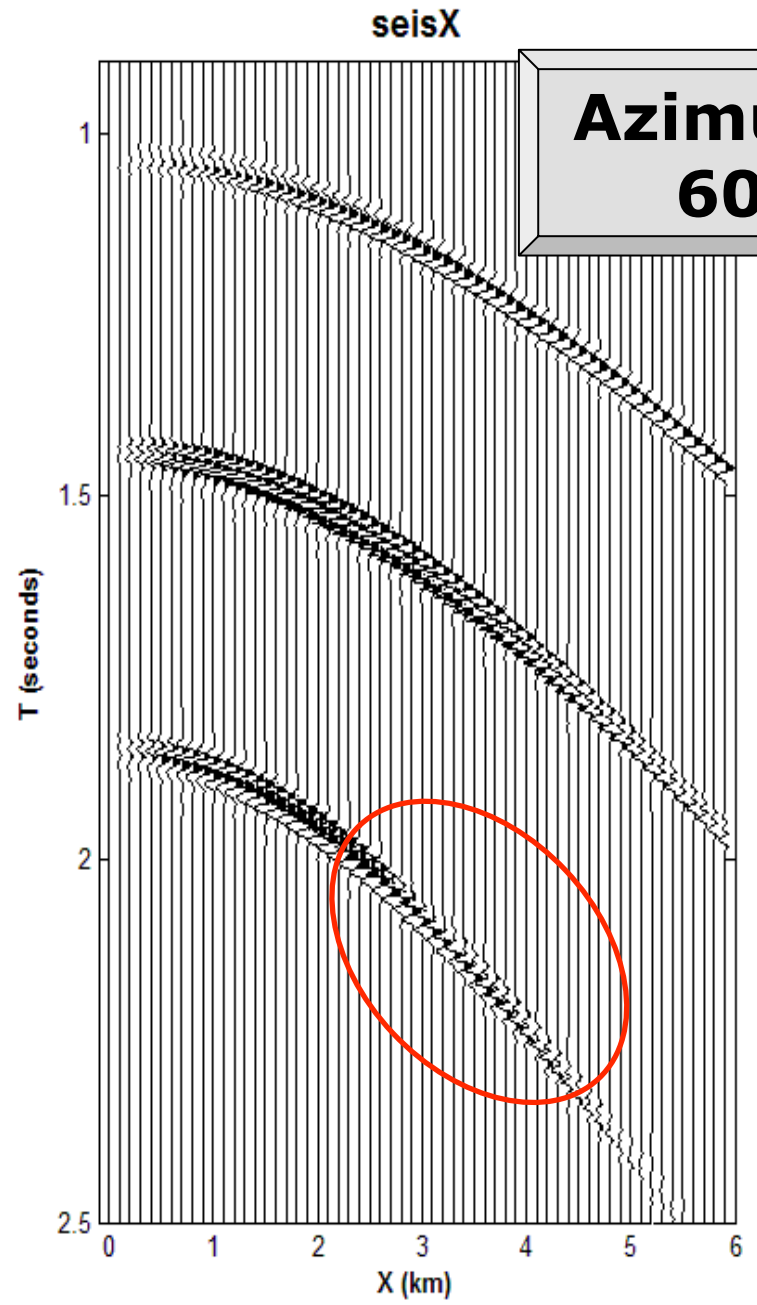
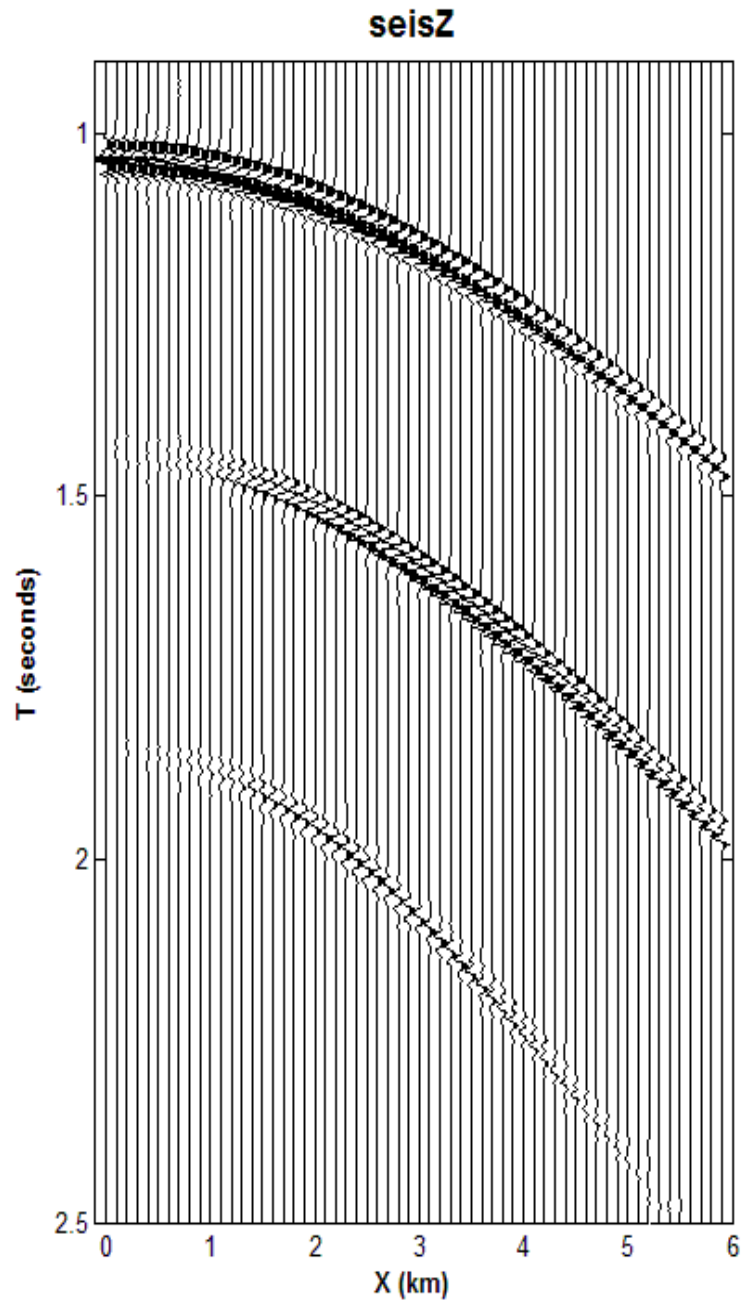




**Azimuth  
30**

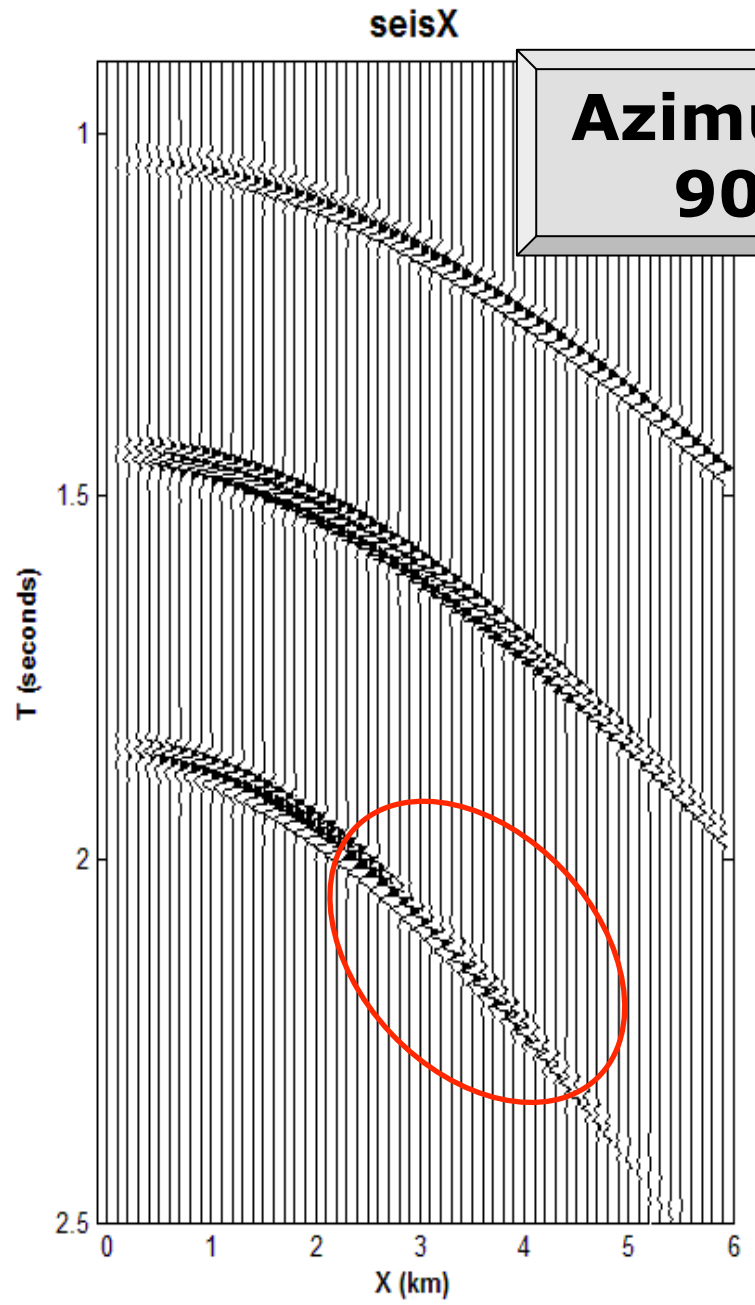
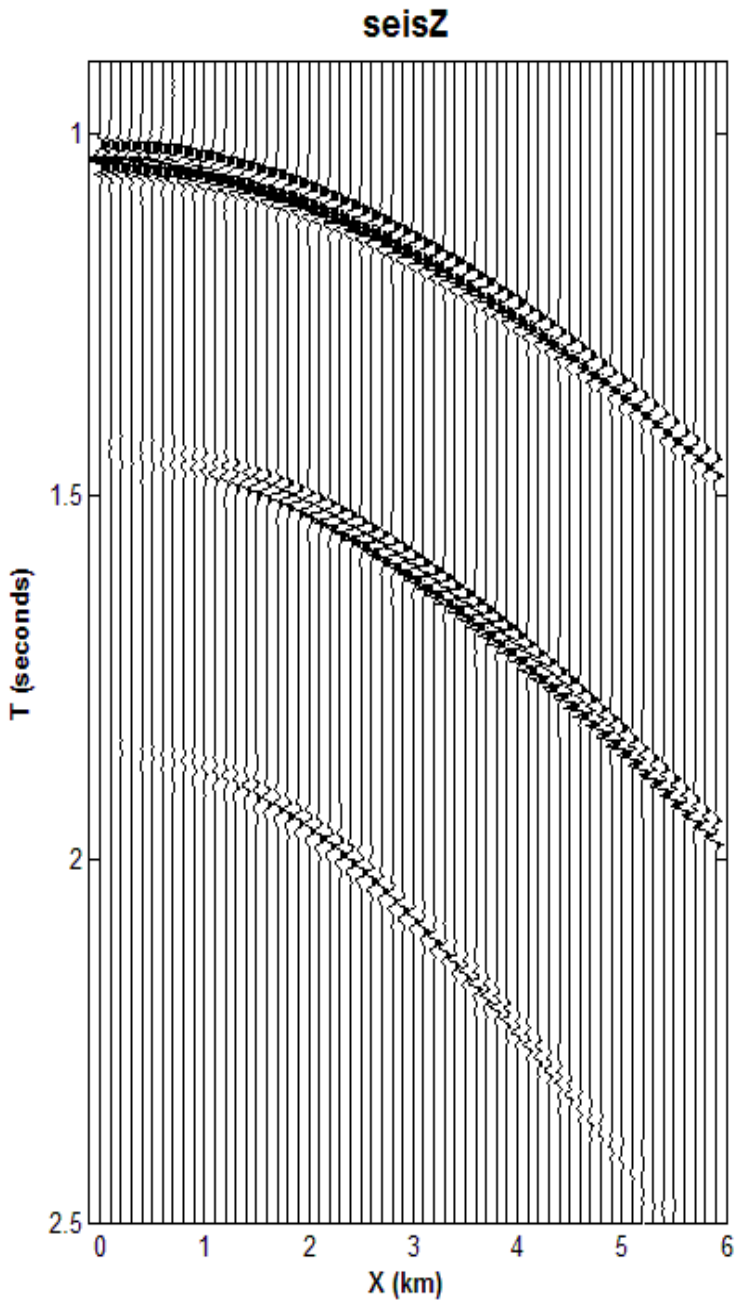


**Azimuth  
45**

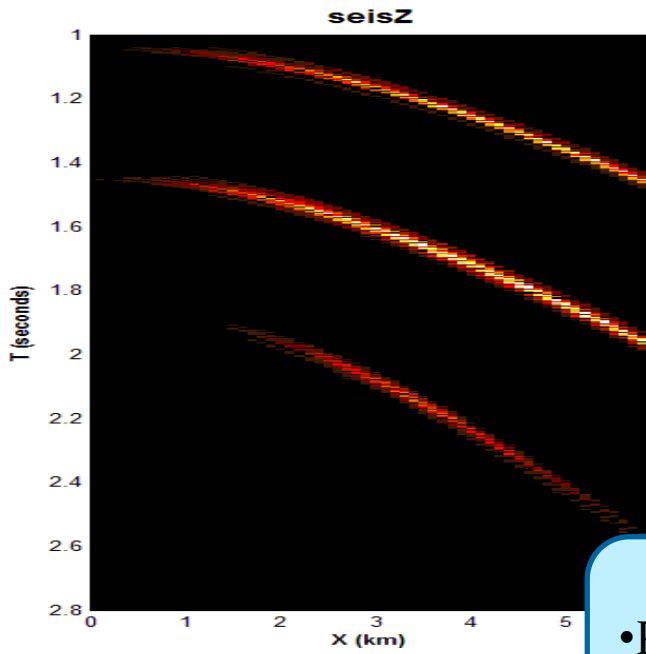


**Azimuth  
60**

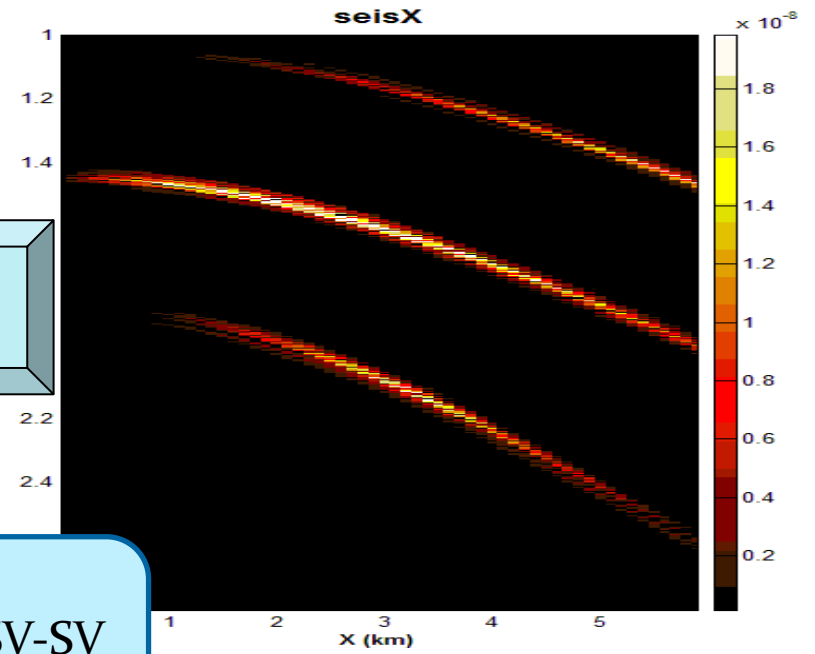




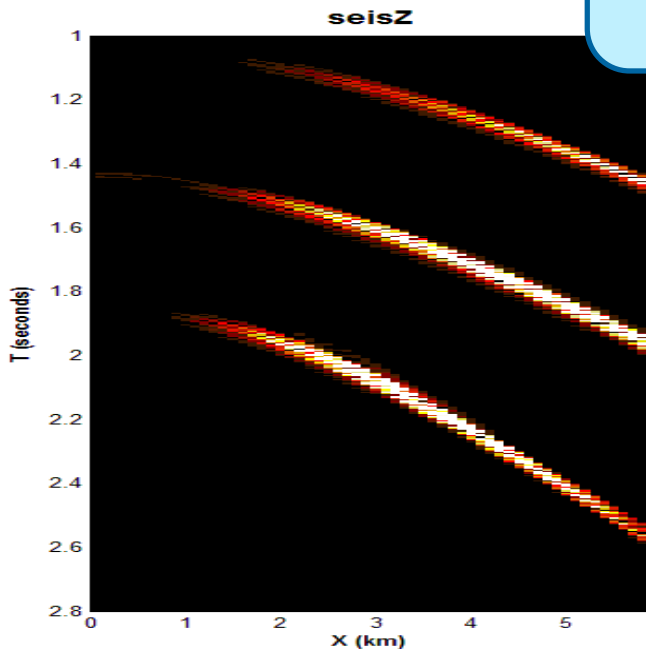
**Azimuth  
90**



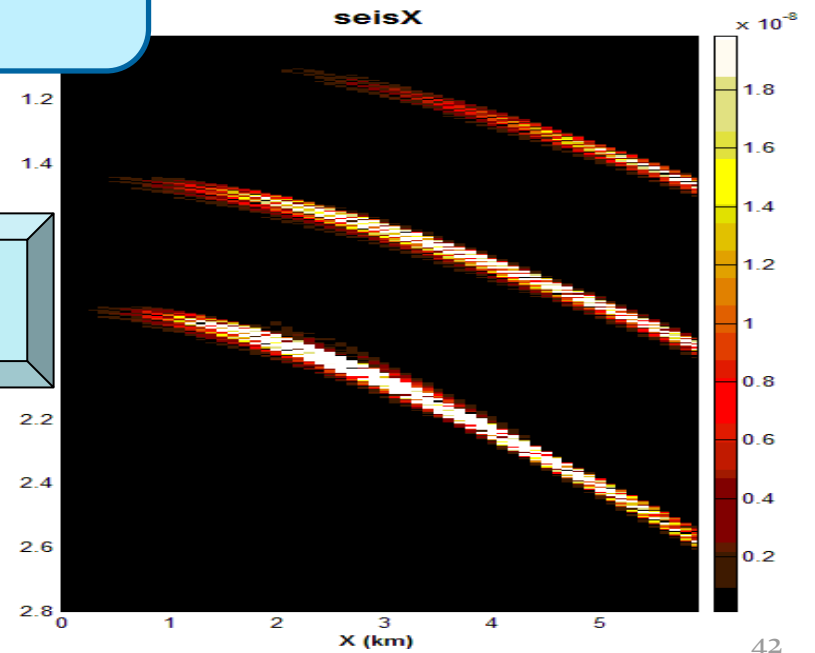
**VTI**



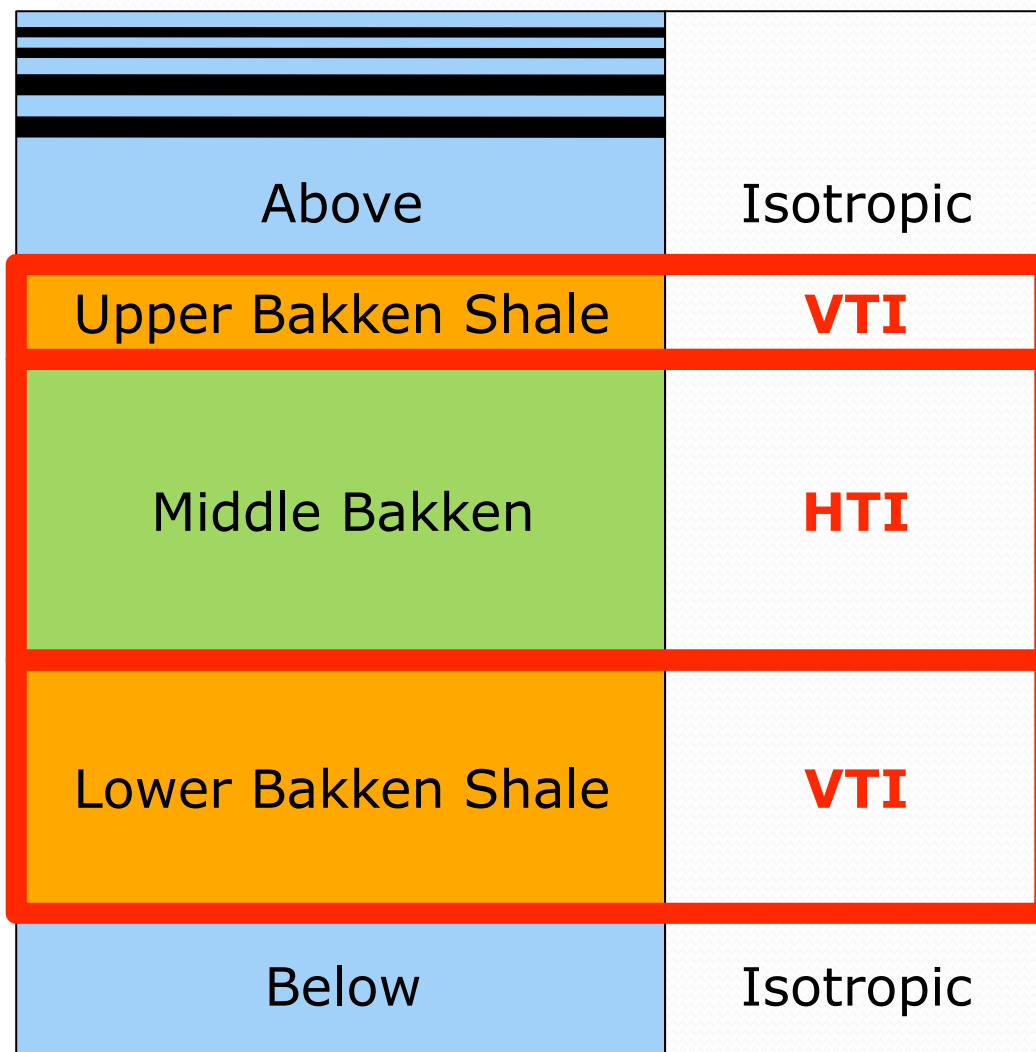
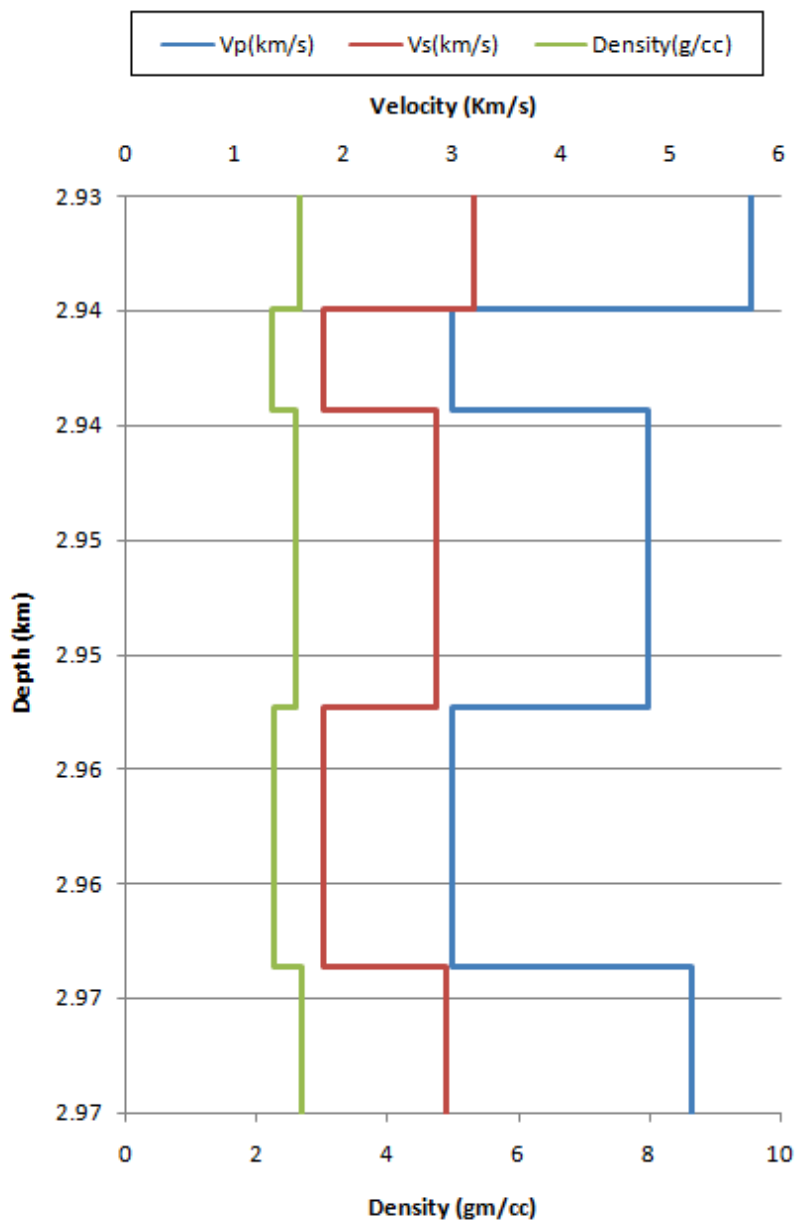
- P-P, P-SV, SV-SV
- offset ranges



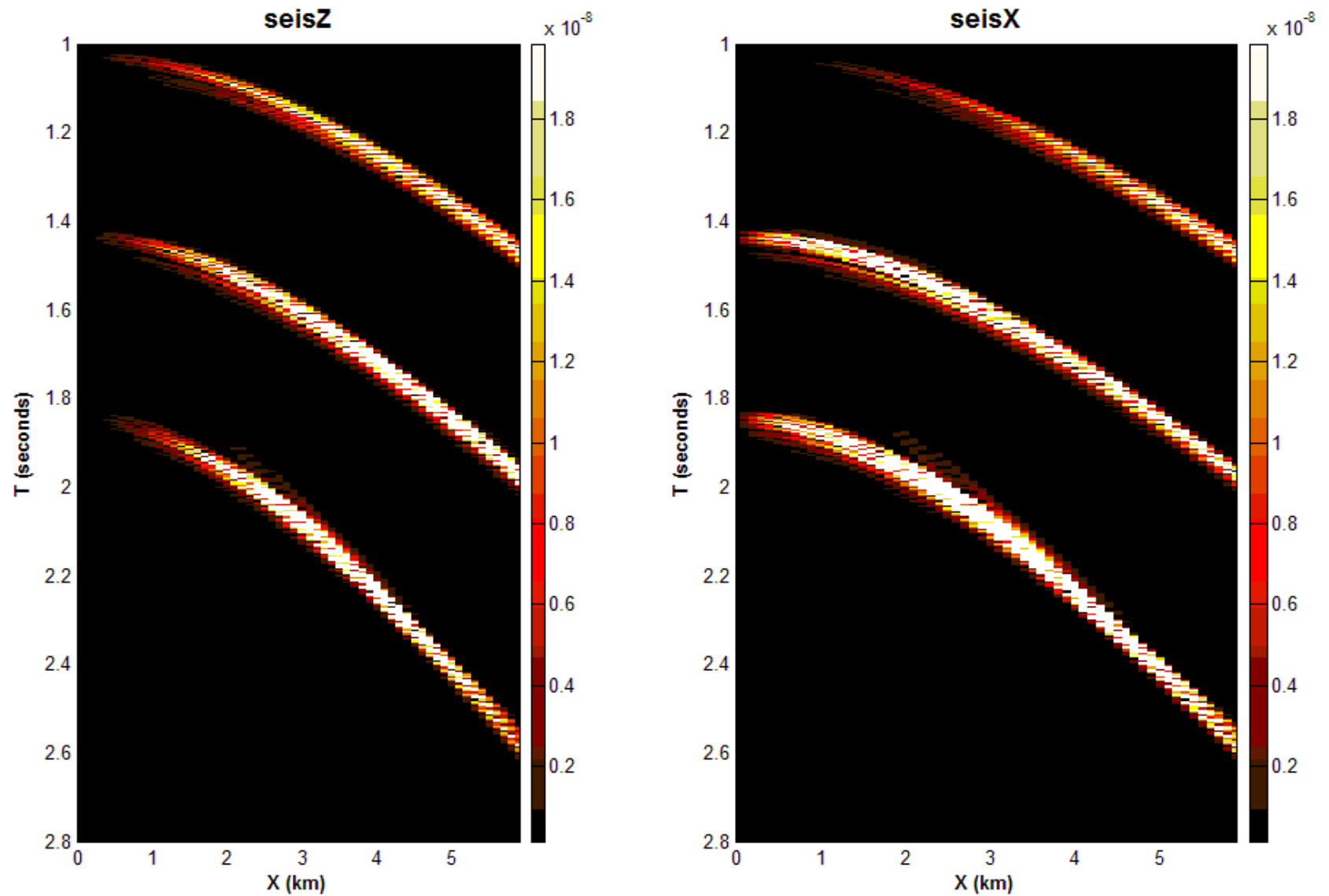
**HTI**



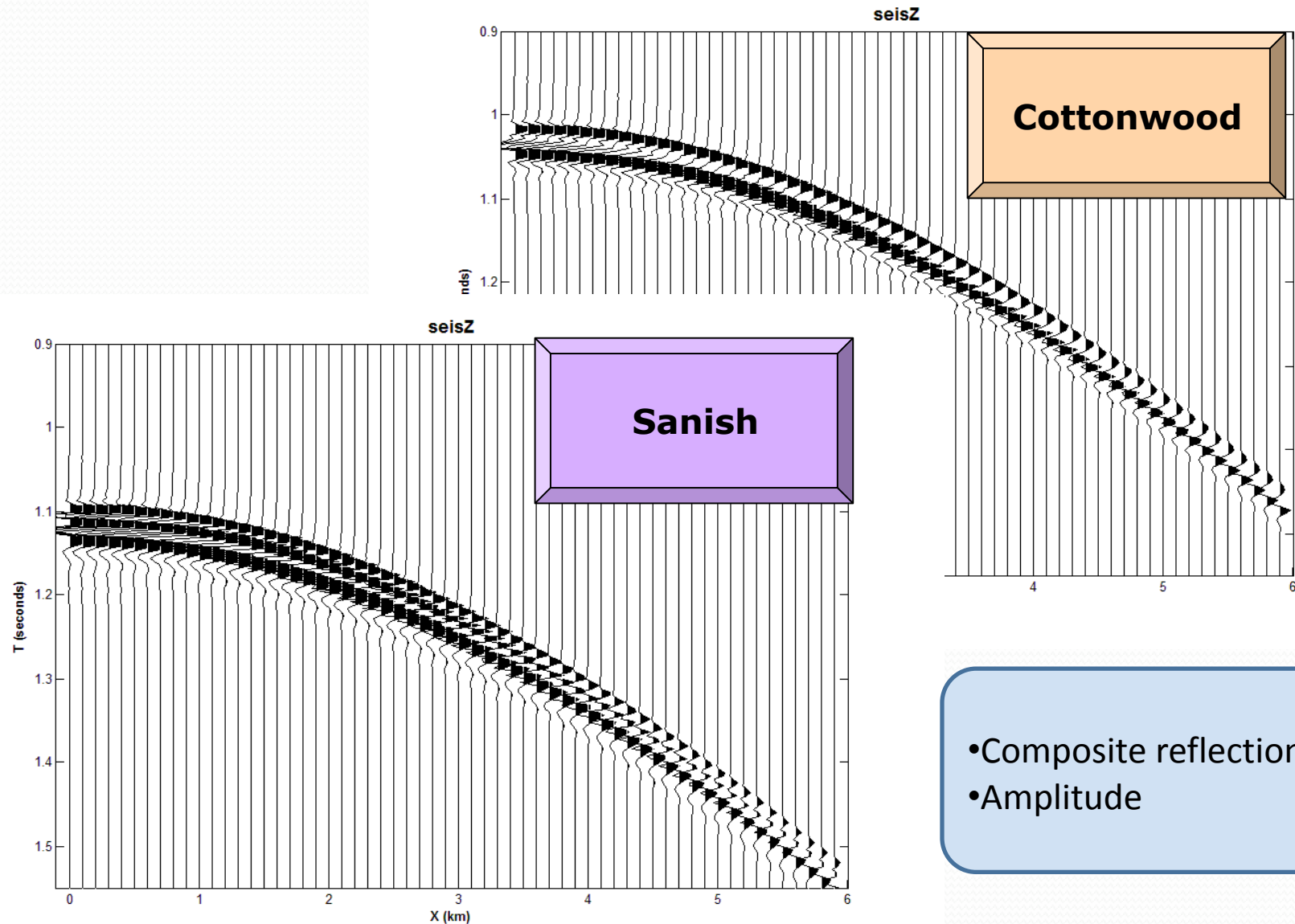
# Modeling Step 4: VTI + HTI



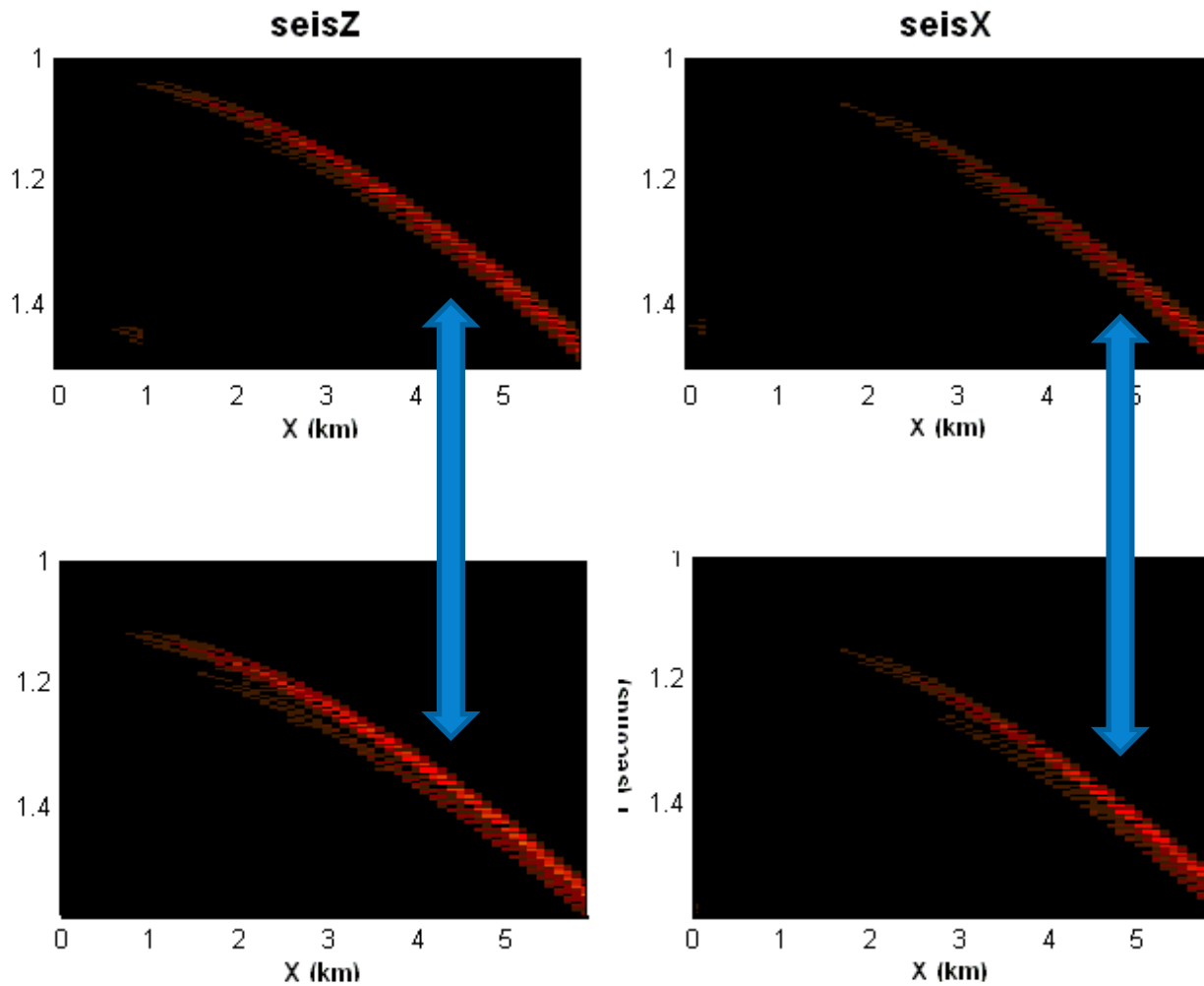
# VTI + HTI: Difference Between Azimuth 0 and 90



# Comparison between Cottonwood and Sanish field



# Difference Between Azimuth 0 and 90



**Cottonwood**

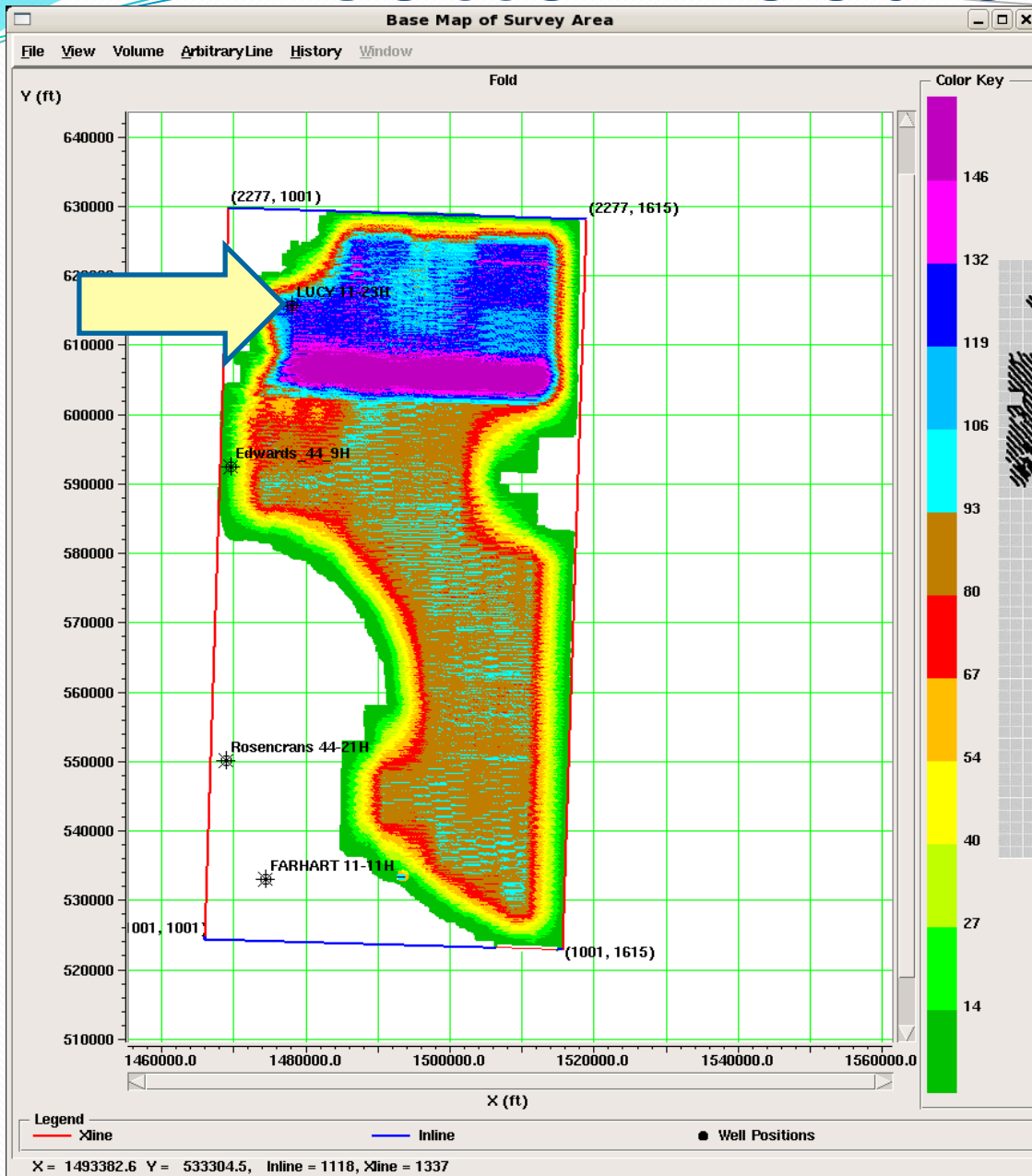
**Sanish**

Brighter color → more difference between two azimuths

# Outline

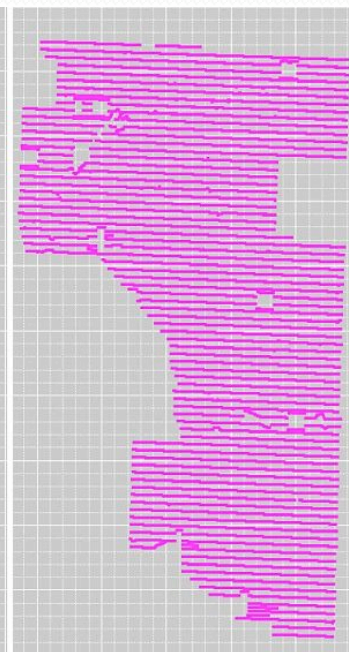
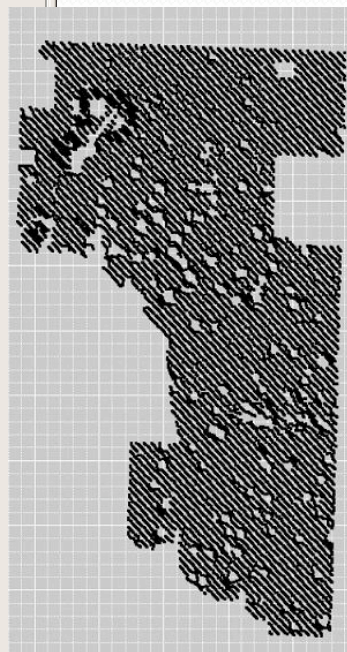
- ❖ Introduction
- ❖ Well log analysis
- ❖ Seismic modeling
- ❖ Field data analysis
- ❖ Mechanical properties
- ❖ Summary

# Cottonwood Seismic



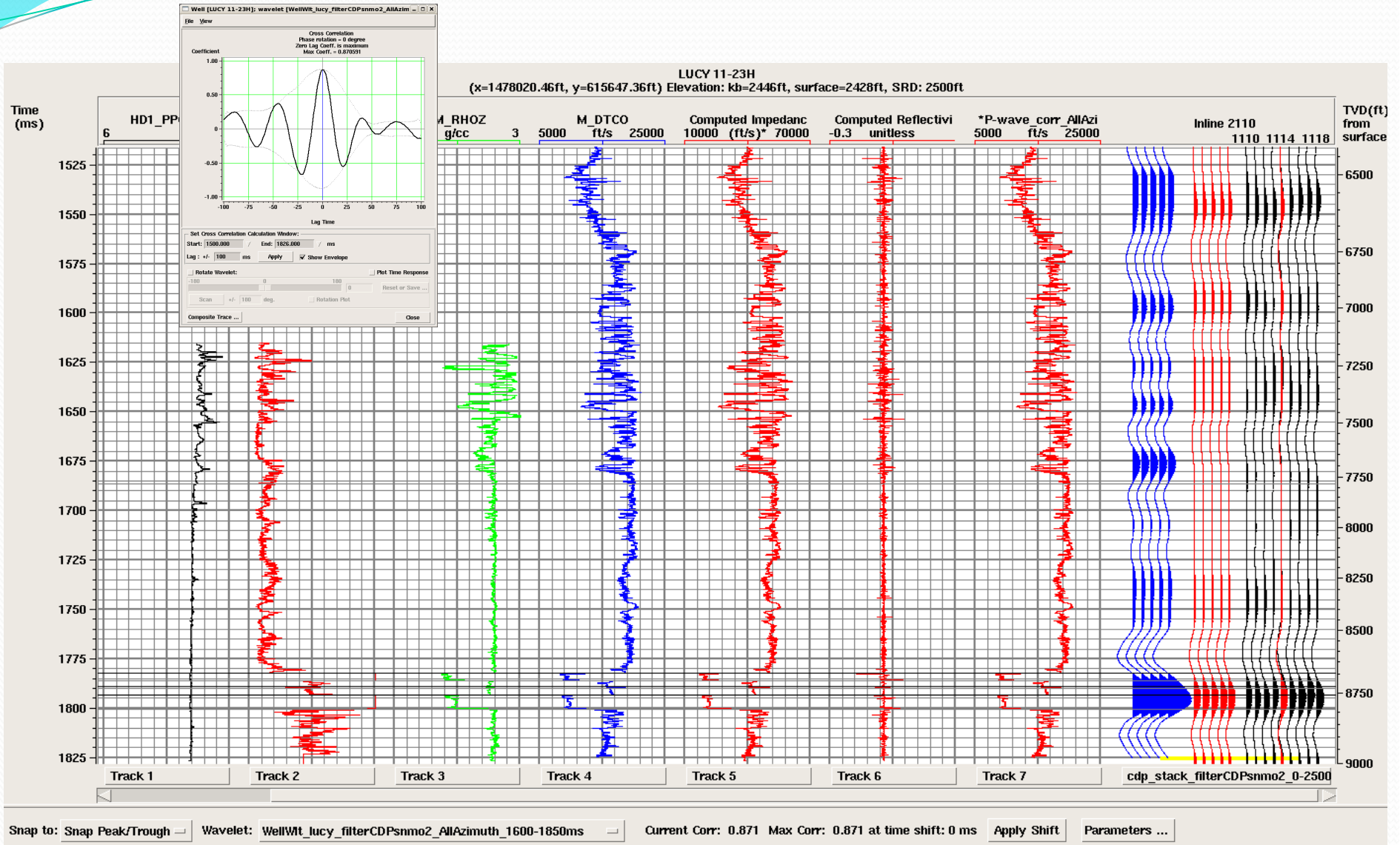
Shots

Receivers

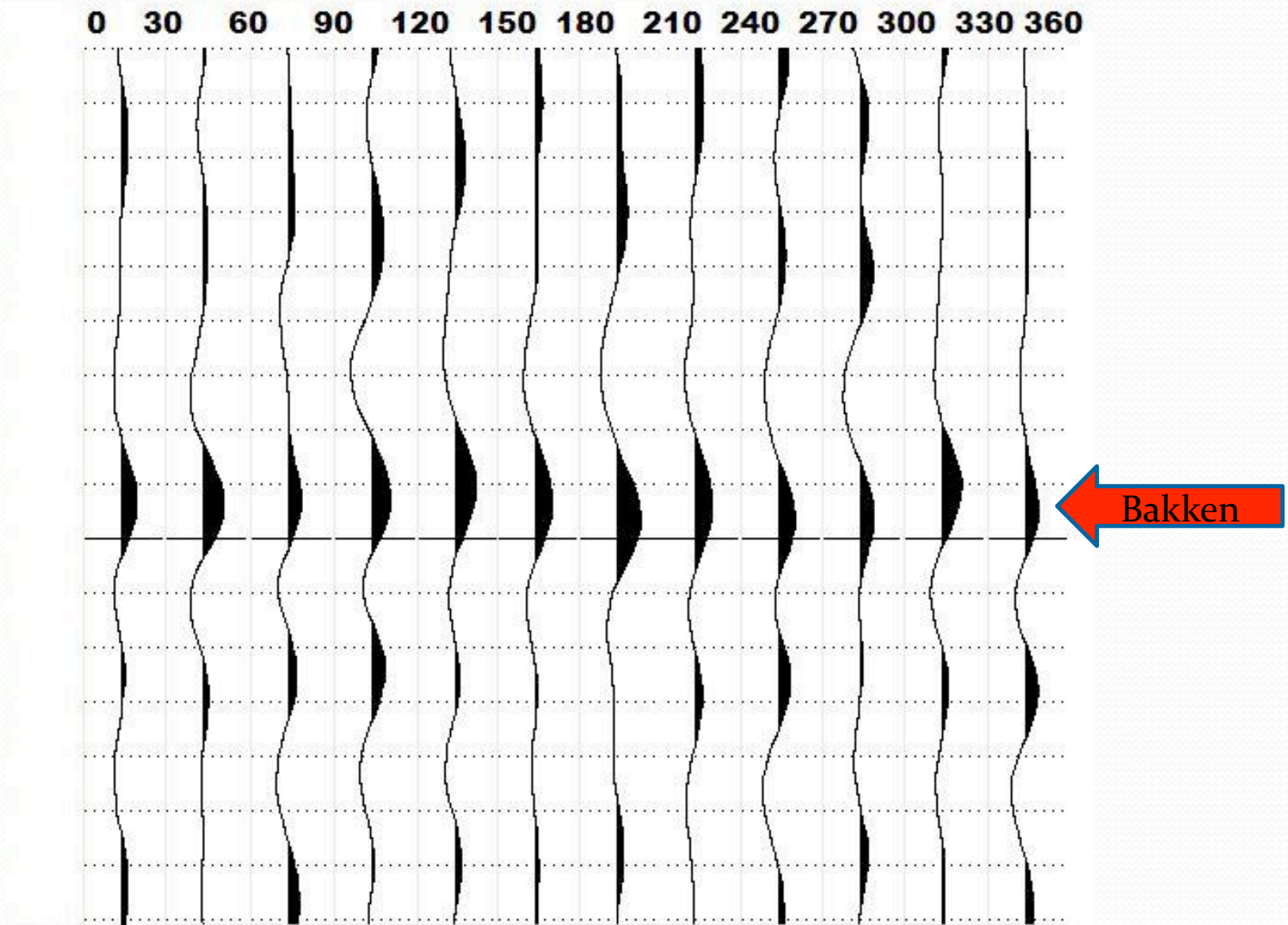




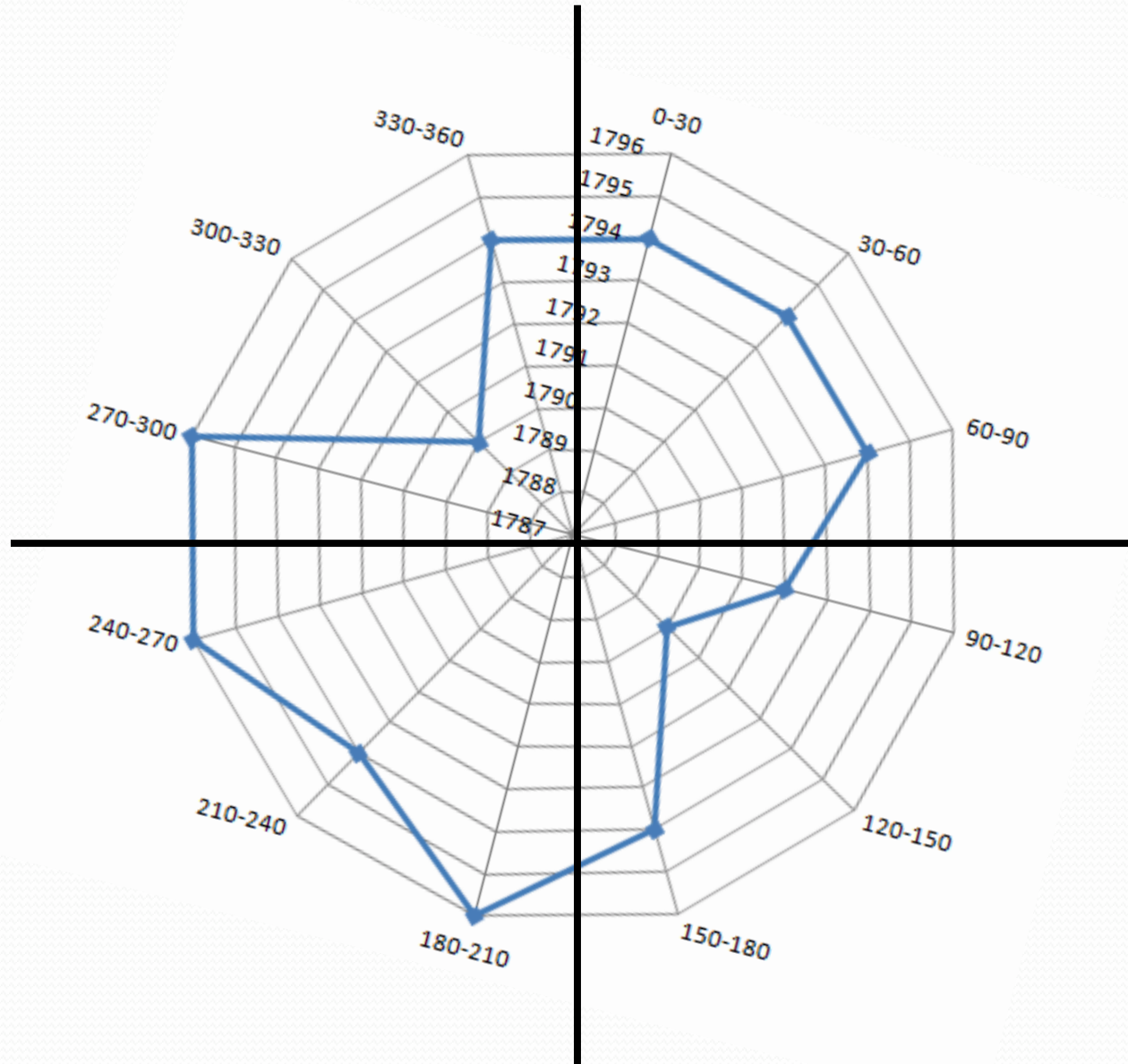
# Seismic Well Tie



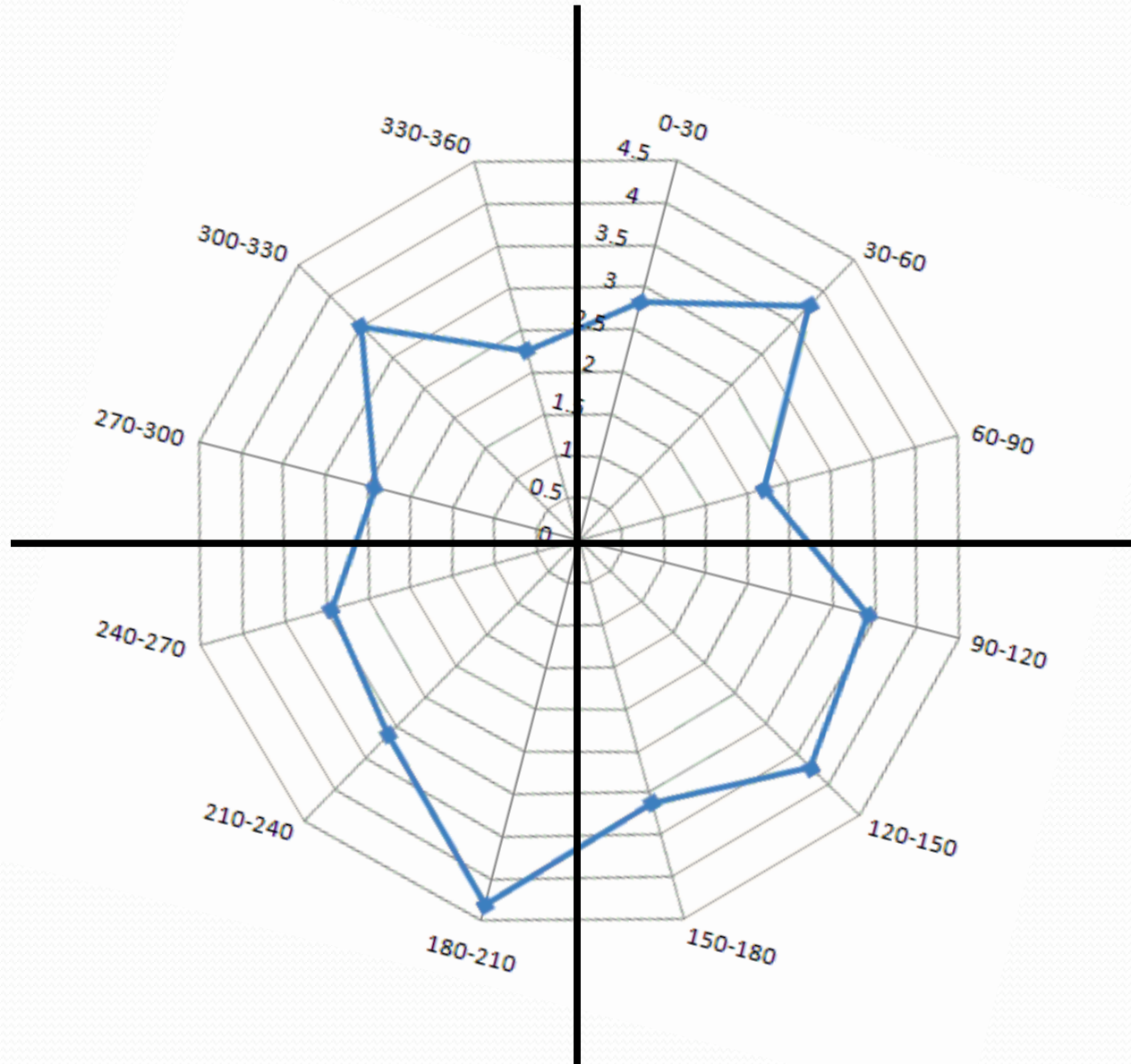
# Azimuthal Stack



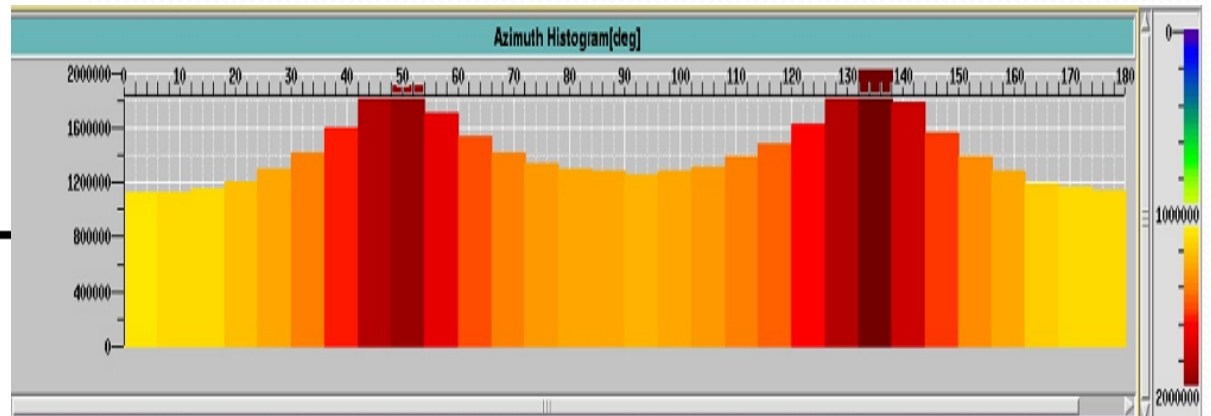
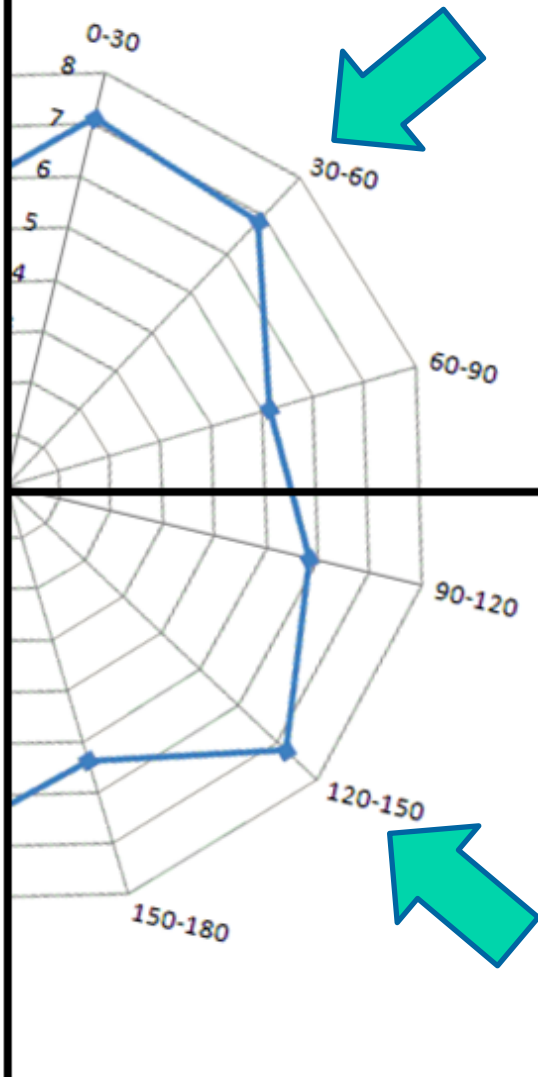
# Azimuthal Variation-Time



# Azimuthal Variation-Amplitude



# Azimuthal Variation (Bi-Directional)- Amplitude



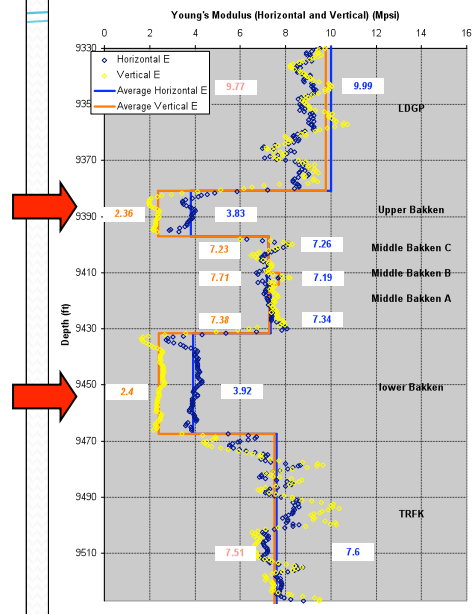
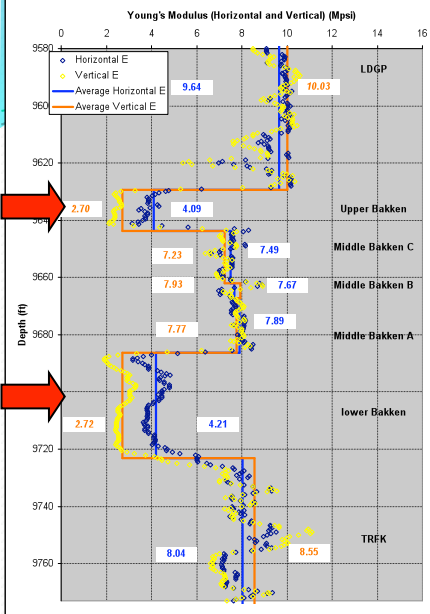
# Outline

- ❖ Introduction
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- ❖ Summary

## Farhart 11-11H

## Rosencrans 44-21H

# Young's Modulus



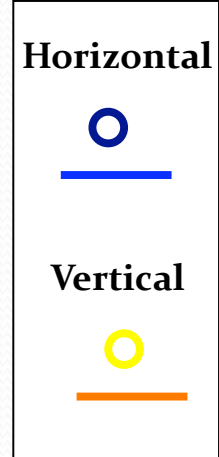
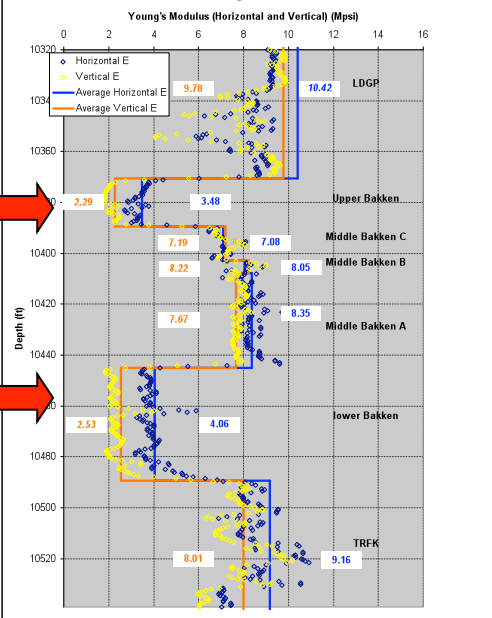
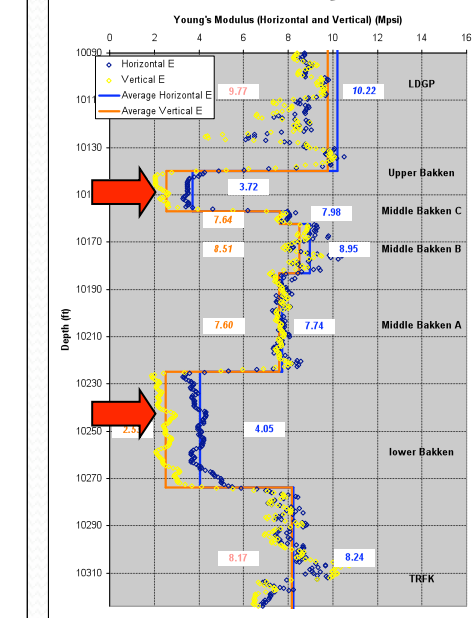
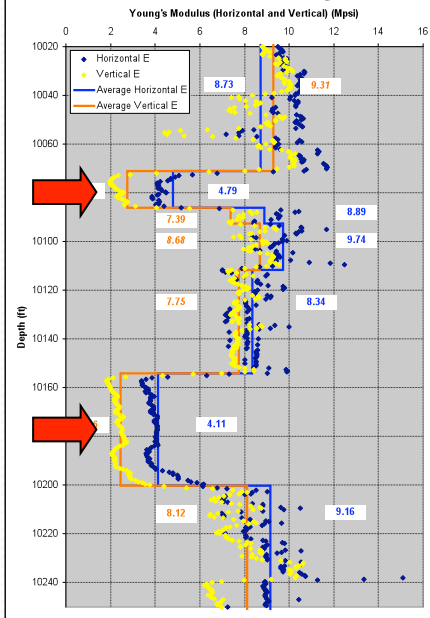
❖ Bakken Shales:  
Vertical < Horizontal

❖ Vertical-Horizontal difference :  
Bakken shale > Middle Bakken

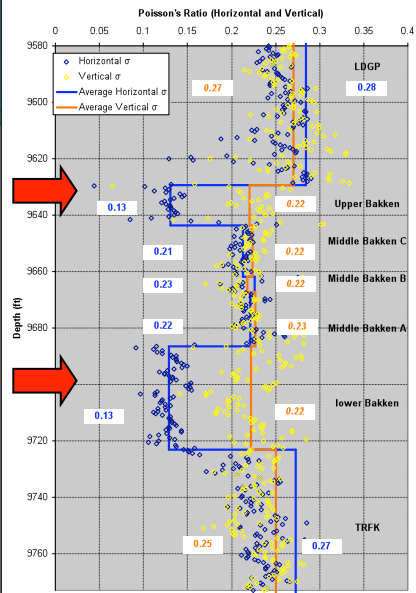
## DCR 43-28H

## DCR 11-5H

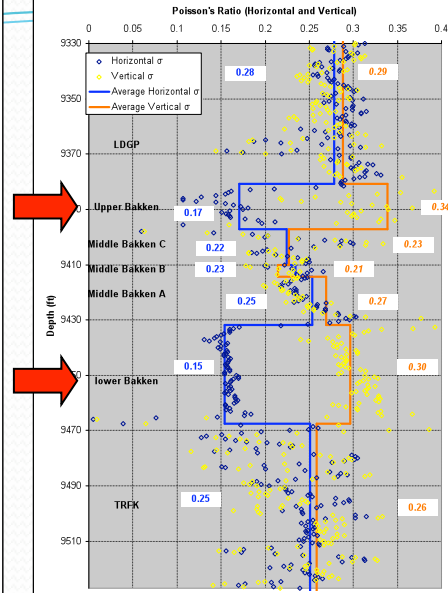
## Annala 11-36H



## Farhart 11-11H



## Rosencrans 44-21H



# Poisson's Ratio

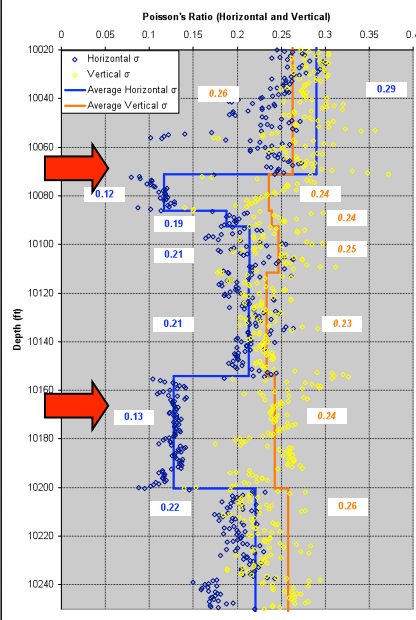
### ❖ Bakken Shales:

- Poisson's Ratio: Horizontal < Vertical
- Variation: Horizontal > Vertical

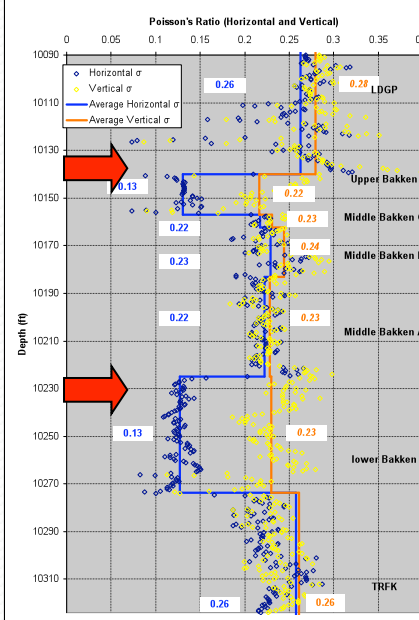
### ❖ Bakken shale vs. Middle Bakken

- Vertical-Horizontal difference
- Horizontal Poisson's ratio variation

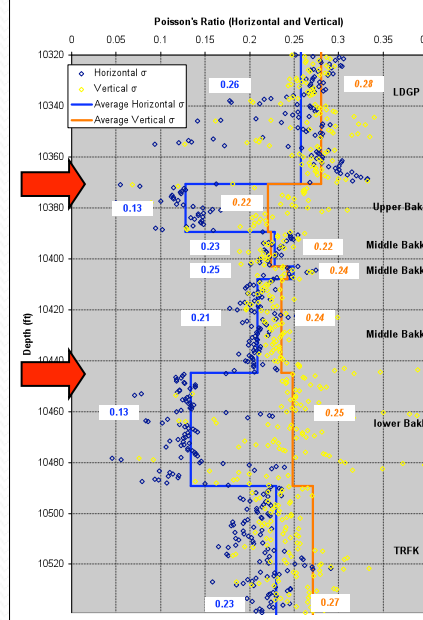
## DCR 43-28H



## DCR 11-5H



## Annala 11-36H



Horizontal

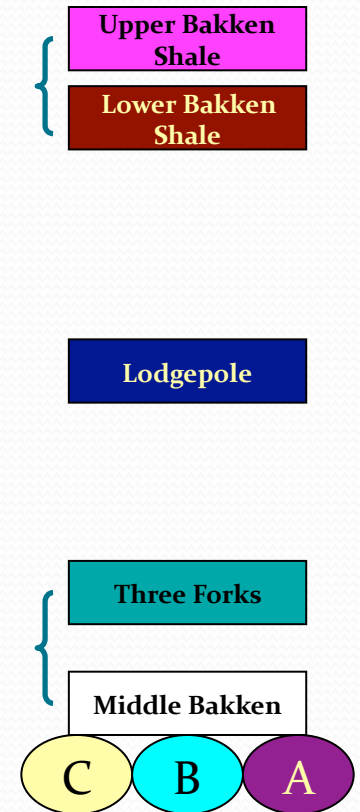
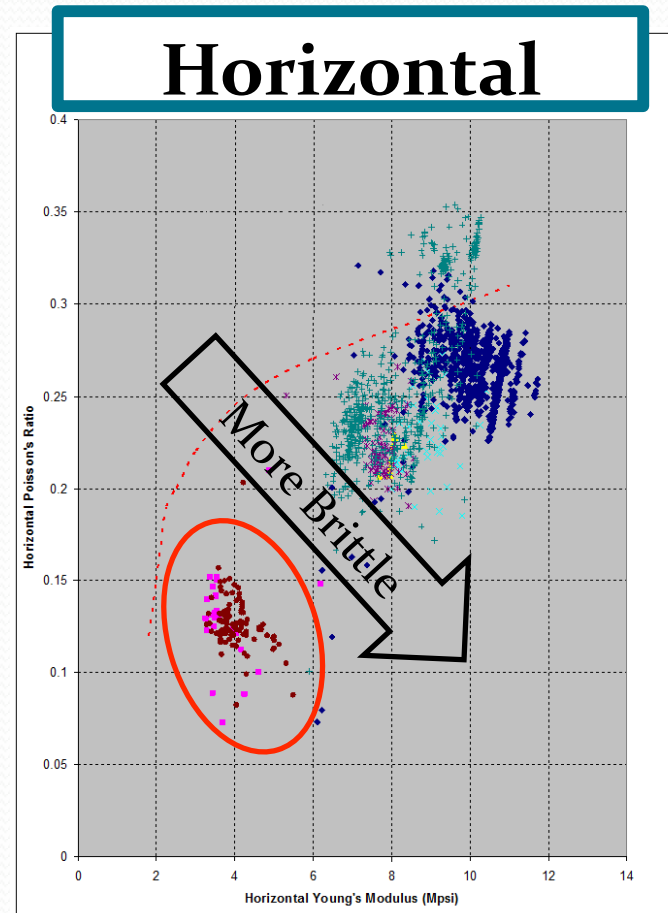
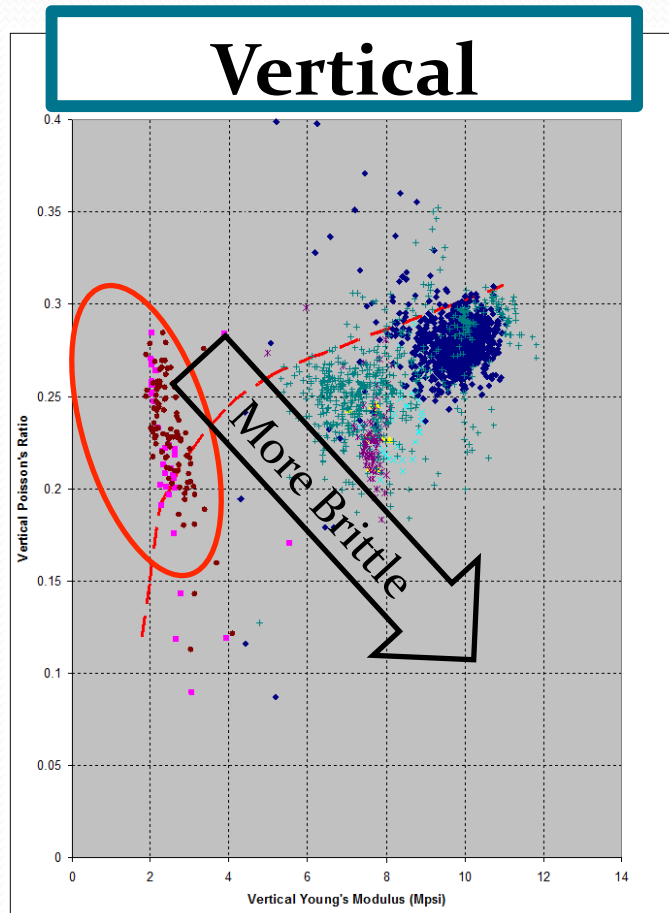


Vertical



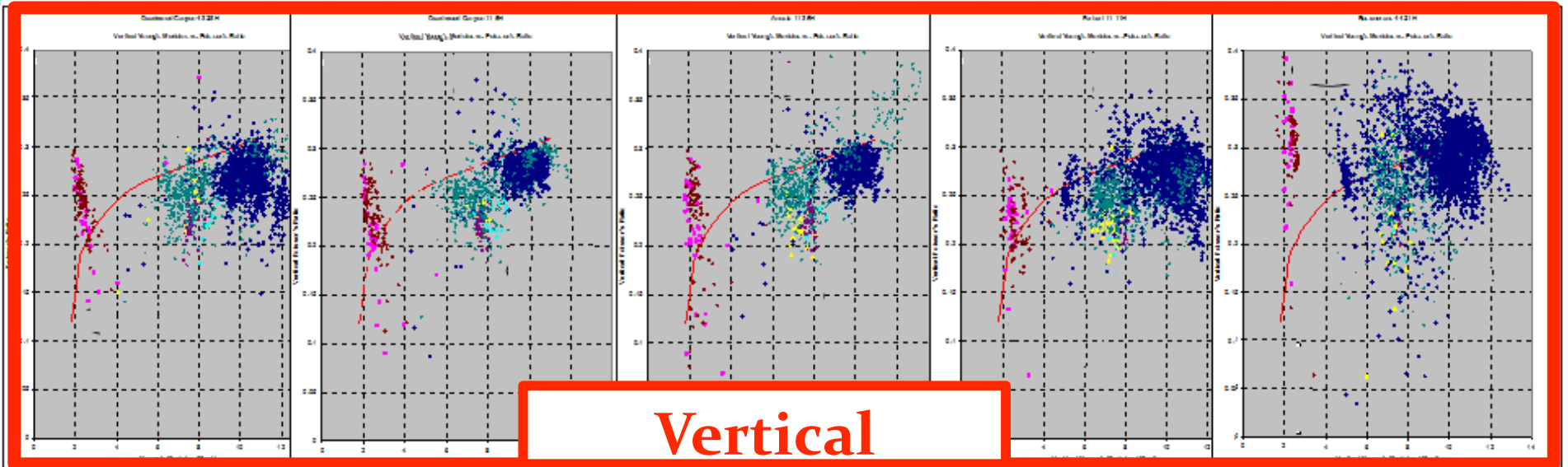


# Young's Modulus vs. Poisson's Ratio



--- Red Line from DFI,2005

# Young's Modulus vs. Poisson's Ratio



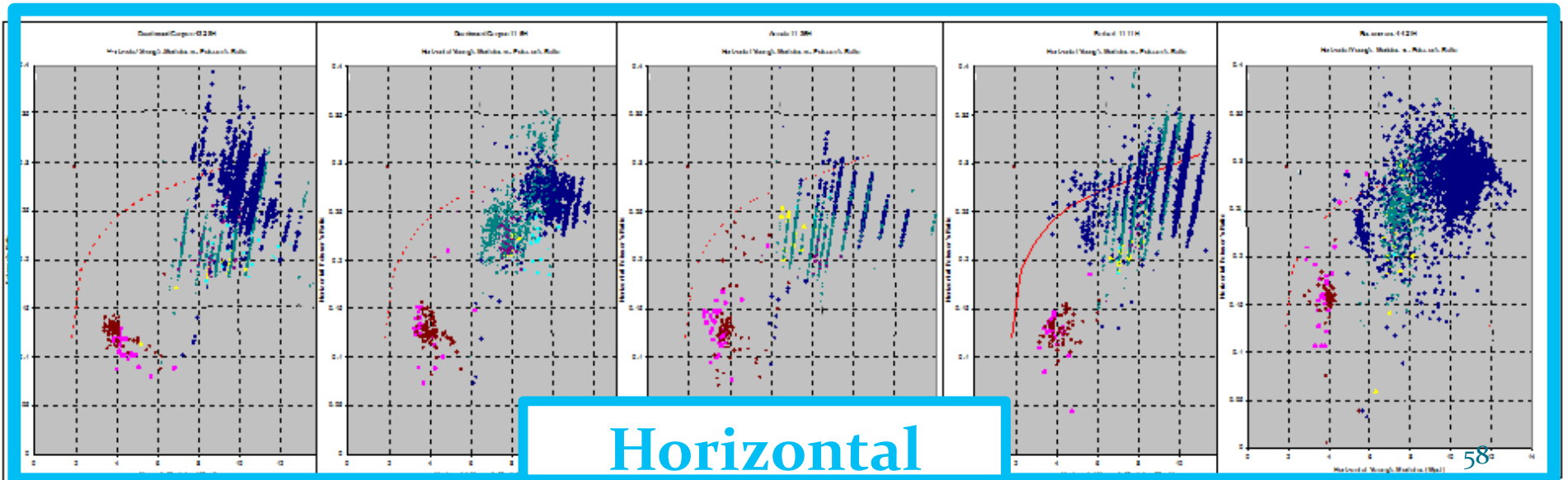
DCR 43-28H

DCR 11-5H

Annala 11-36H

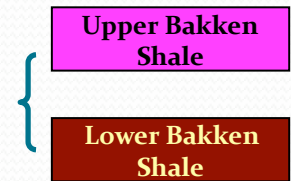
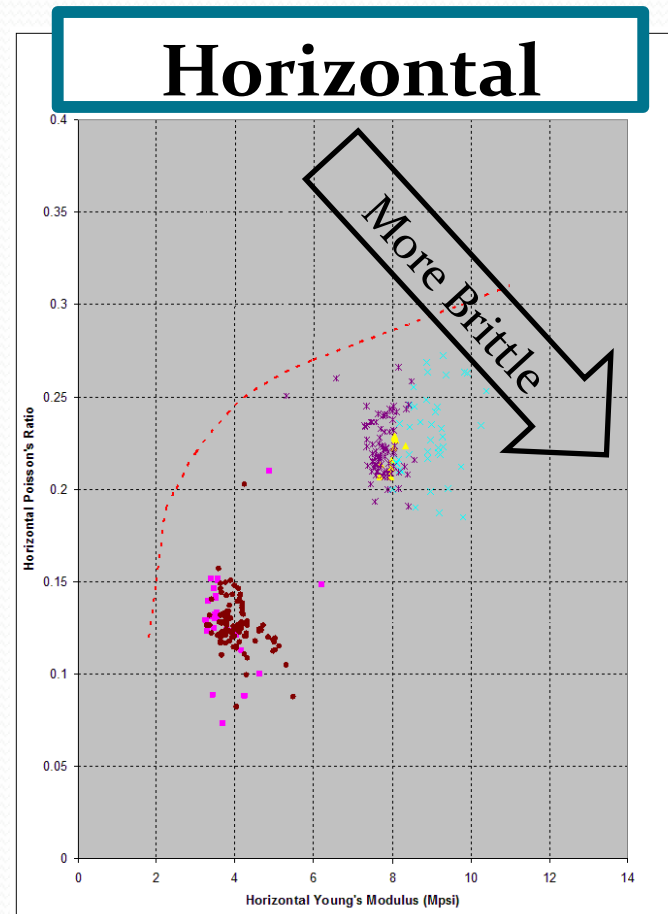
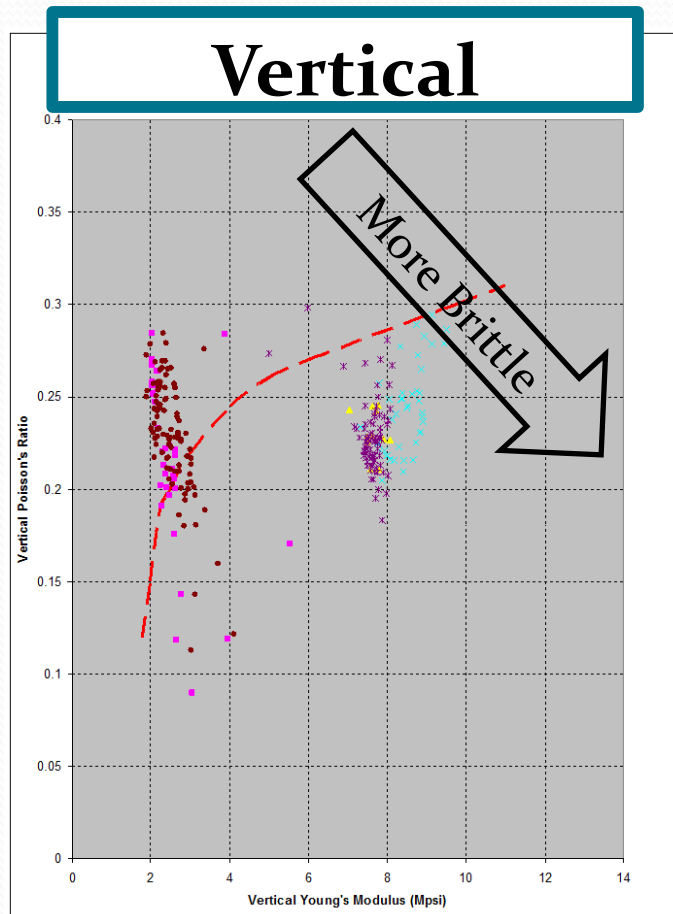
Farhart 11-11H

Rosencrans 44-21H



Horizontal

# Young's Modulus vs. Poisson's Ratio



Middle Bakken

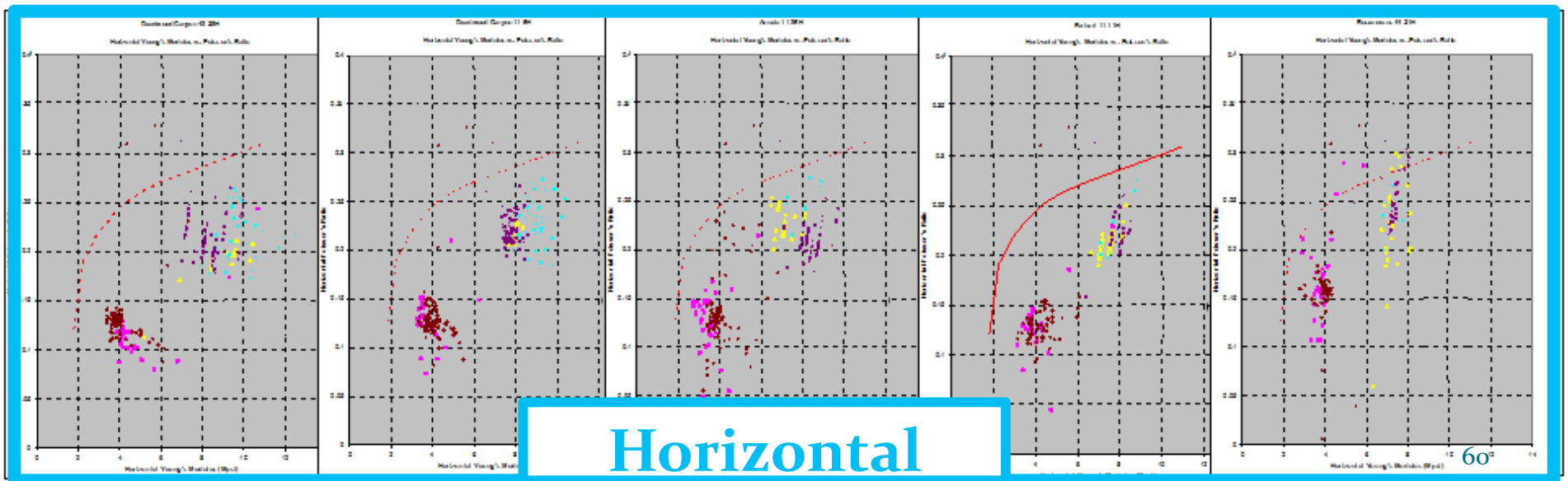
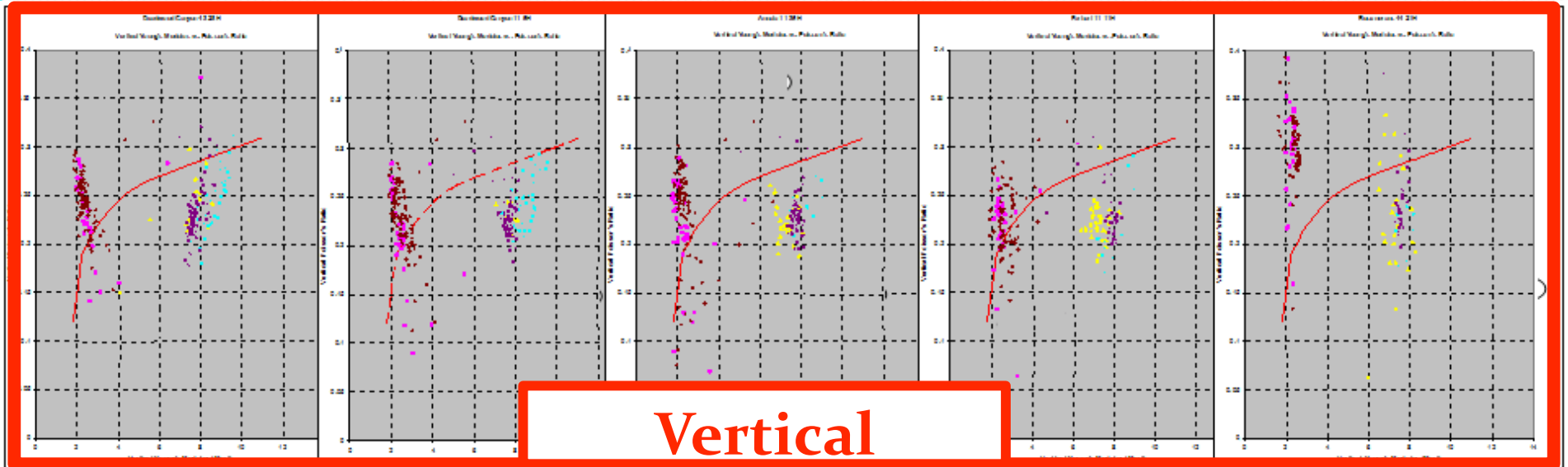
C

B

A

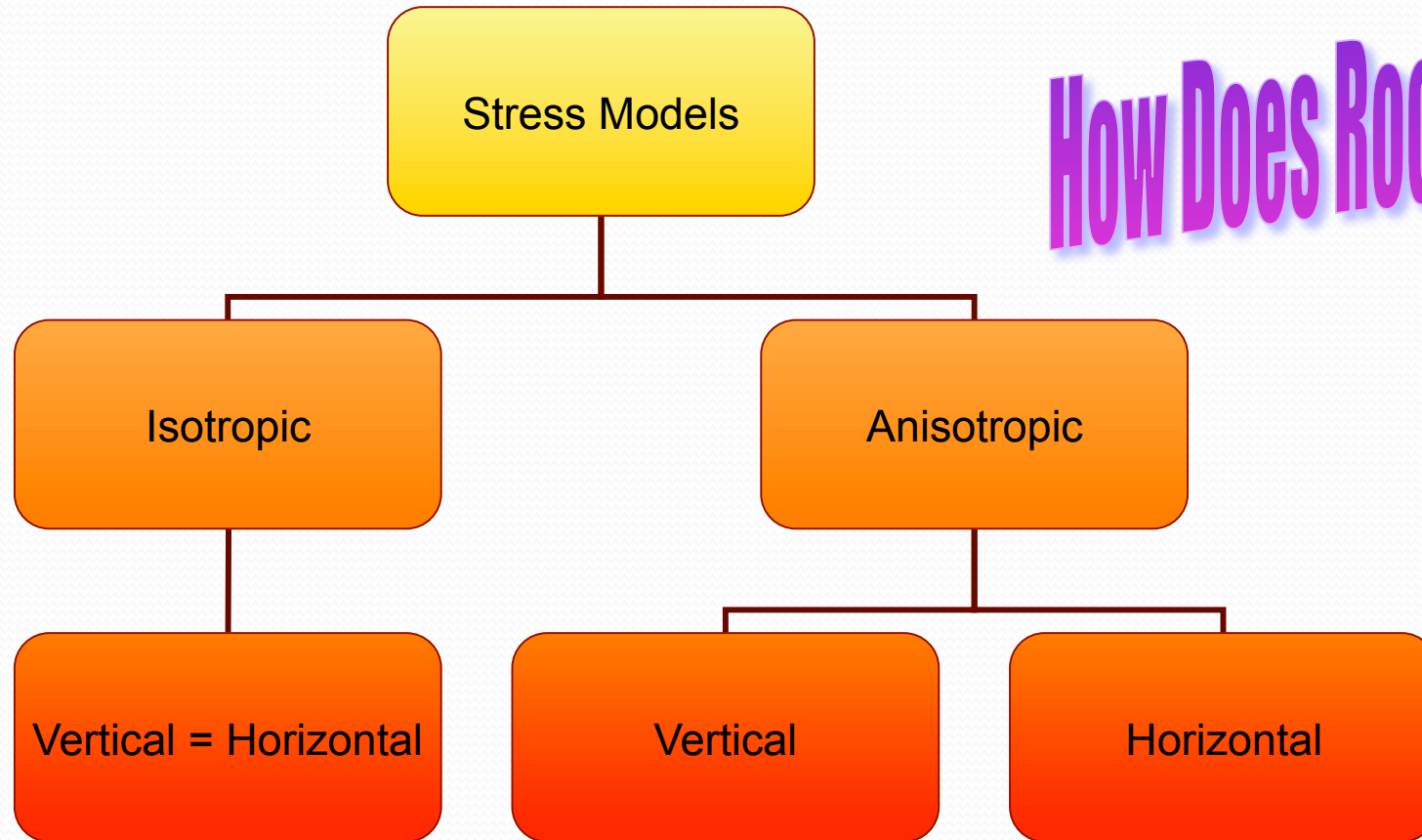
--- Red Line from DFI,2005

# Young's Modulus vs. Poisson's Ratio

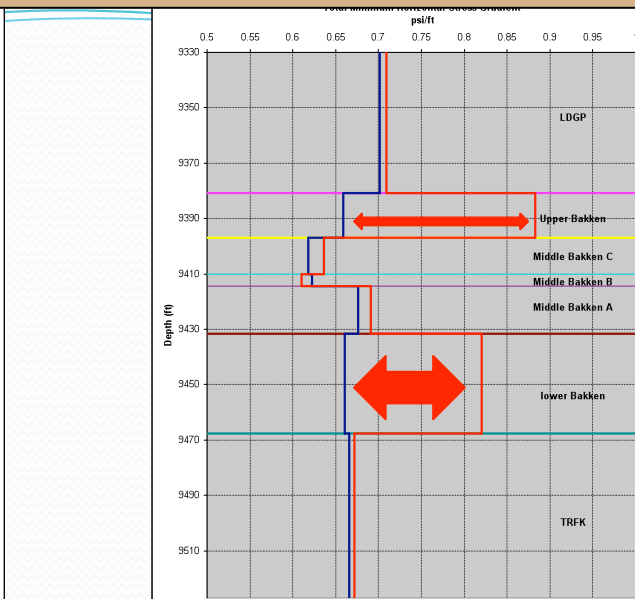
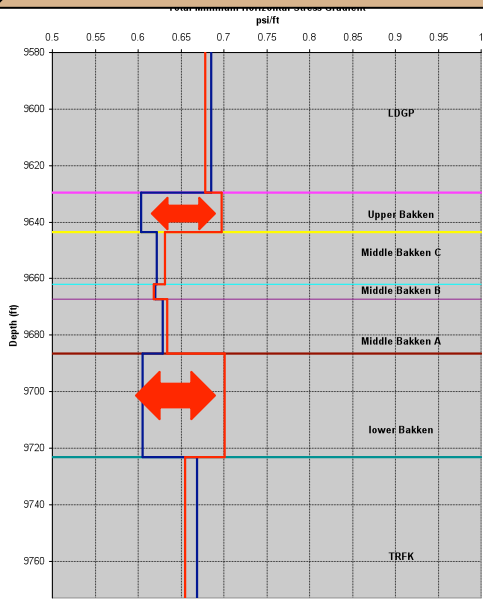


# Stress Models

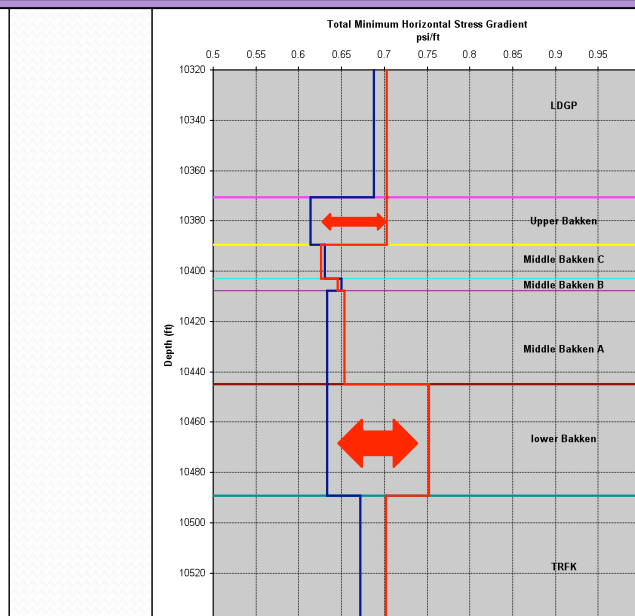
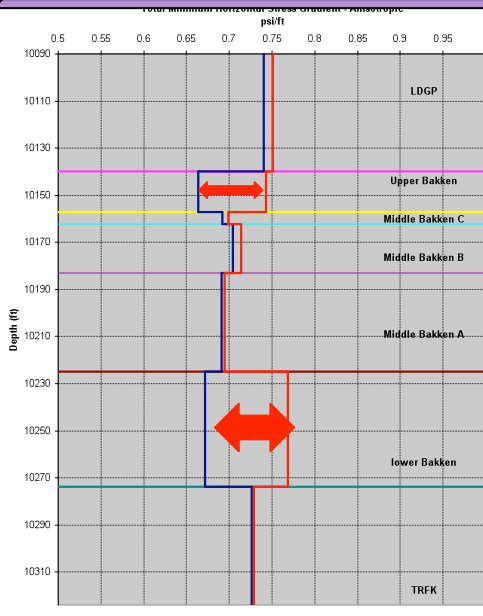
How Does Rock Break?






# Cottonwood Field



# Sanish Field



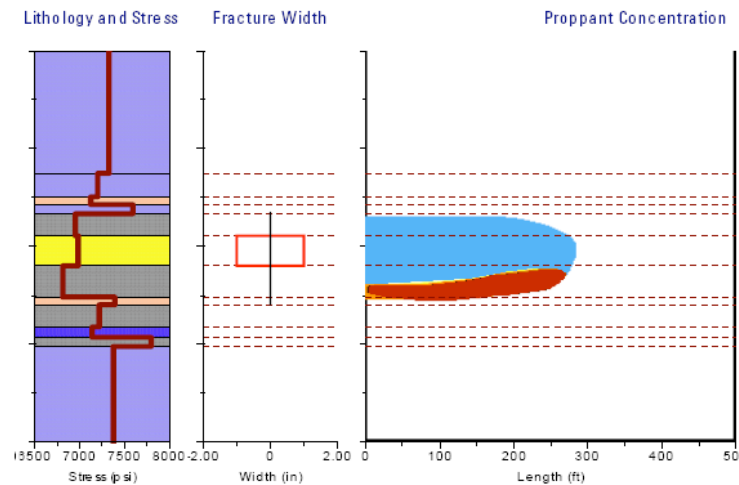
# Stress Gradient

Anisotropic Model	
Isotropic Model	
Difference	

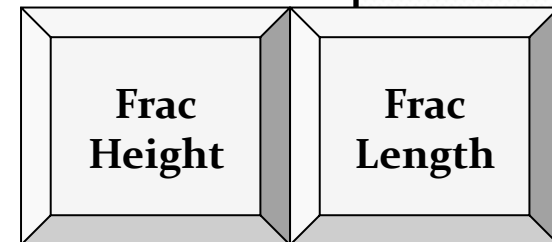
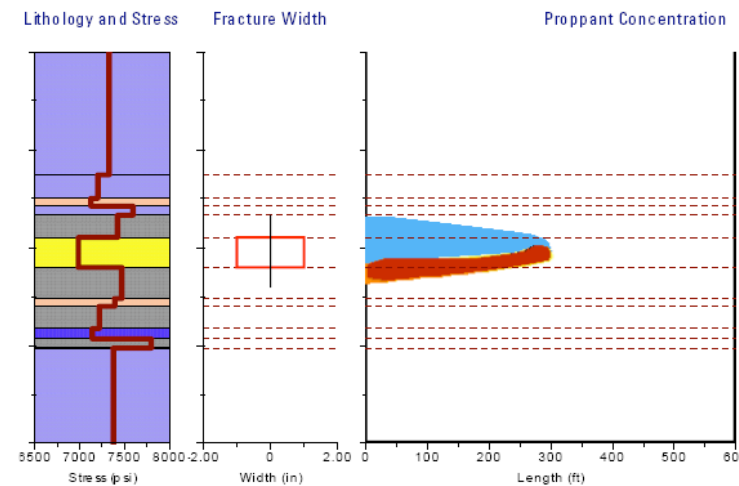
# Stress Models and Fracture Stimulation

## Bakken Shale Stimulation Design – Impact of Anisotropy

Isotropic  
Stress  
Model  
(Slickwater)

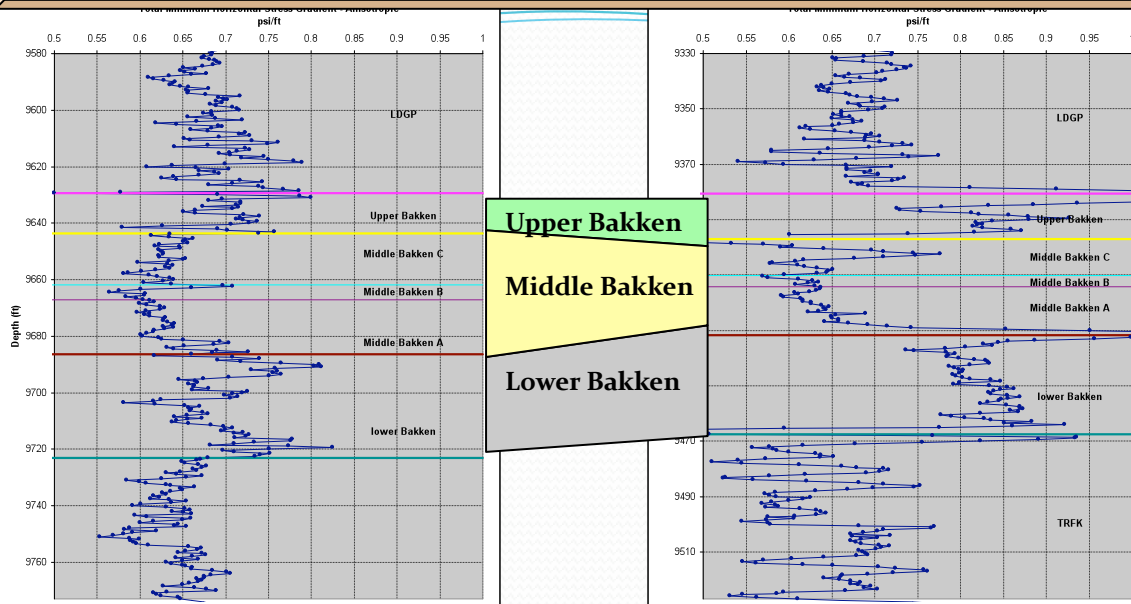


Anisotropic  
Stress  
Model  
(Slickwater)

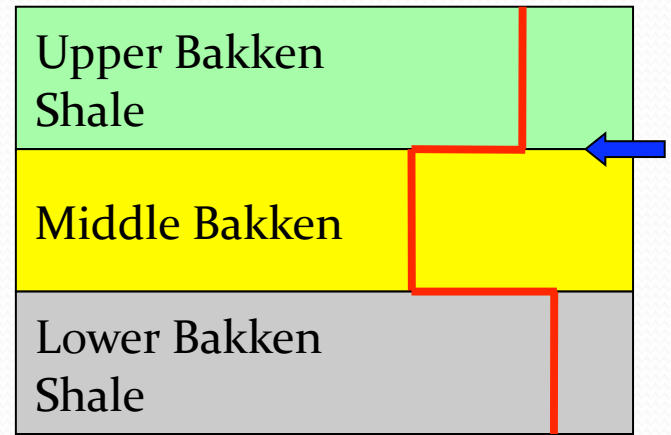


**Schlumberger**

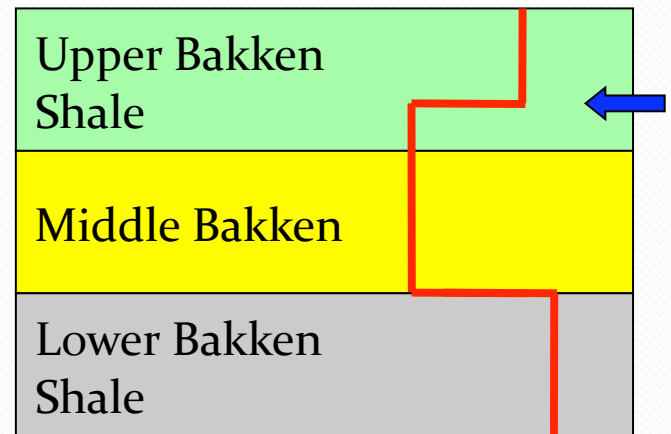
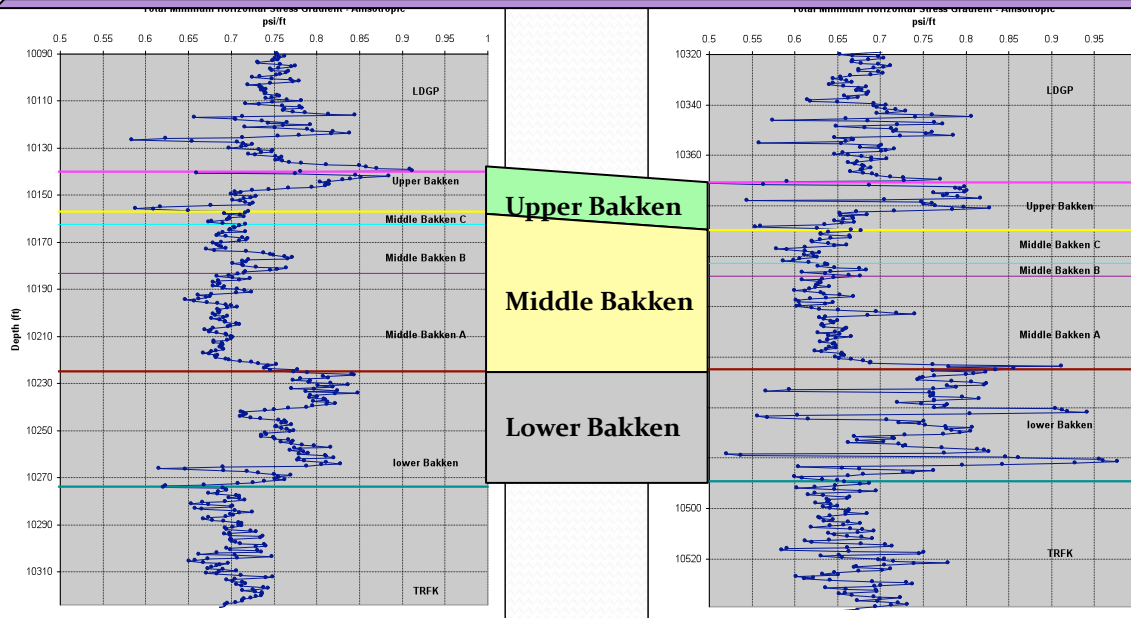
# Cottonwood Field



# Anisotropic Stress Gradient



# Sanish Field





# Outline

- ❖ Introduction
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# Summary

- ❖ The Upper and Lower Bakken shales are characterized by low density , low P and S wave velocities and low  $V_p/V_s$  ratio.
- ❖ The log data suggest that the Upper and Lower Bakken shales are anisotropic while the Middle Bakken may be considered as isotropic.
- ❖ Although the bed thickness of each member of the Bakken is below seismic resolution, it is still possible to observe the difference between seismic responses of the isotropic and anisotropic models.
- ❖ The VTI and HTI anisotropy have different seismic responses. S wave and C wave carry more HTI anisotropy information than P wave.

# Summary

- ❖ The Middle Bakken is sandwiched between the anisotropic Upper and Lower Bakken shales, however, we can still identify the HTI characters of the Middle Bakken.
- ❖ The presence of fracture results in azimuthal anisotropy, which can be observed from wide azimuth seismic data. For P wave, the anisotropy is more pronounced at mid to far offset seismic data.
- ❖ Bakken thickness variation contributes a lot to the difference in seismic responses between Sanish and Cottonwood field.
- ❖ Preliminary azimuthal analysis of field seismic data suggests an acquisition footprint.
- ❖ Study the anisotropy of the Bakken may be critical to understand the variation in production.

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- Robert H. Tatham
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