UT-AUSTIN EDGER FORUM

Workshop on Shales

bp

Anisotropy and Seismic Characterization of the Bakken Formation, East Williston Basin, North Dakota

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The University of Texas at Austin

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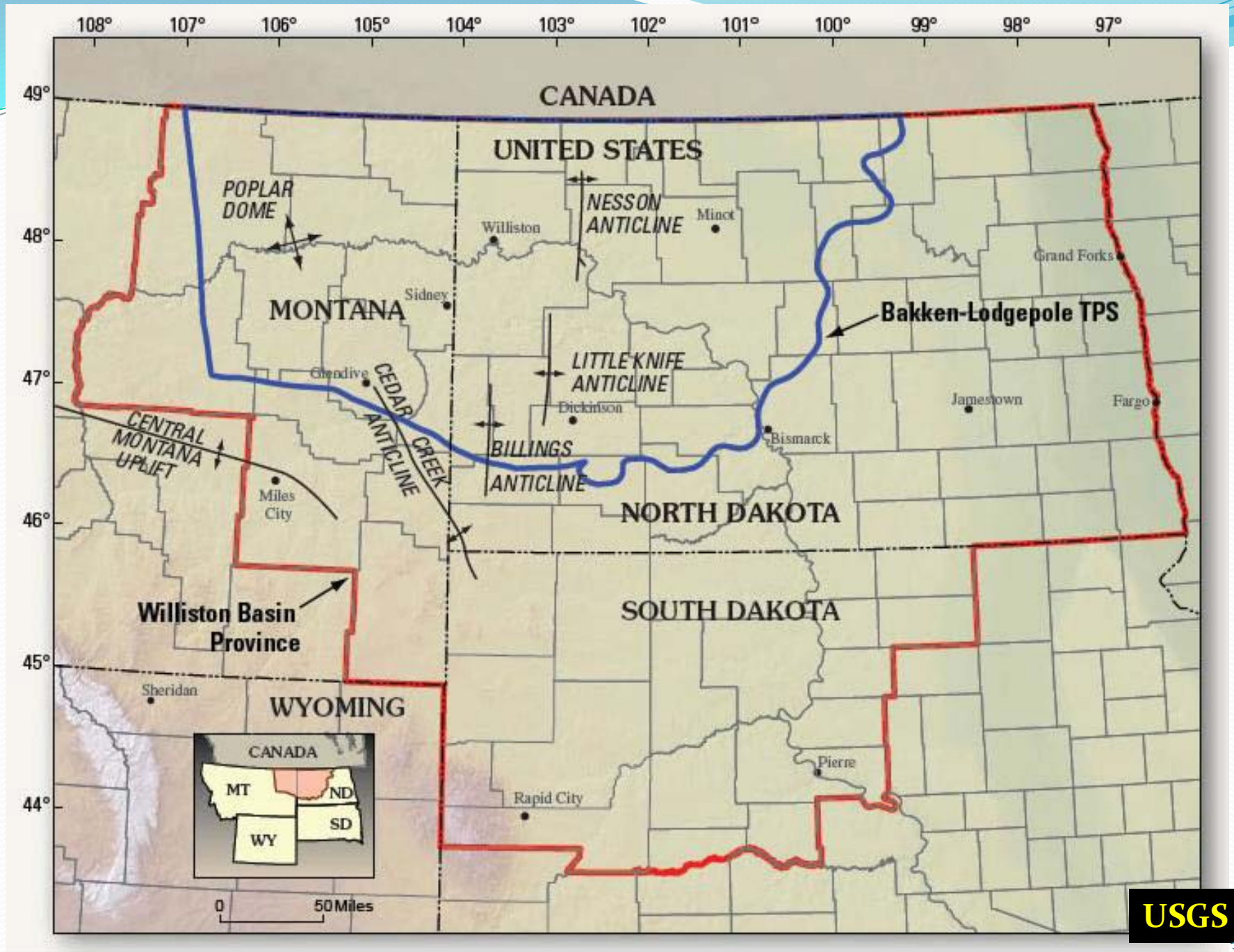
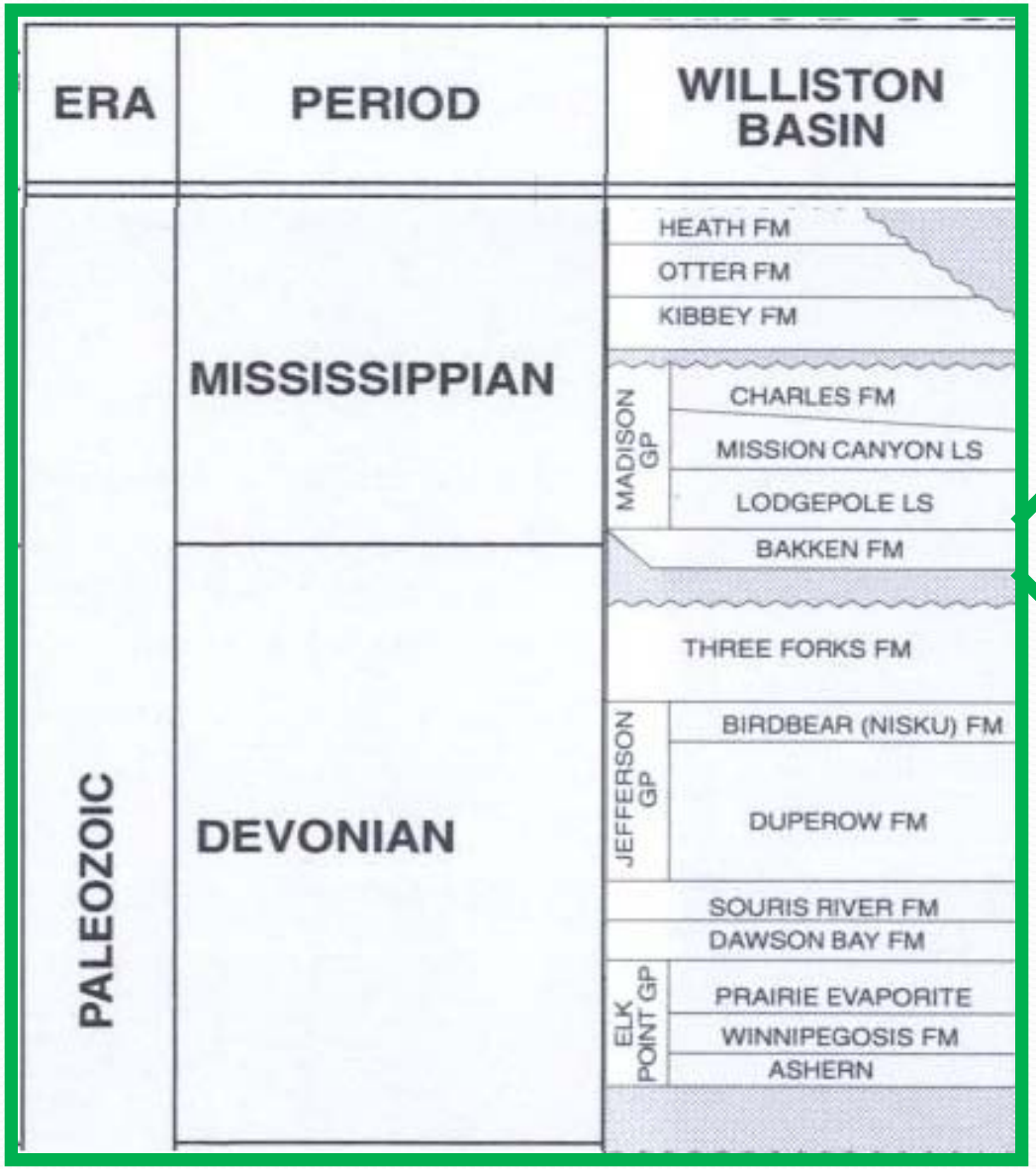
John A. & Katherine G. JACKSON SCHOOL OF GEOSCIENCES

Outline

- Introduction
- Well log analysis
- Seismic modeling
- Summary
- Acknowledgements


108°
107°
106°
105°
104°
103°
102°
101°
100°
99°
98°
97°
49°
48°
47°
46°
45°
44°
CANADA
UNITED STATES
POPLAR DOME
NESSON ANTICLINE
Williston
Minot
Grand Forks
MONTANA
Sidney
Bakken-Lodgepole TPS
LITTLE KNIFE ANTICLINE
Glendive
CEDAR CREEK ANTICLINE
Dickinson
Jamestown
Fargo
Bismarck
CENTRAL MONTANA UPLIFT
BILLINGS ANTICLINE
Miles City
NORTH DAKOTA
Williston Basin Province
SOUTH DAKOTA
Sheridan
WYOMING
CANADA
MT
ND
SD
WY
Pierre
Rapid City
0
50 Miles
USGS

Stratigraphy

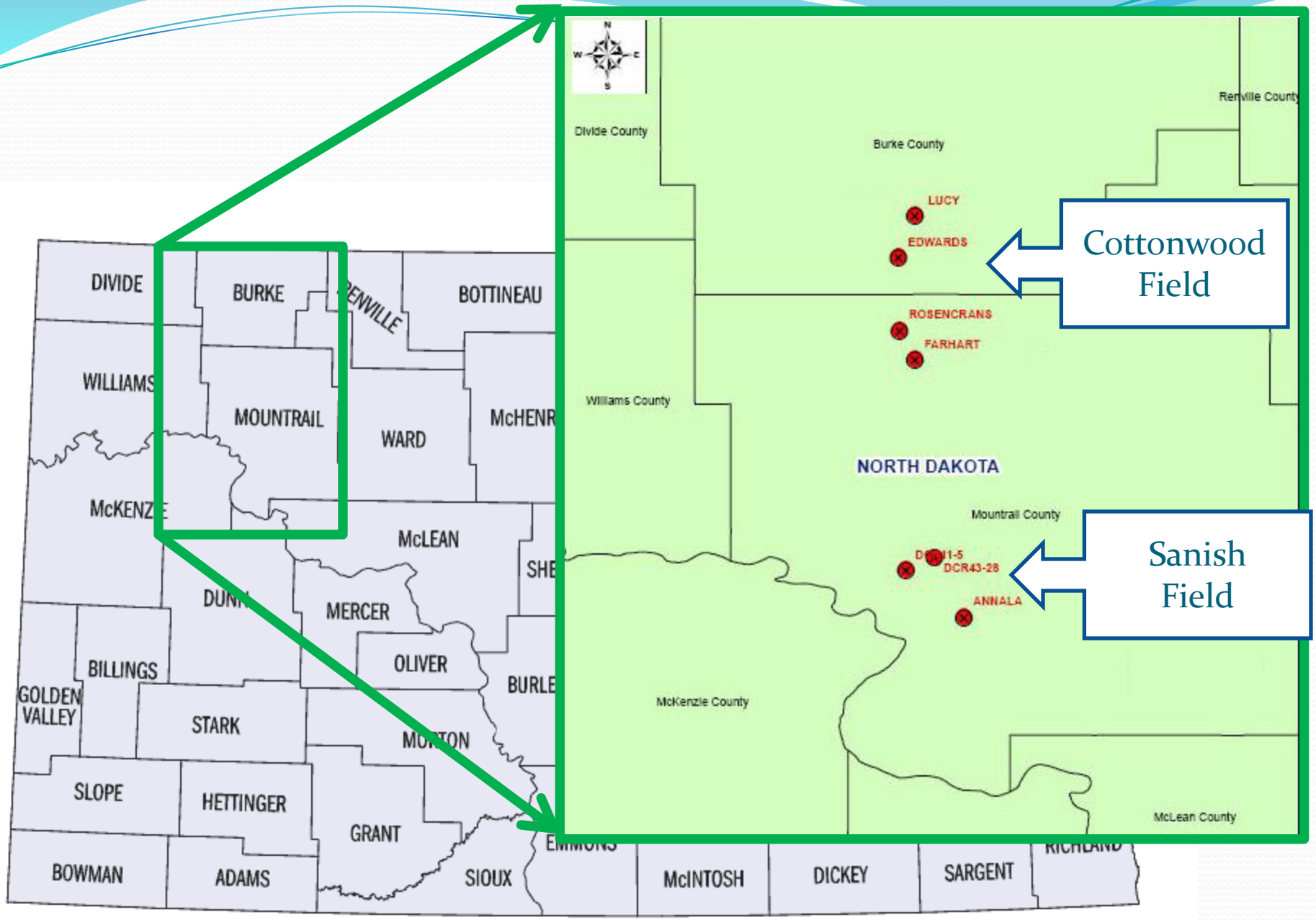


Upper Bakken Shale

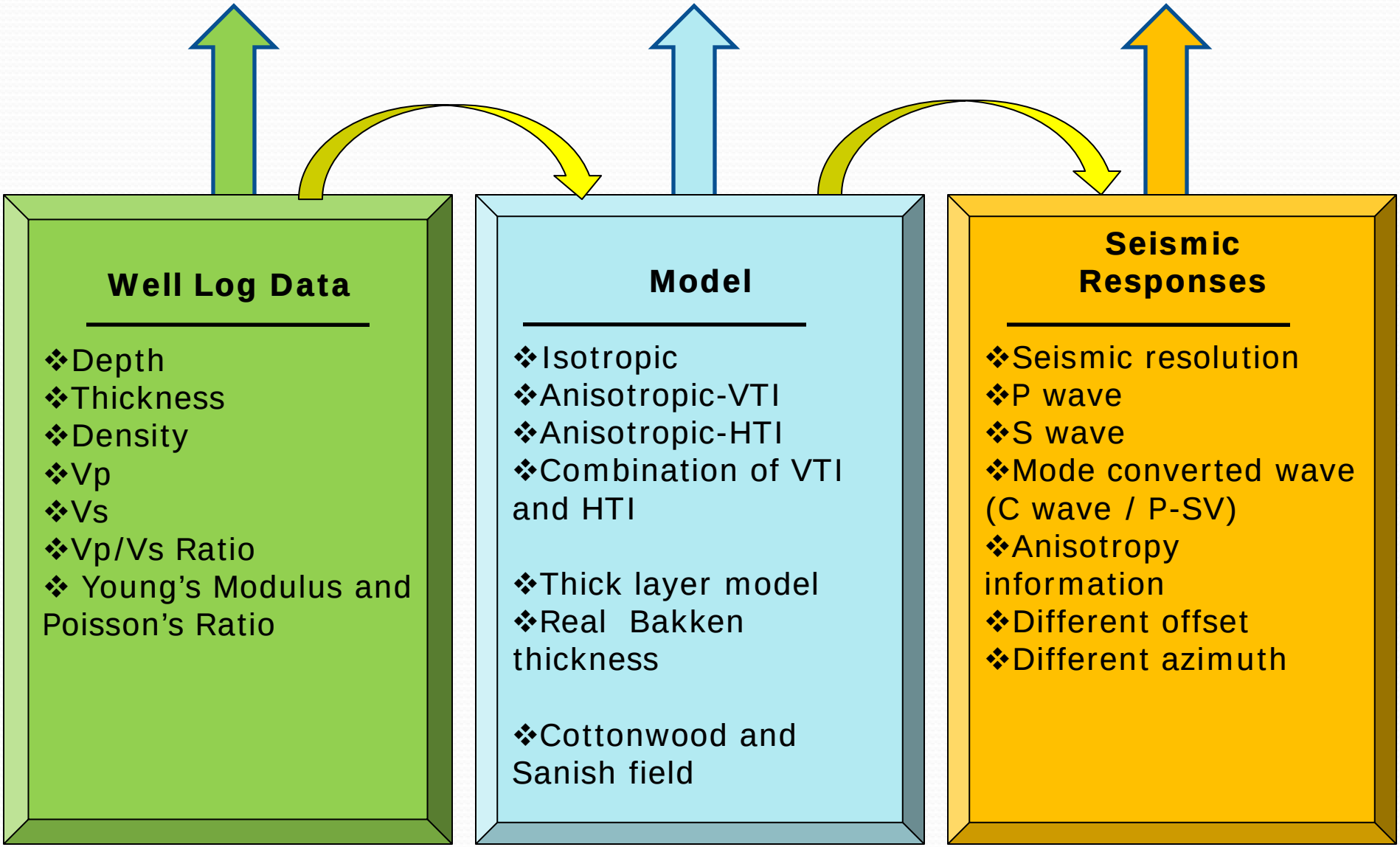
Middle Bakken

Lower Bakken Shale

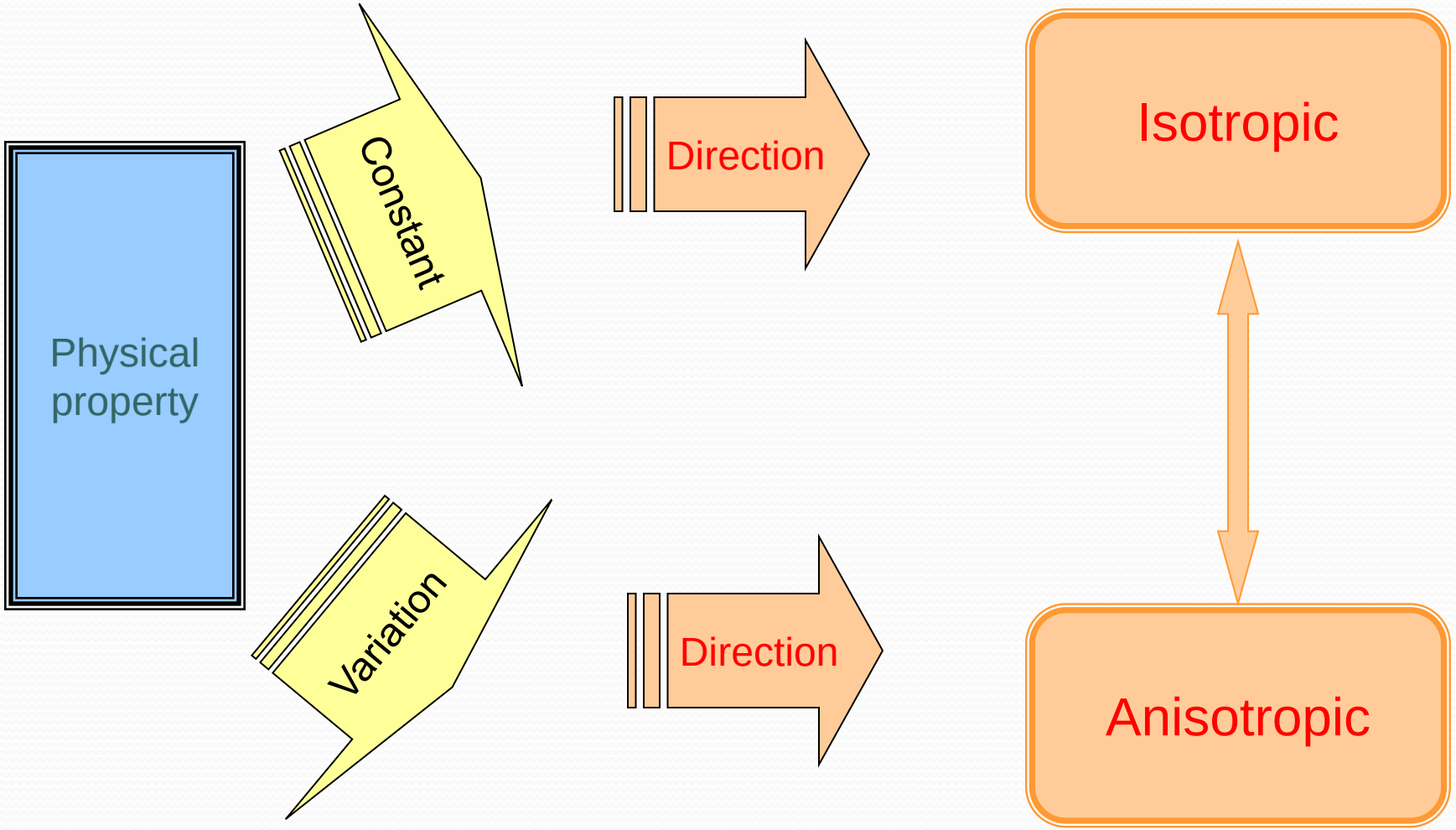
Modified from Montana Board of Oil and Gas


DIVIDE
BURKE
BOTTINEAU
WILLIAMS
MOUNTRAIL
WARD
McHENR
McKENZ
McLEAN
DUNN
MERCER
OLIVER
BILLINGS
GOLDEN VALLEY
STARK
SLOPE
HETTINGER
GRANT
BOWMAN
ADAMS
SIOUX
McINTOSH
DICKEY
SARGENT
Divide County
Burke County
LUCY
EDWARDS
ROSENCRANS
FARHART
Williams County
NORTH DAKOTA
Mountrail County
DCR43-28
ANNALA
McKenzie County
McLean County
Cottonwood Field
Sanish Field

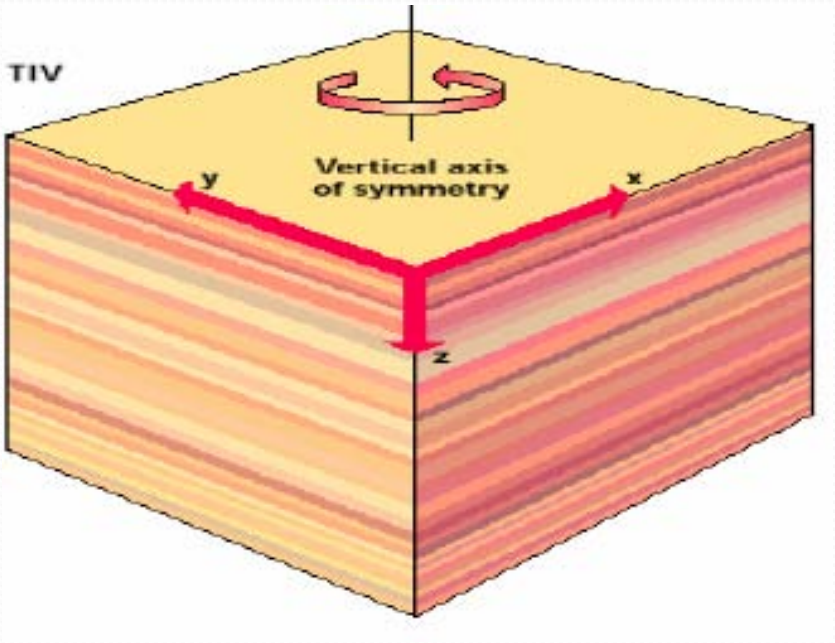
Identify seismically observable characteristics of the Bakken Shale associated with the productivity

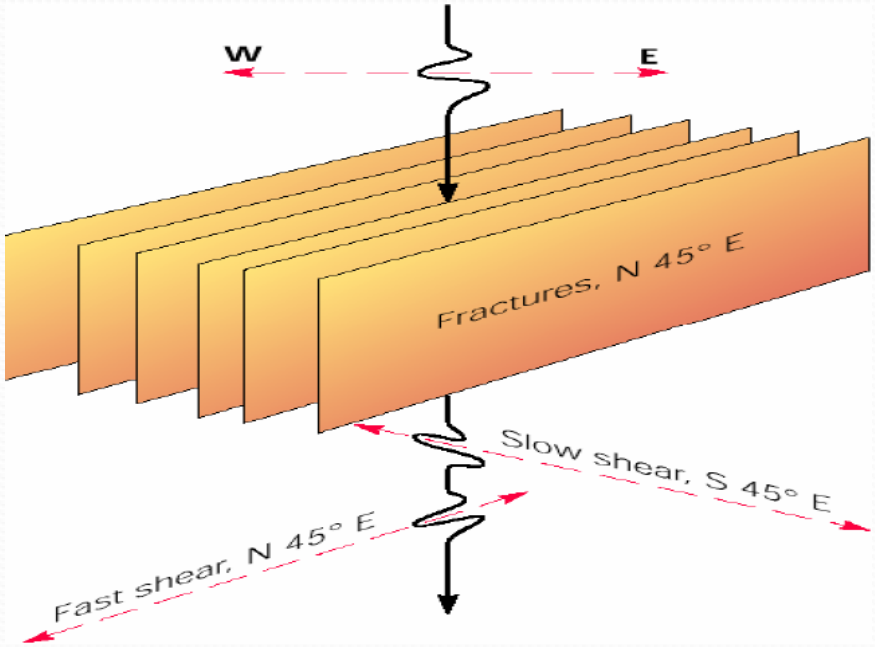


What is anisotropy ?



Transversely Isotropic – VTI & HTI





Schlumberger

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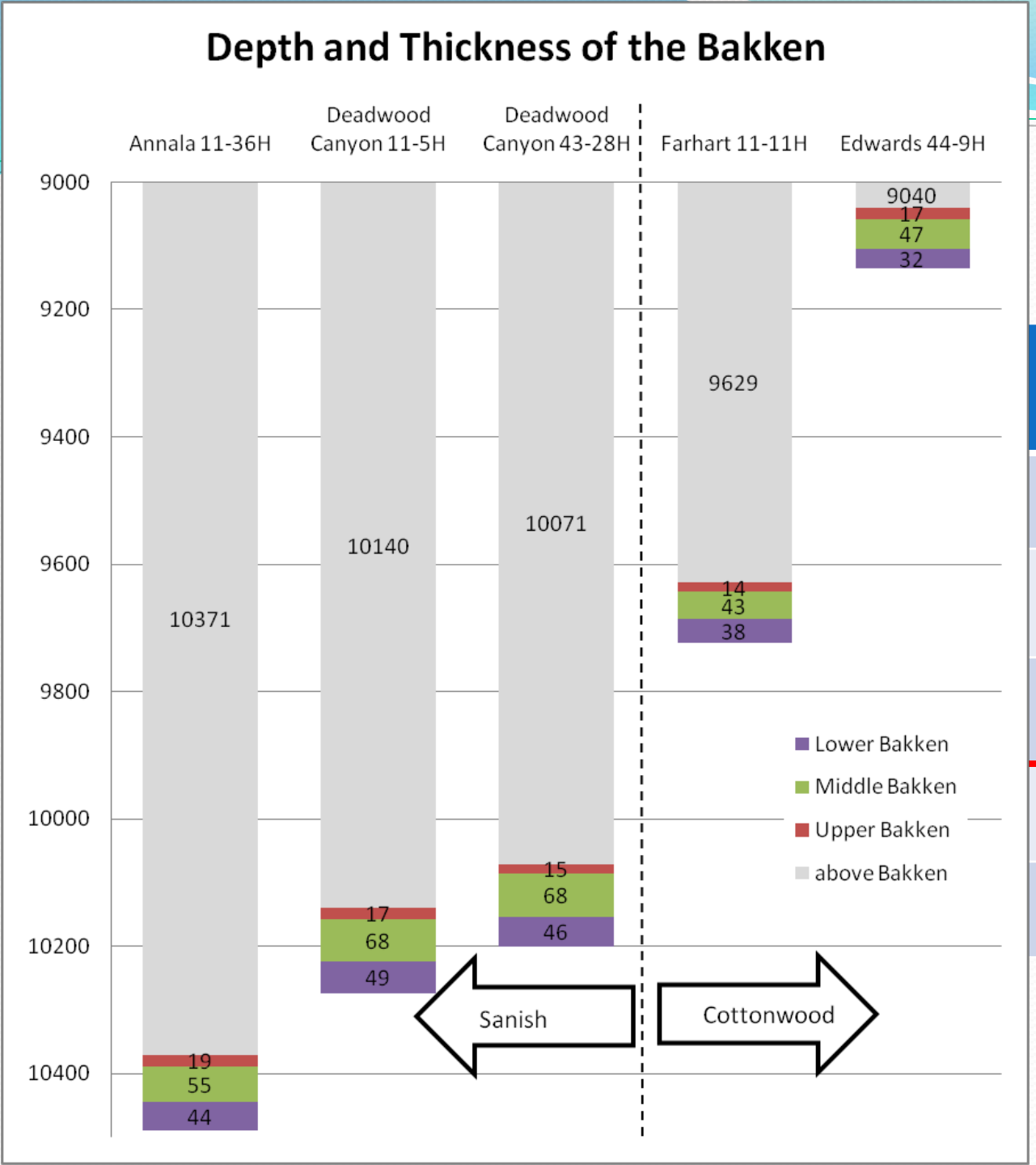
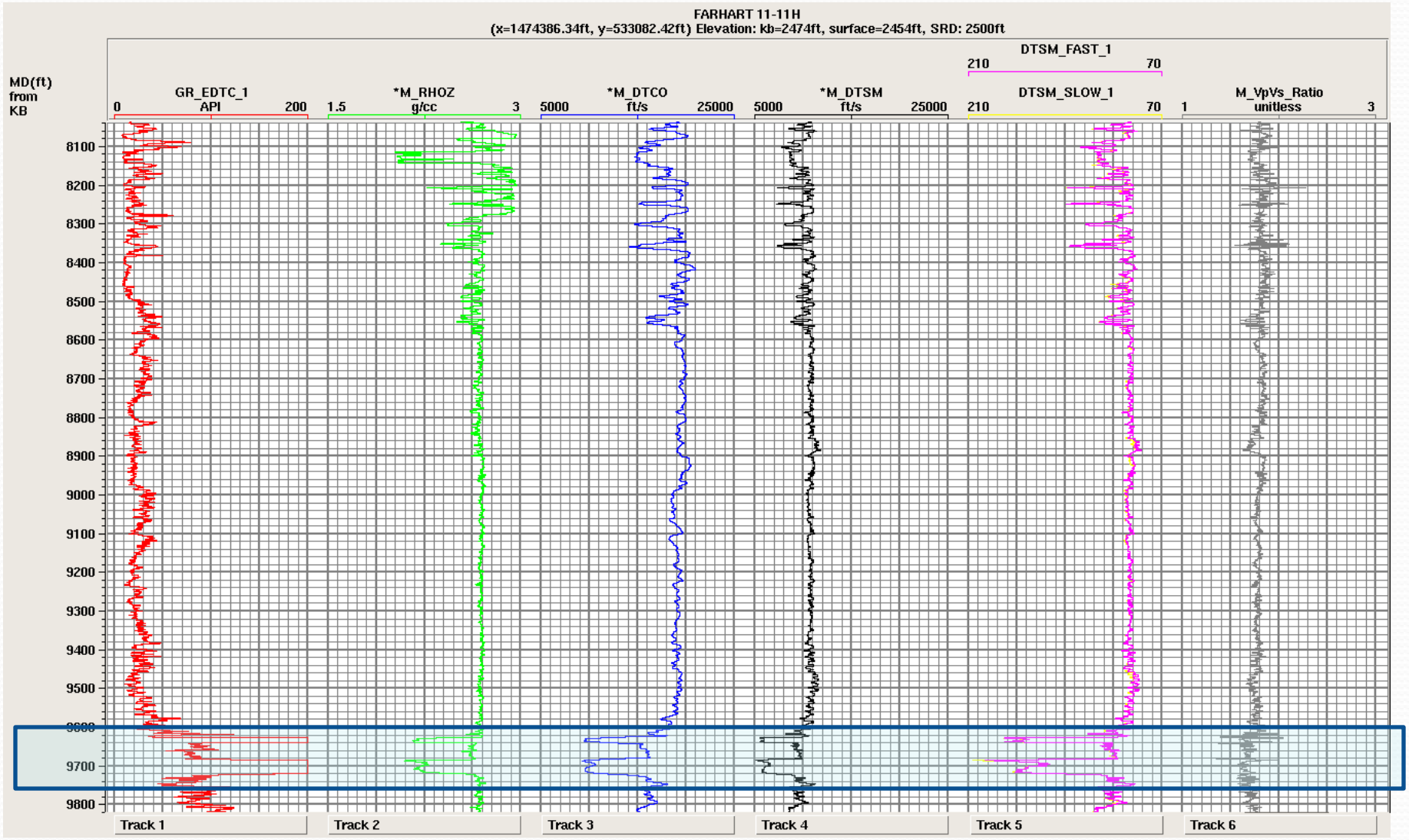
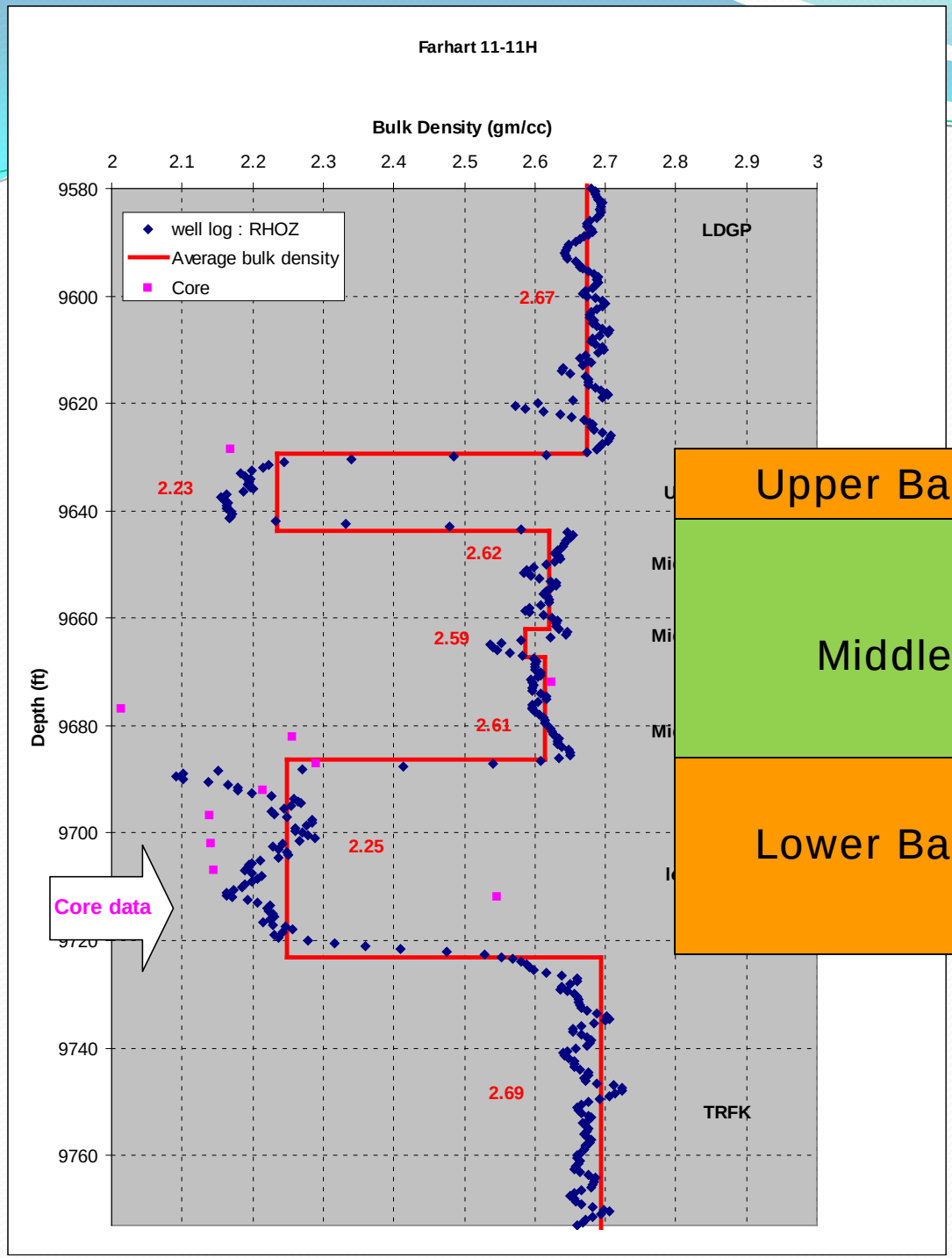
Depth and thickness



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


FARHART 11-11H
(x=1474386.34ft, y=533082.42ft) Elevation: kb=2474ft, surface=2454ft, SRD: 2500ft
MD(ft)
from
KB
GR_EDTC_1
API
0
200
*M_RHOZ
g/cc
1.5
3
*M_DTCO
ft/s
5000
25000
*M_DTSM
ft/s
5000
25000
DTSM_FAST_1
210
70
DTSM_SLOW_1
210
70
M_VpVs_Ratio
unitless
1
3
8100
8200
8300
8400
8500
8600
8700
8800
8900
9000
9100
9200
9300
9400
9500
9700
9800
Track 1
Track 2
Track 3
Track 4
Track 5
Track 6

Density



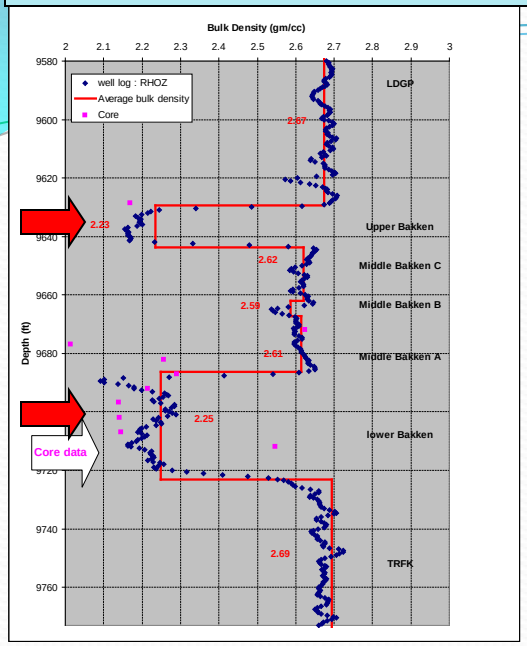
Upper Bakken Shale

Middle Bakken

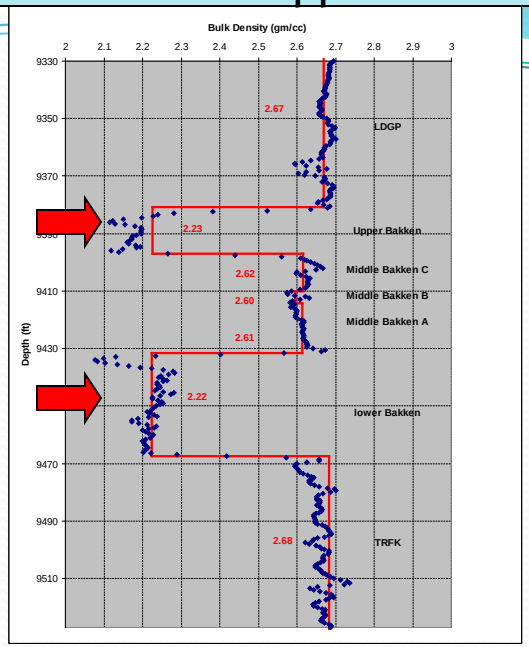
Lower Bakken Shale

Density

Farhart 11-11H



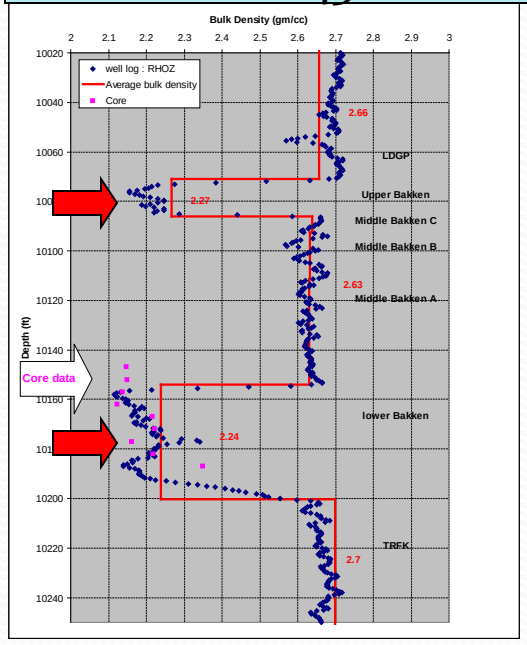
Rosencrans 44-21H



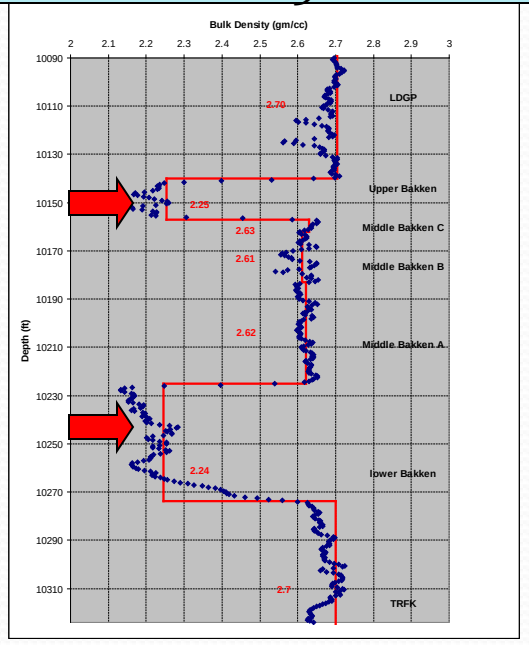
Average Density (gm/cc)

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

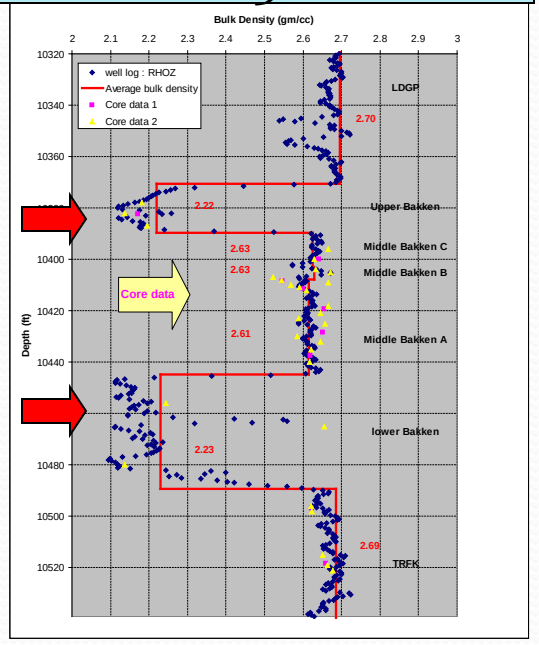
DCR 43-28H



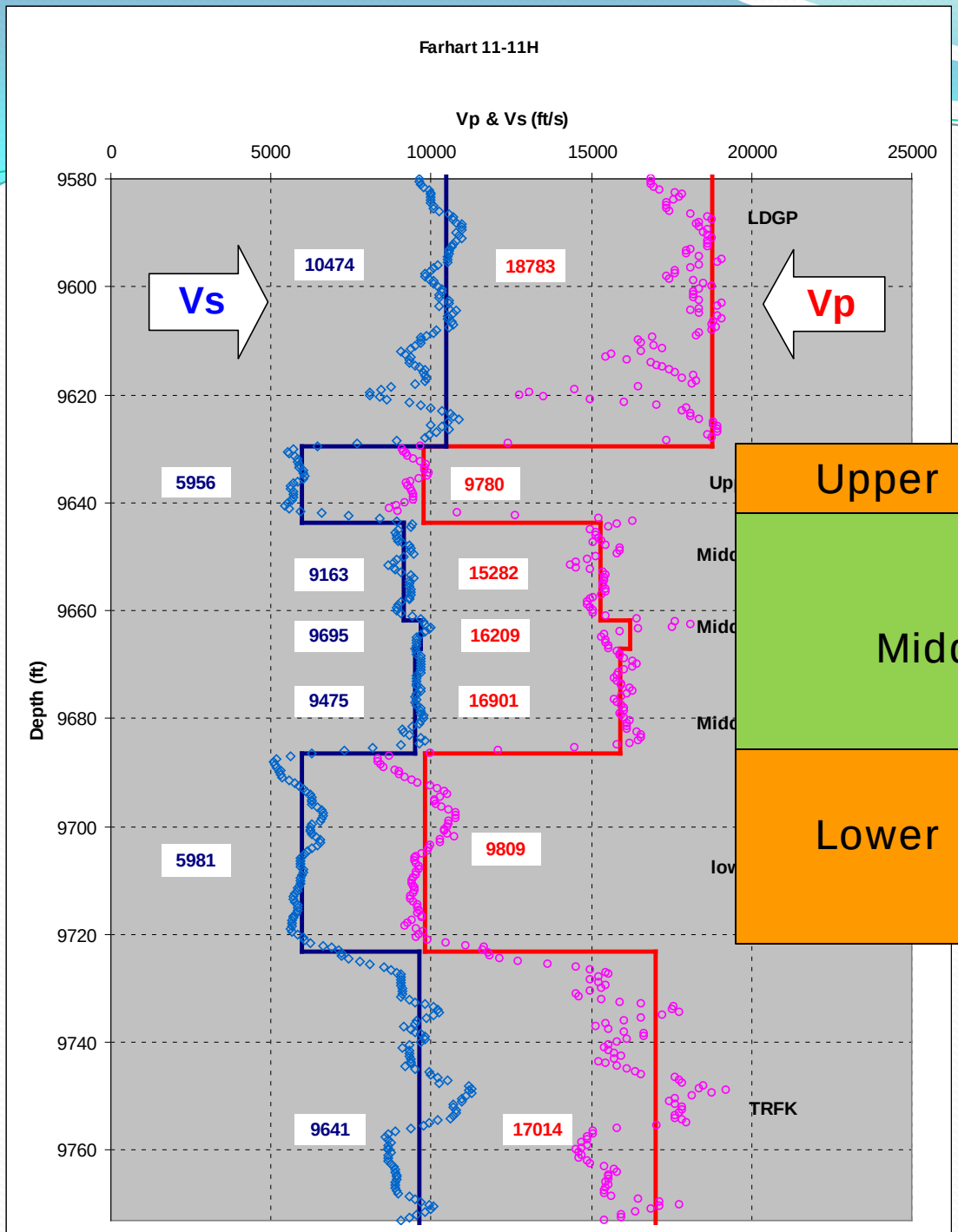
DCR 11-5H



Annala 11-36H

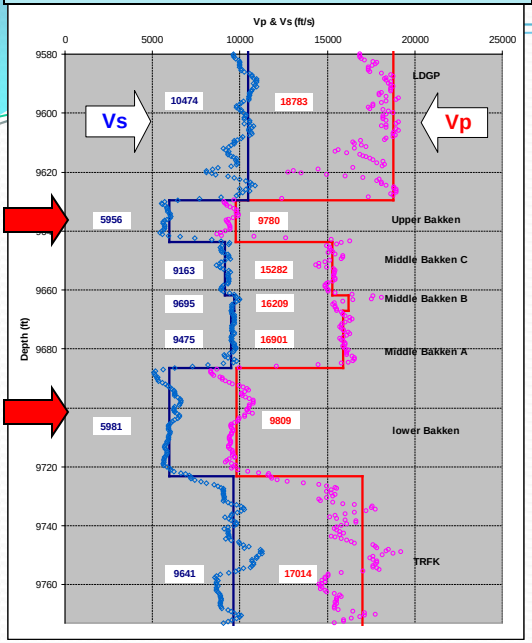


P-wave and S-wave Velocity



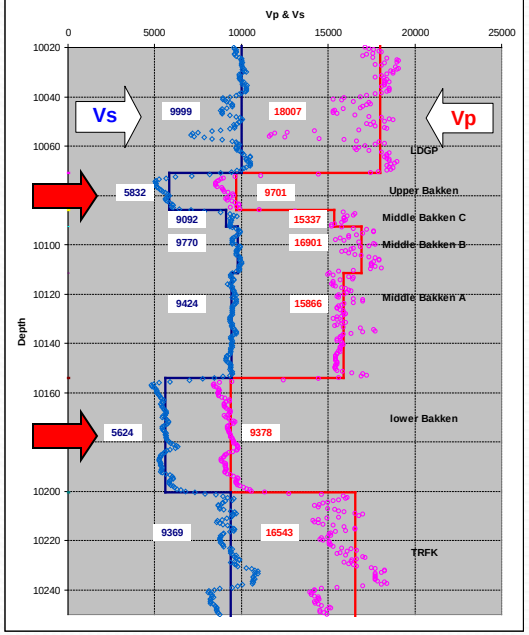
P-wave and S-wave Velocity

Farhart 11-11H

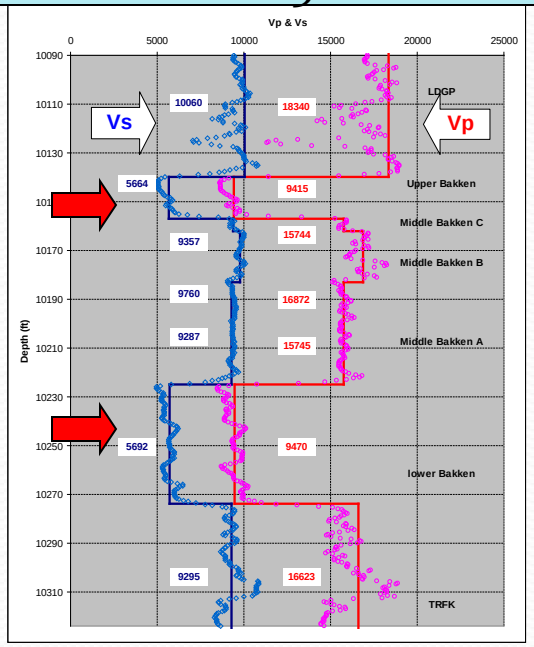


- **Bakken Shales : Low P and S velocity**
  - Vp: ~9500ft/s
  - Vs: ~5700ft/s
- **Middle Bakken :**
  - Vp: ~16000ft/s
  - Vs: ~9400ft/s

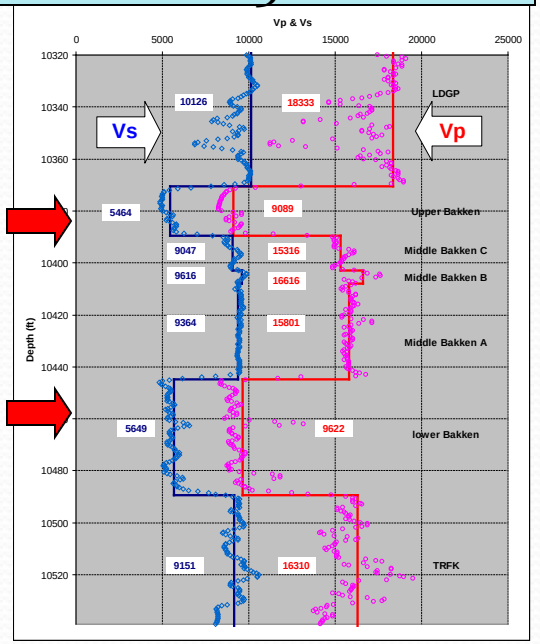
DCR 43-28H



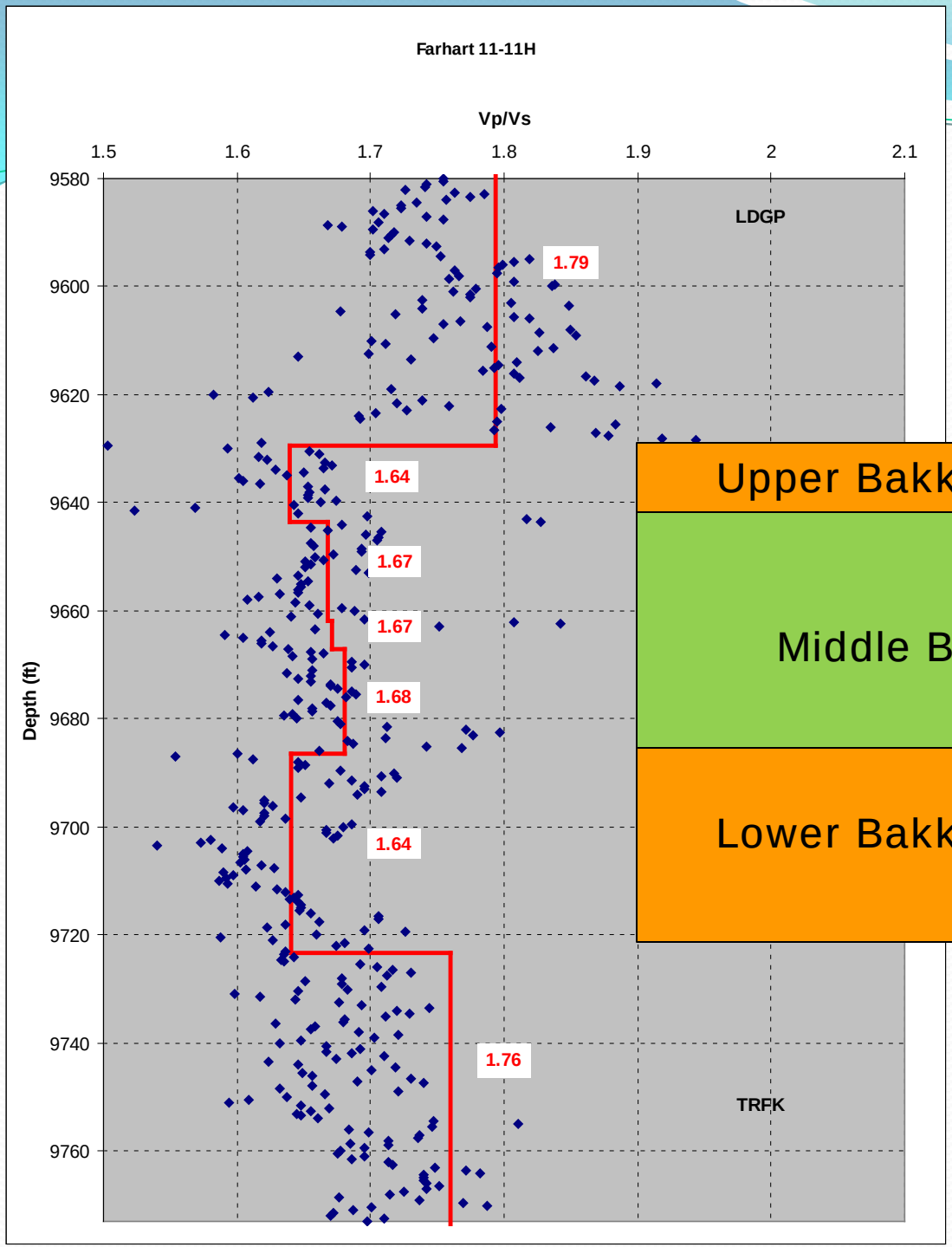
DCR 11-5H



Annala 11-36H



Vp / Vs



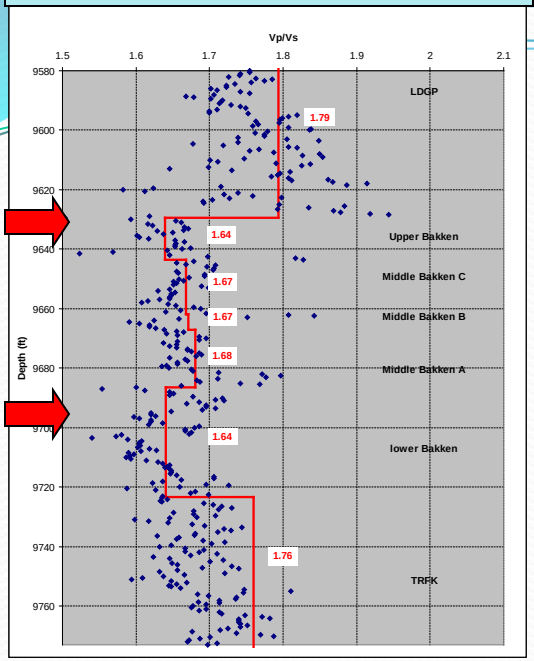
Upper Bakken Shale

Middle Bakken

Lower Bakken Shale

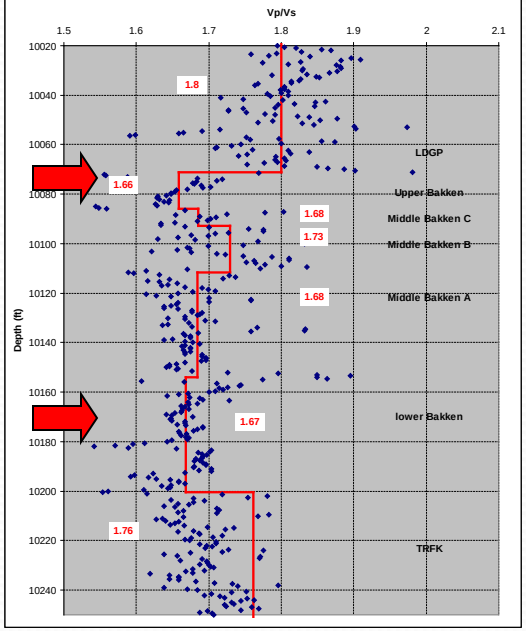
Vp / Vs

Farhart 11-11H

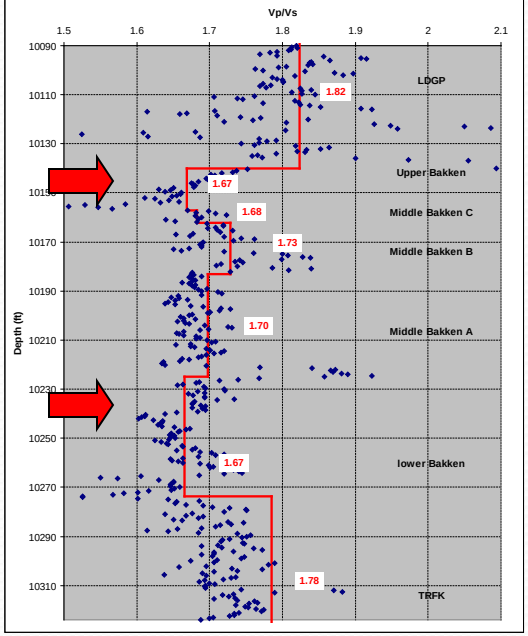


- **Bakken Shale : Low Vp/Vs**

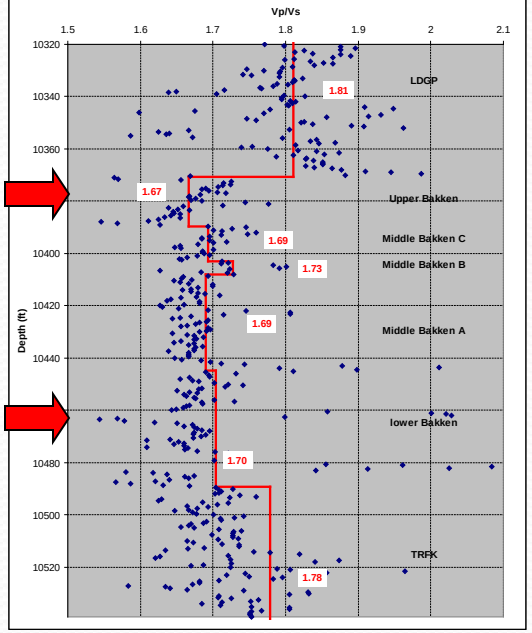
DCR 43-28H



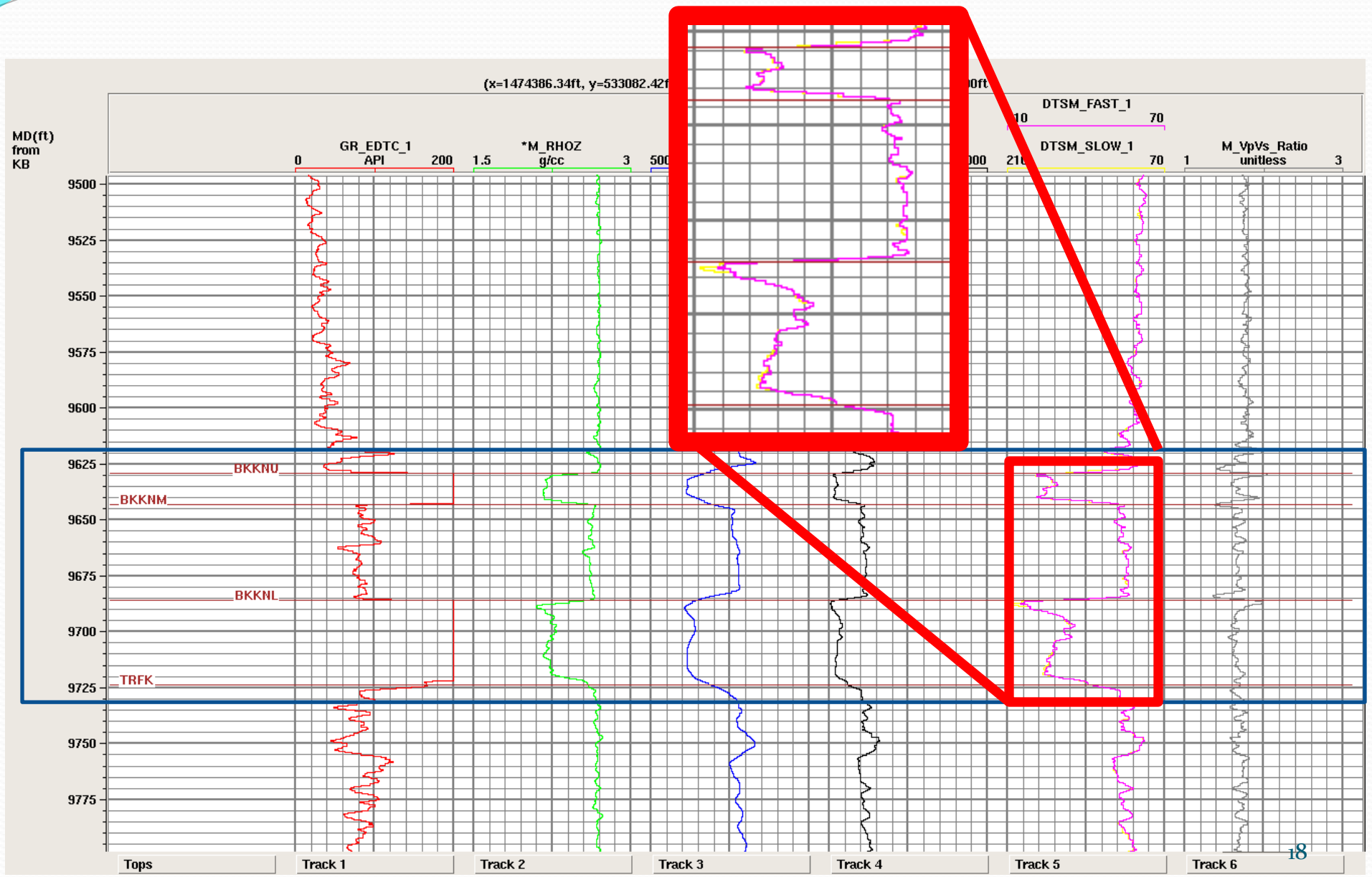
DCR 11-5H



Annala 11-36H



Fast Shear and Slow Shear ?



Young's Modulus and Poisson's Ratio

		Young's Modulus Horizontal / Vertical					Poisson's Ratio 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
Upper Bakken Shale		1.62	1.52	1.74	1.47	1.52	0.5	0.59	0.5	0.6	0.58
Middle Bakken	C	1.00	1.04	1.20	1.04	0.98	0.99	0.95	0.79	0.94	1.02
	B	0.93	0.97	1.12	1.05	0.98	1.09	1.04	0.84	0.93	1.03
	A	1.01	1.02	1.08	1.02	1.09	0.94	0.98	0.91	0.97	0.89
Lower Bakken Shale		1.64	1.55	1.67	1.60	1.60	0.52	0.58	0.54	0.55	0.54

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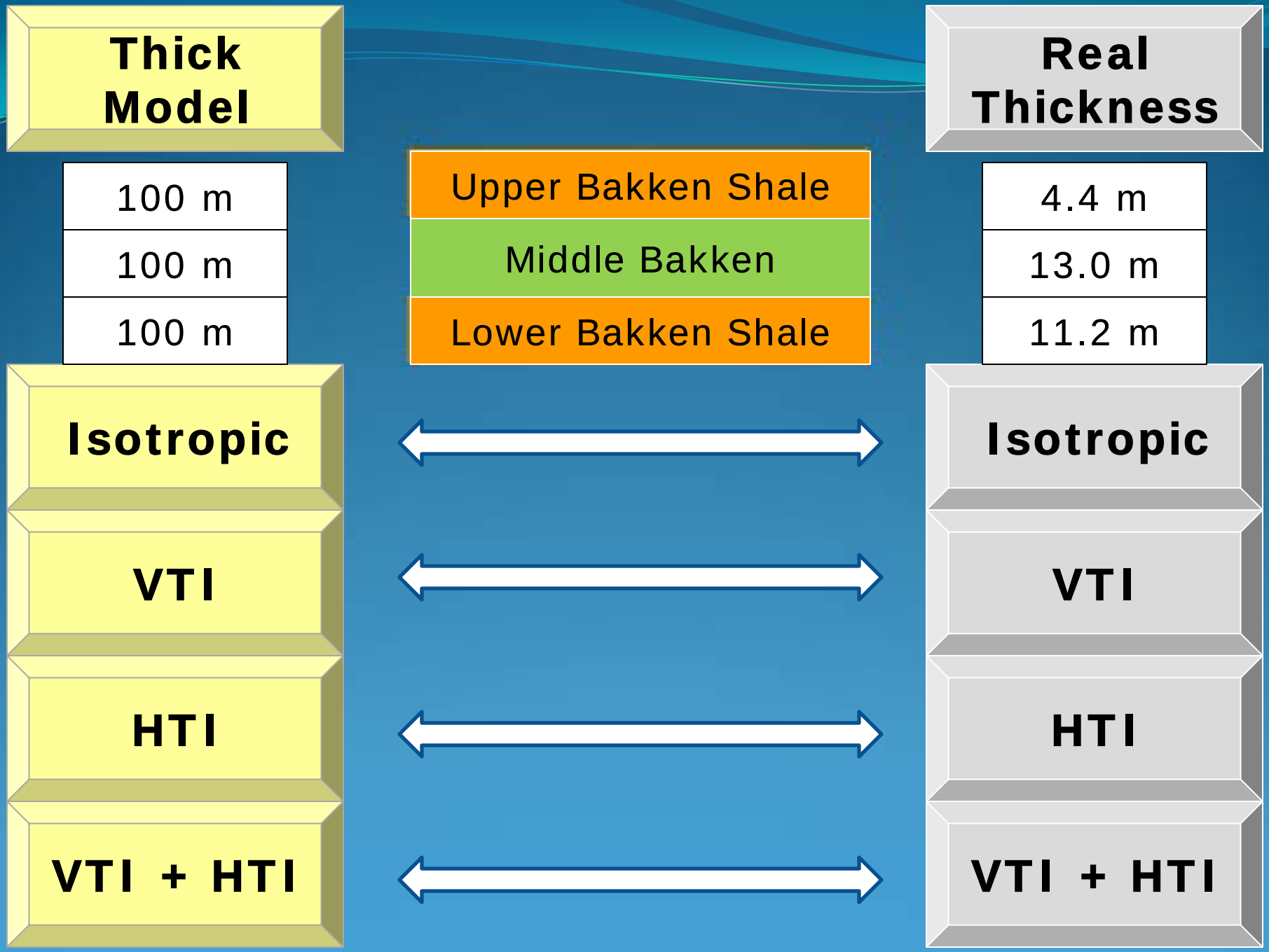
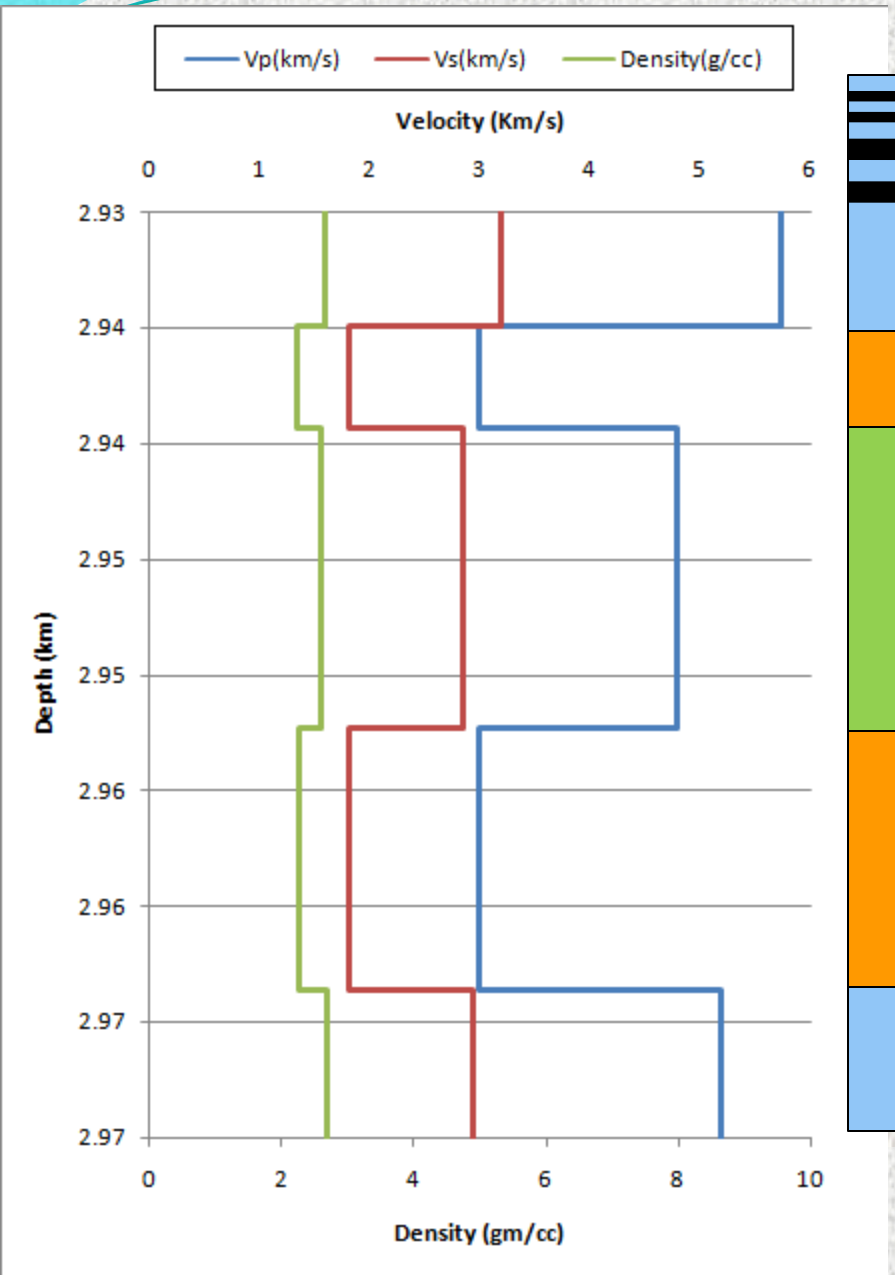
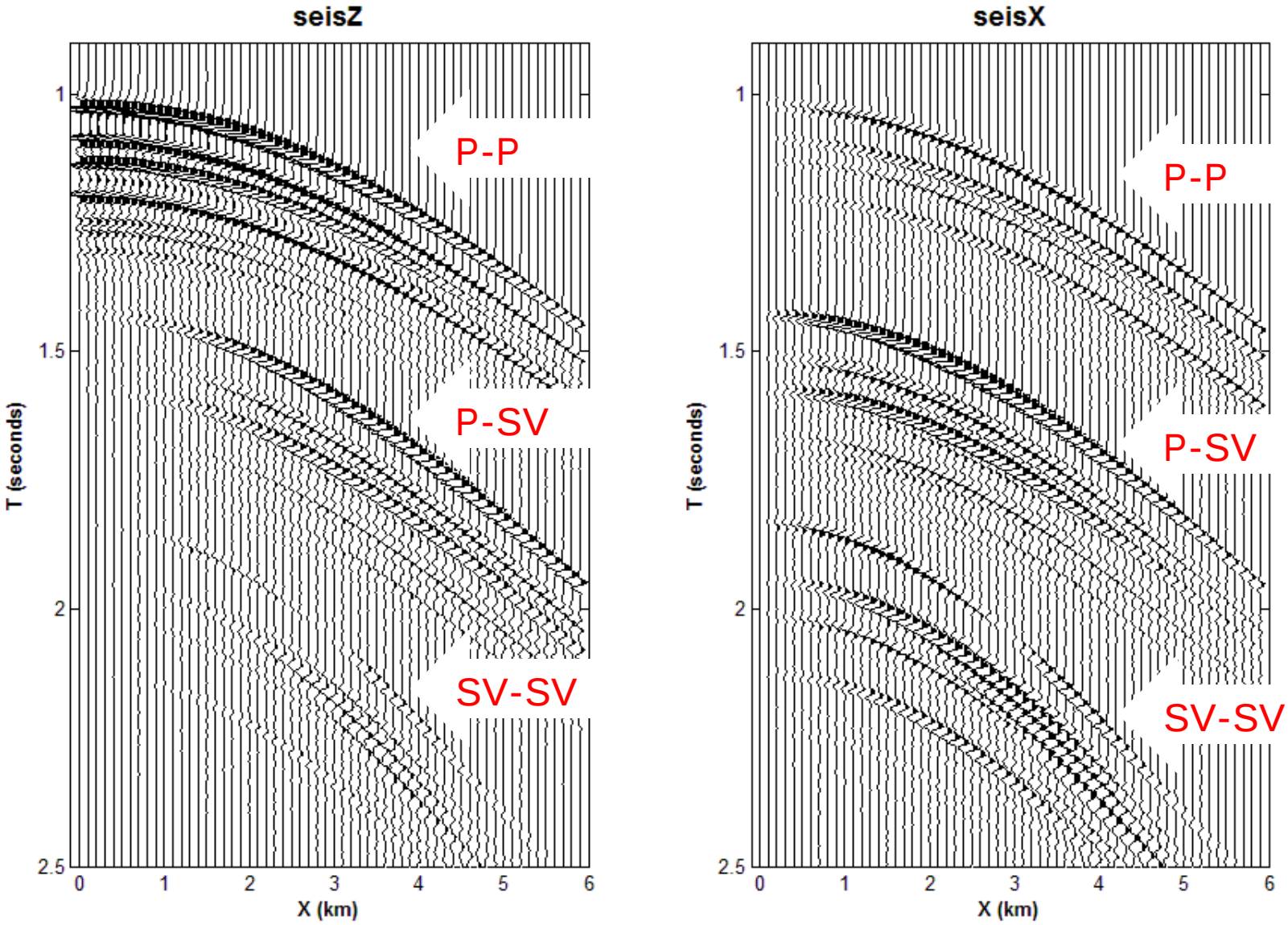

Thick Model
100 m
100 m
100 m
Isotropic
VTI
HTI
VTI + HTI
Upper Bakken Shale
Middle Bakken
Lower Bakken Shale
Real Thickness
4.4 m
13.0 m
11.2 m
Isotropic
VTI
HTI
VTI + HTI

Modeling Step 1: Isotropic

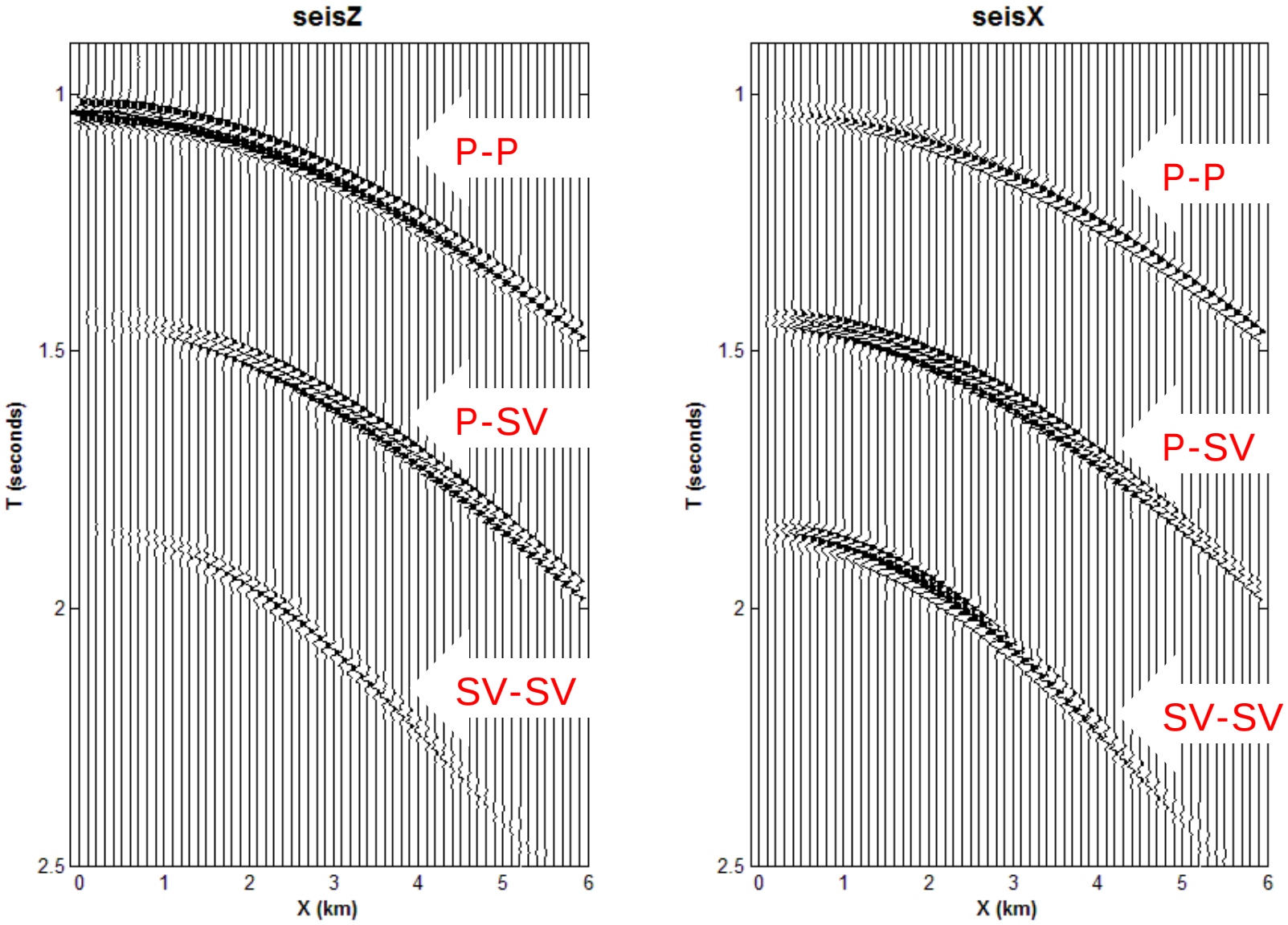


Above	Isotropic
Upper Bakken Shale	Isotropic
Middle Bakken	Isotropic
Lower Bakken Shale	Isotropic
Below	Isotropic

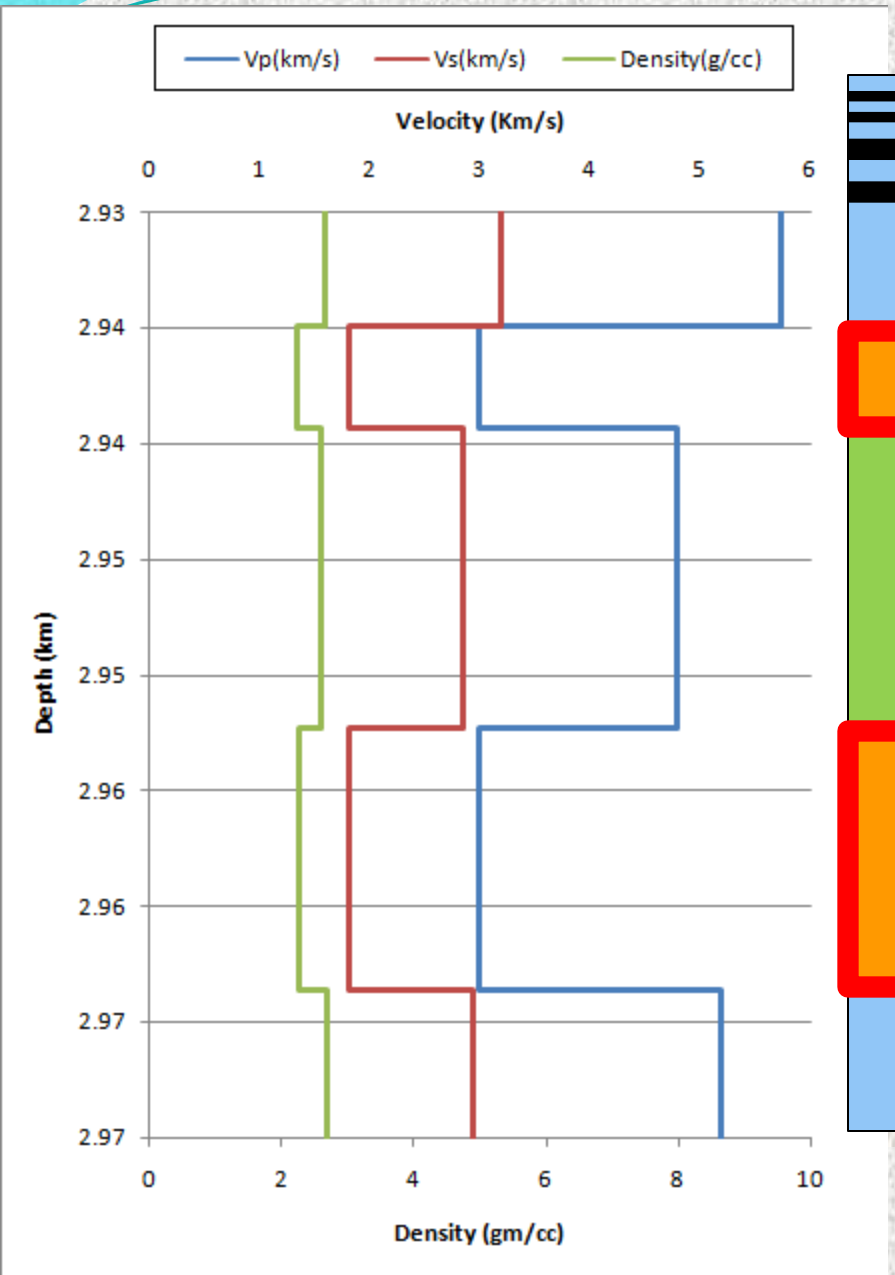
Thick Model

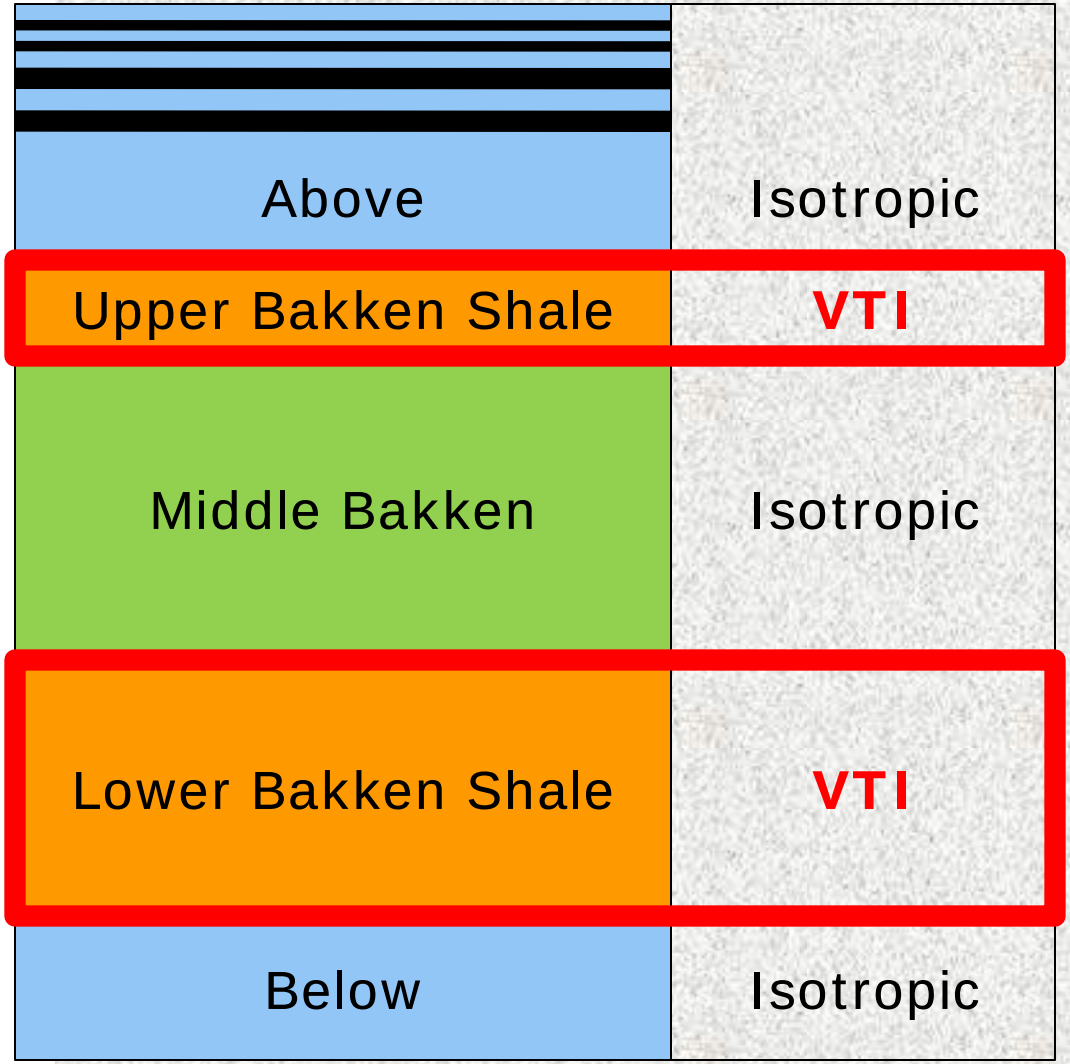


Real Bakken Thickness



Modeling Step 2: Anisotropic-VTI





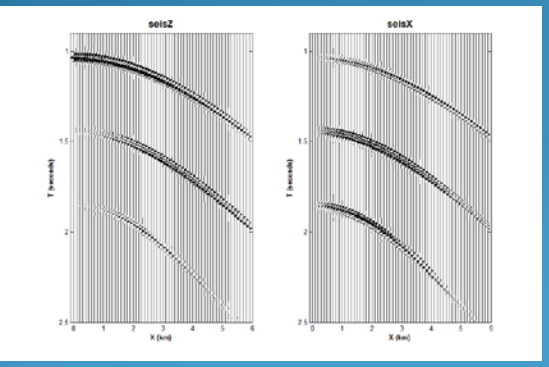
Isotropic Response

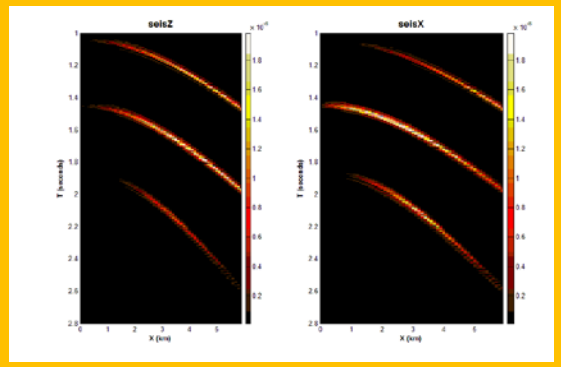
+

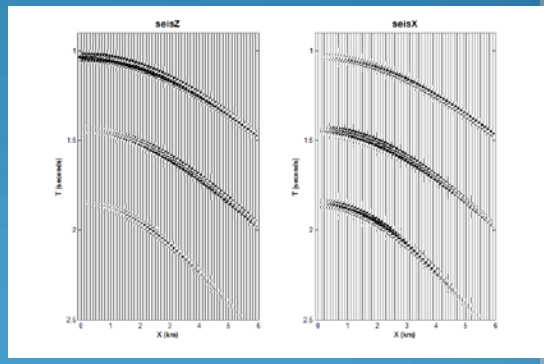
Anisotropy Information

=

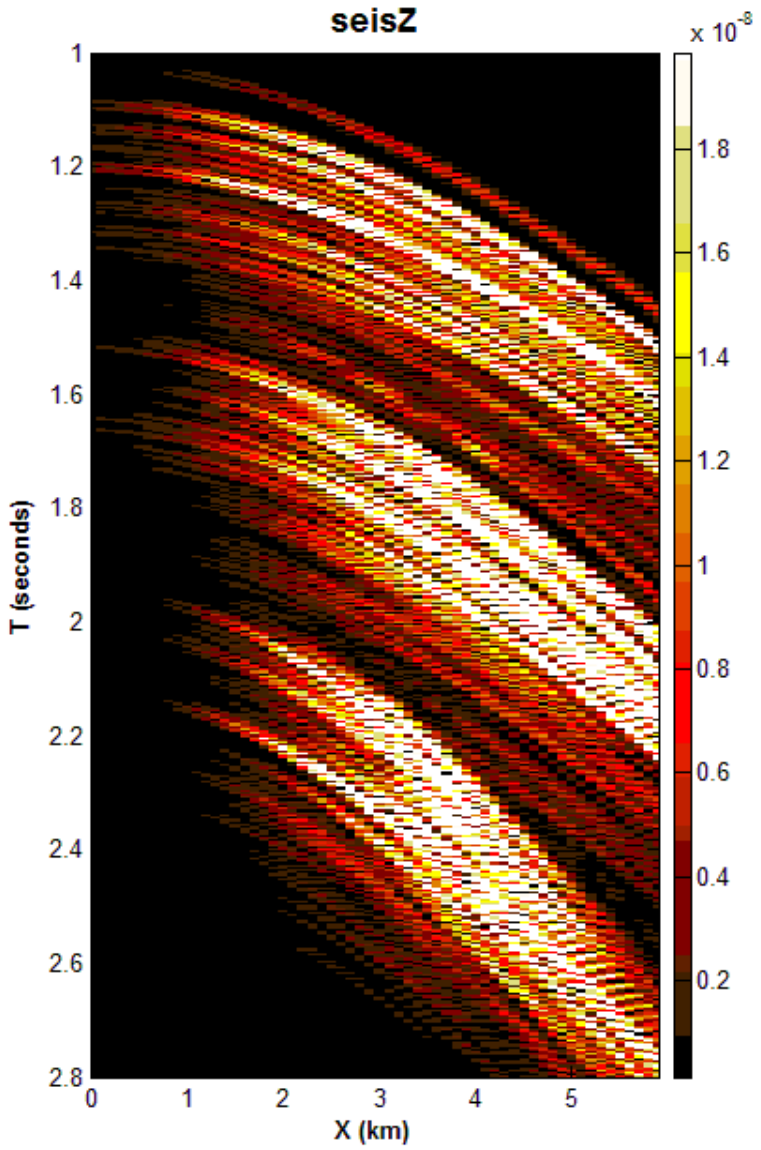
Total Anisotropic Seismic Response

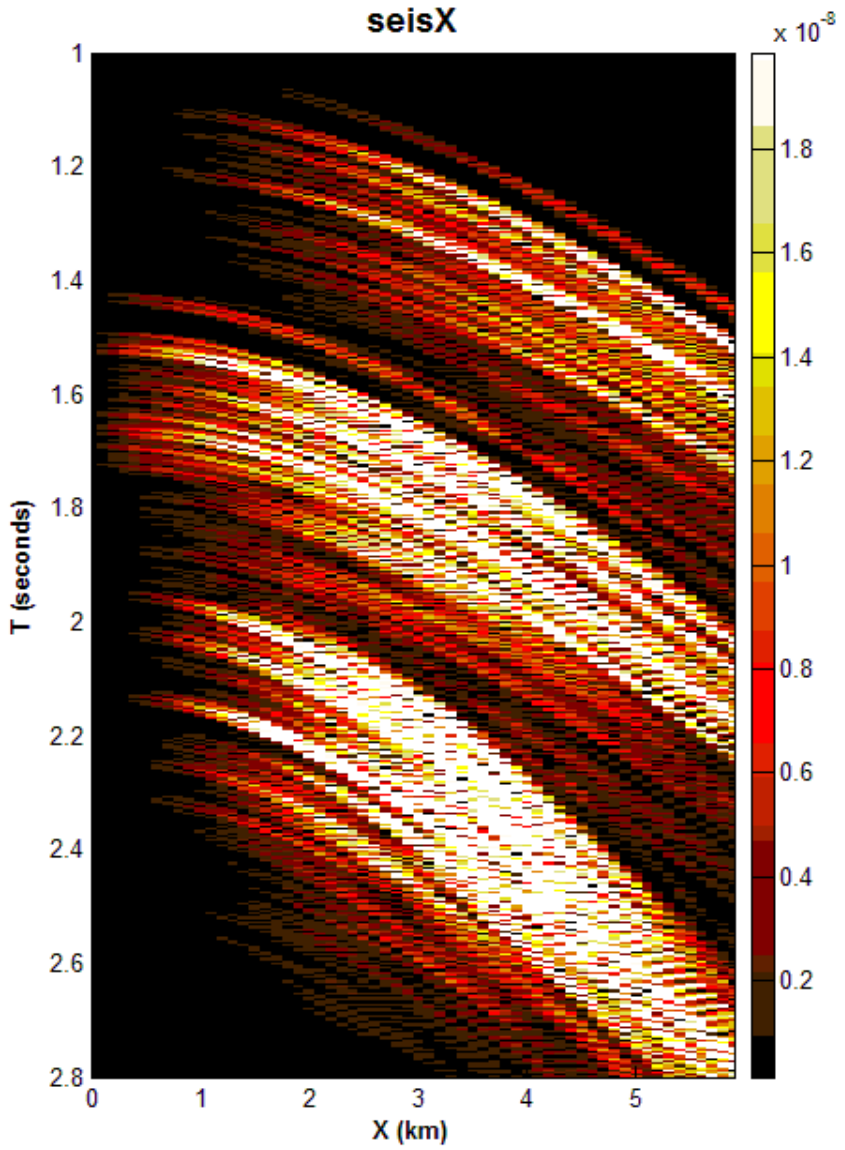




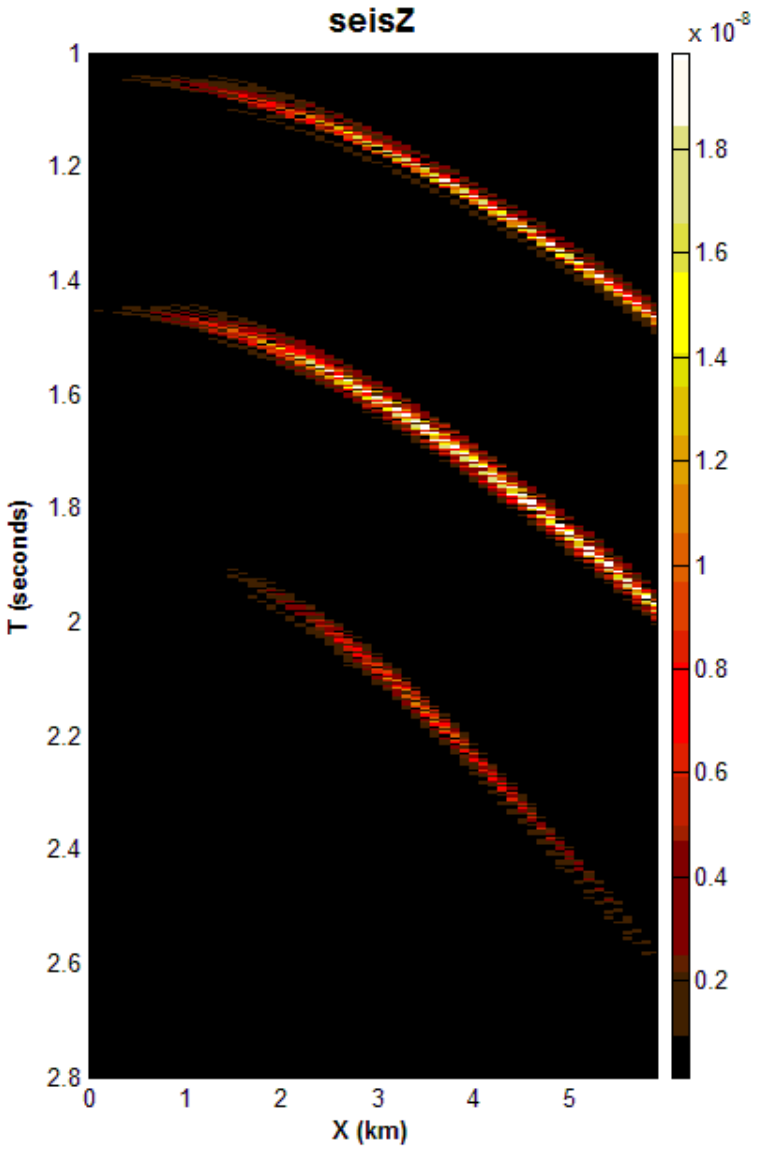


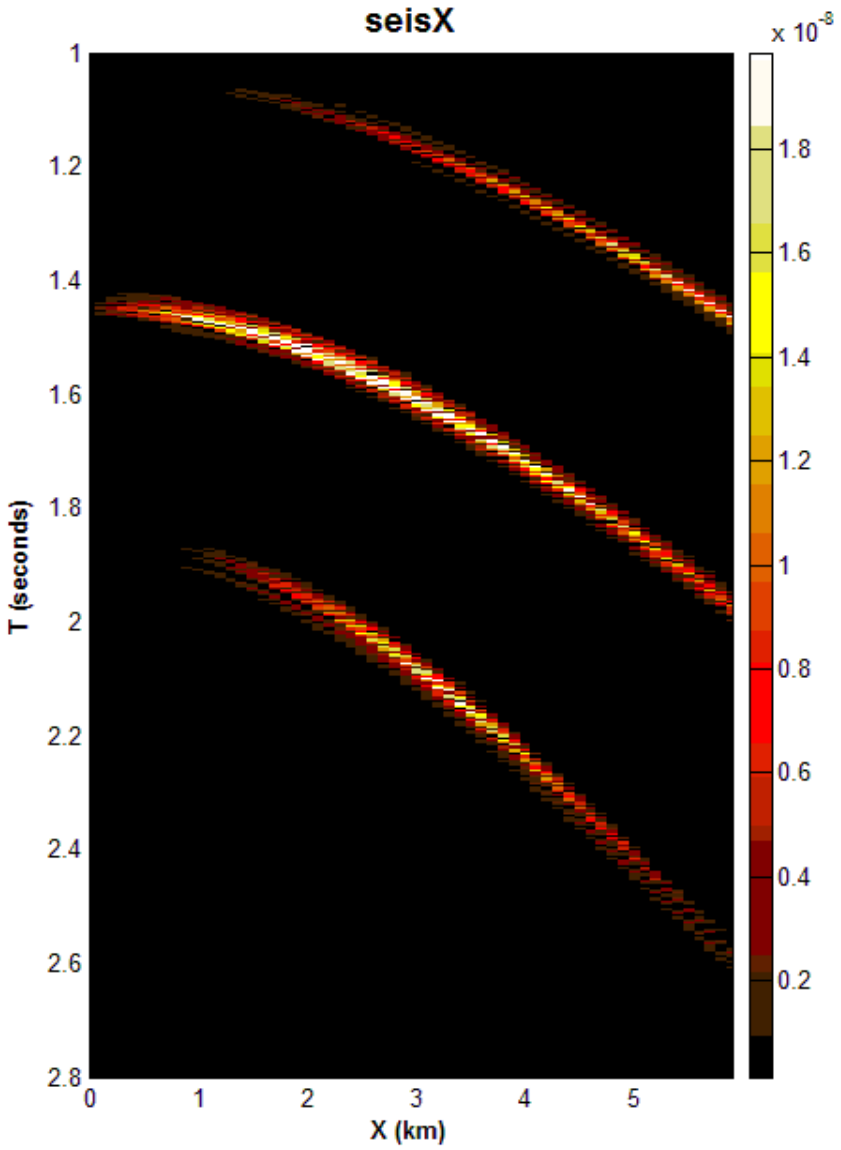
Thick Model: VTI Anisotropy information



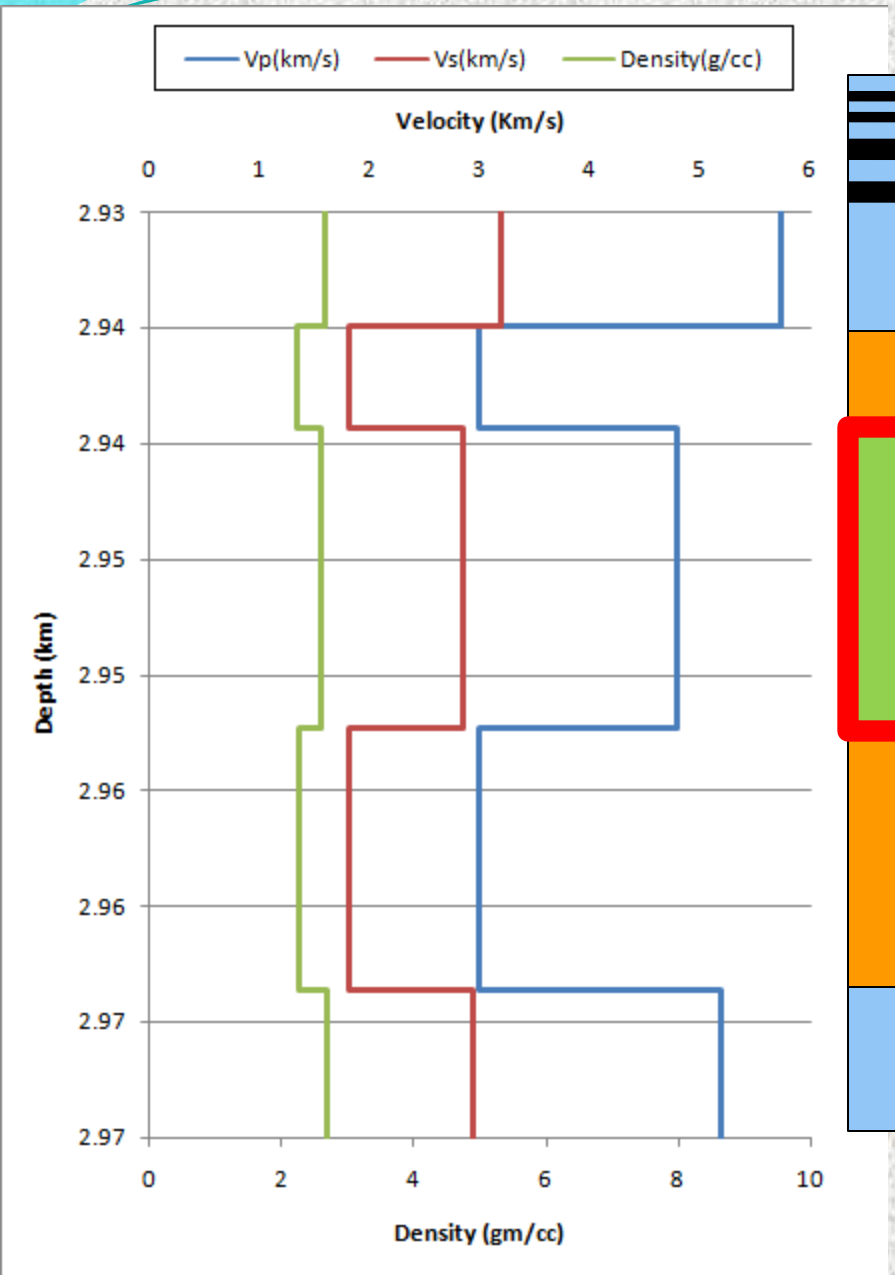


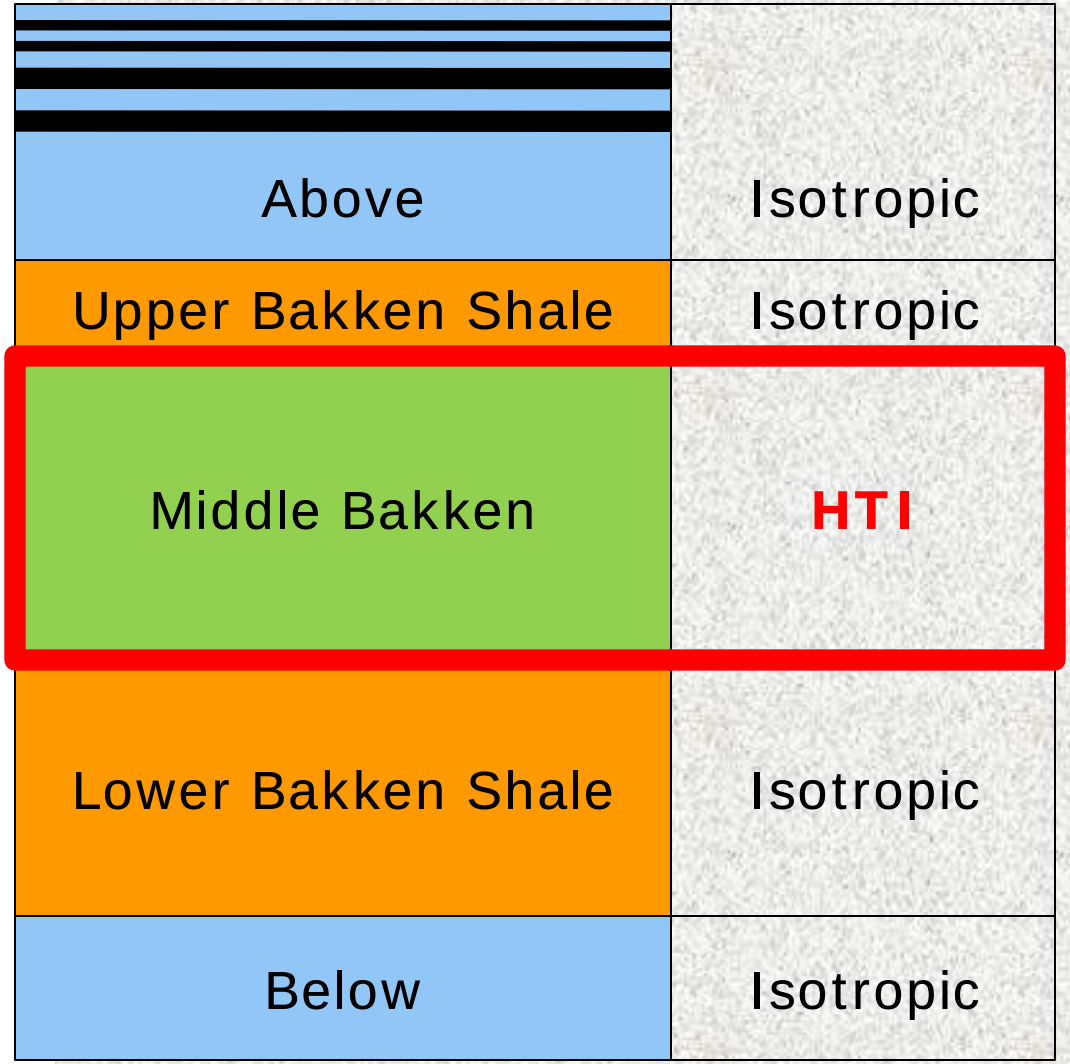
Real Bakken Thickness: VTI Anisotropy information



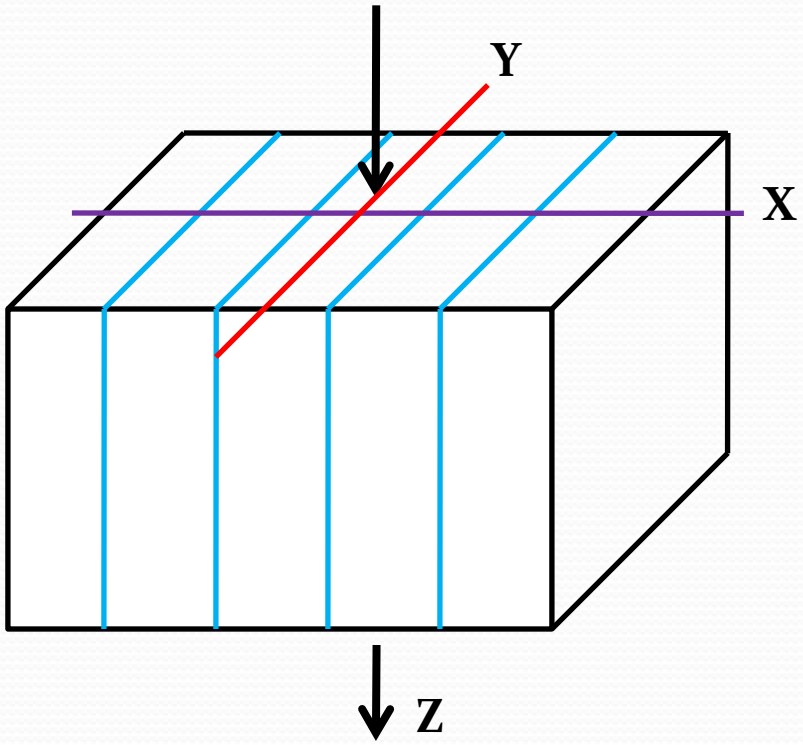


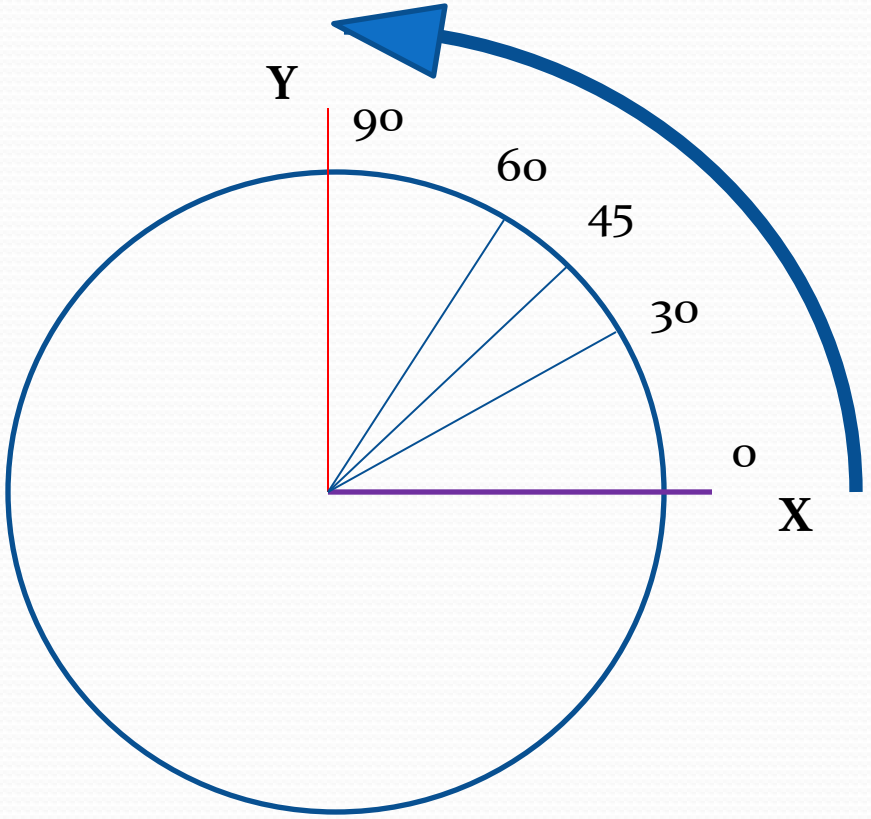
Modeling Step 3: HTI

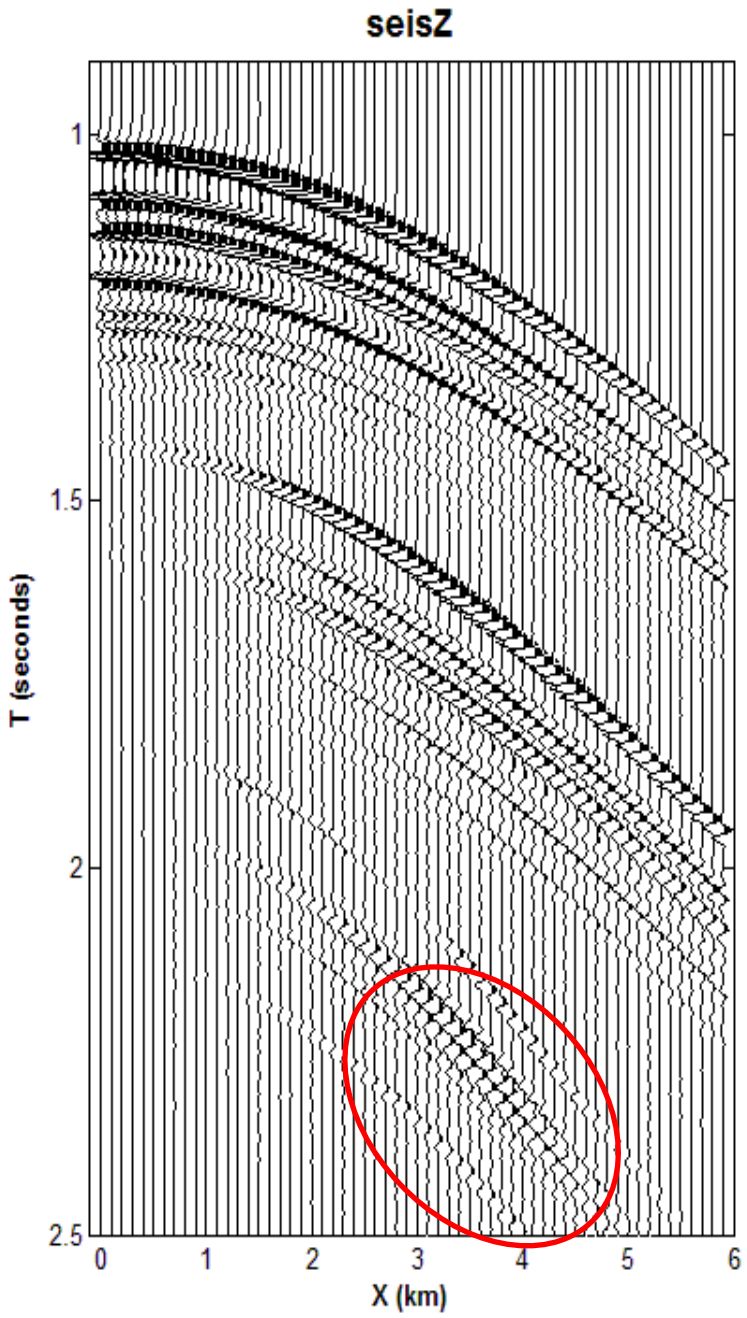


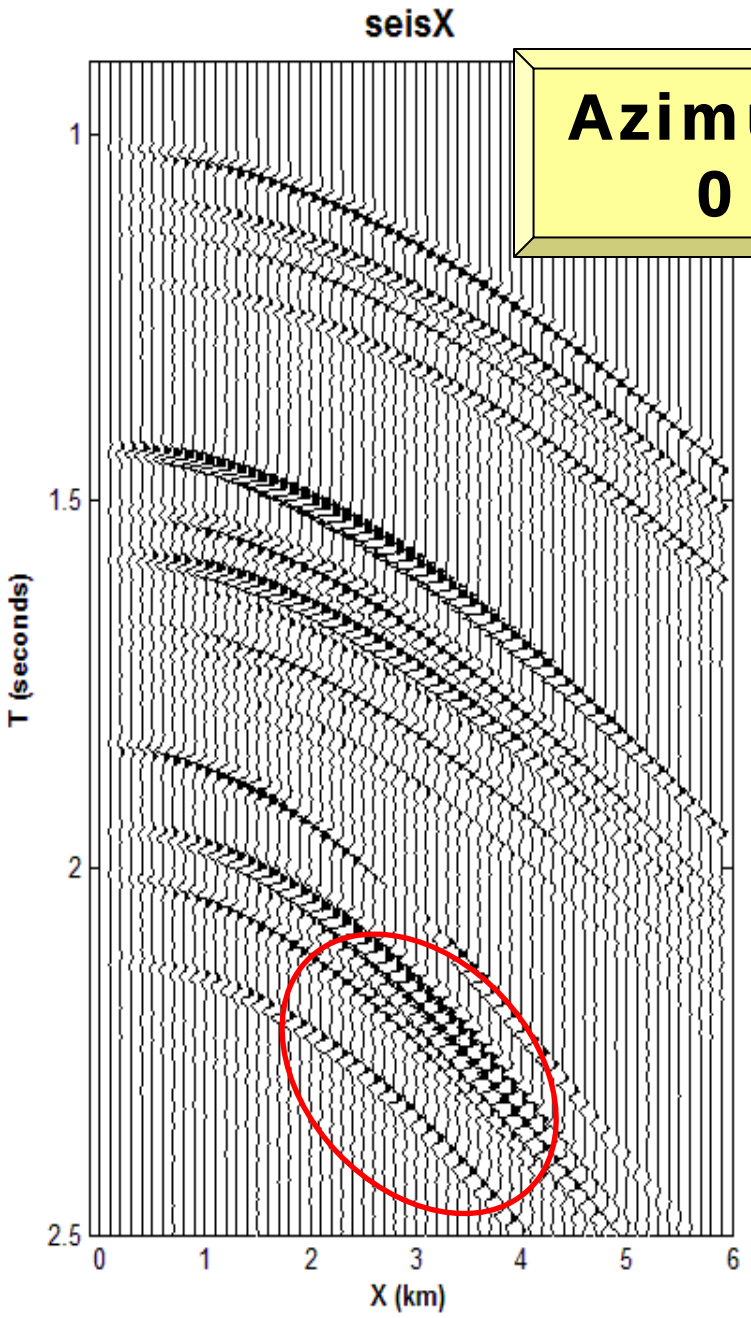


Azimuthal Anisotropy

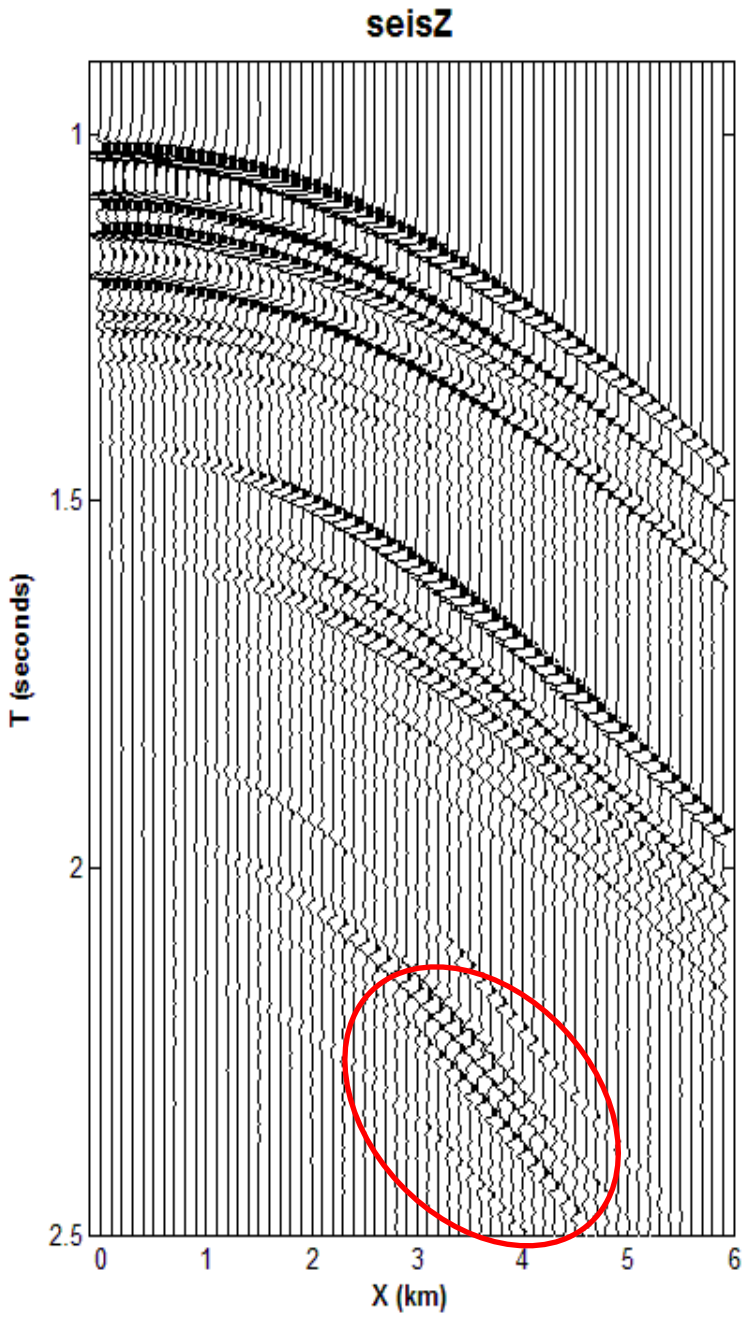


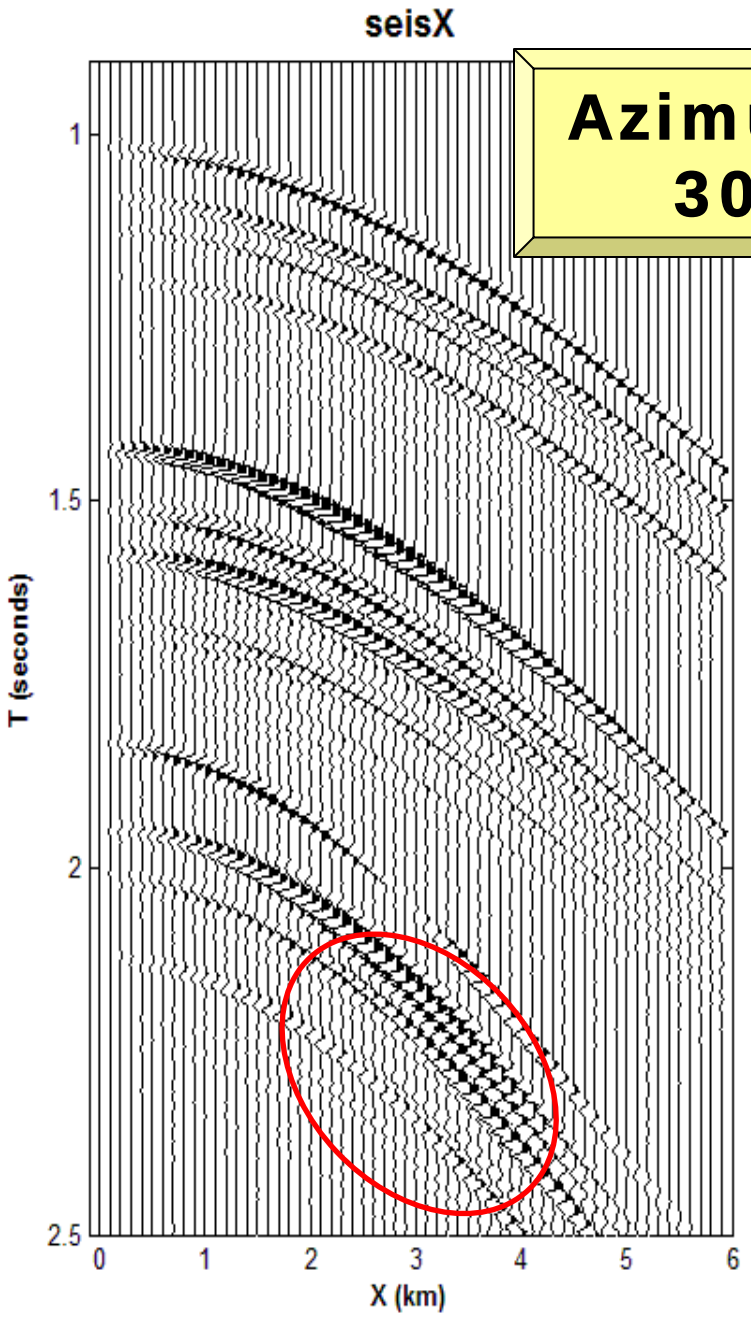



seisZ
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

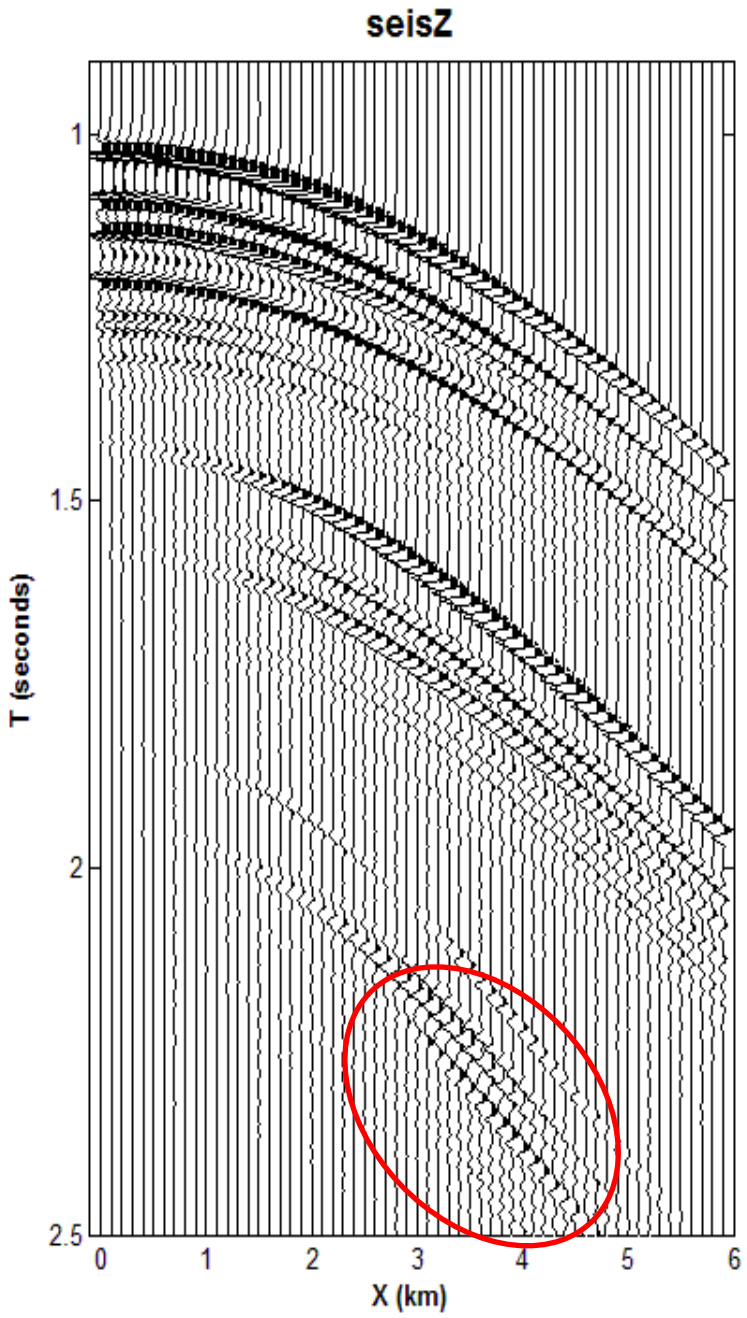

seisX
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

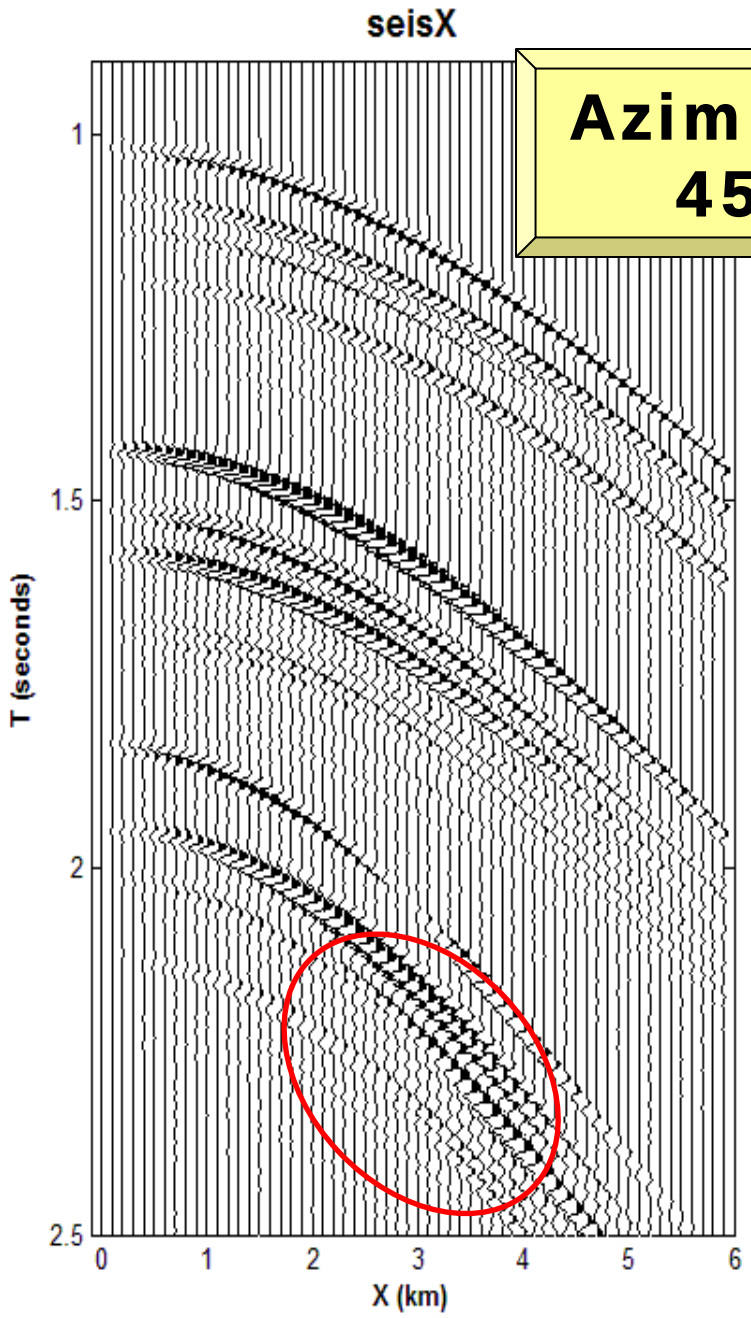
Azimuth 0


seisZ
T (seconds)
X (km)
1
1.5
2
2.5
0
1
2
3
4
5
6

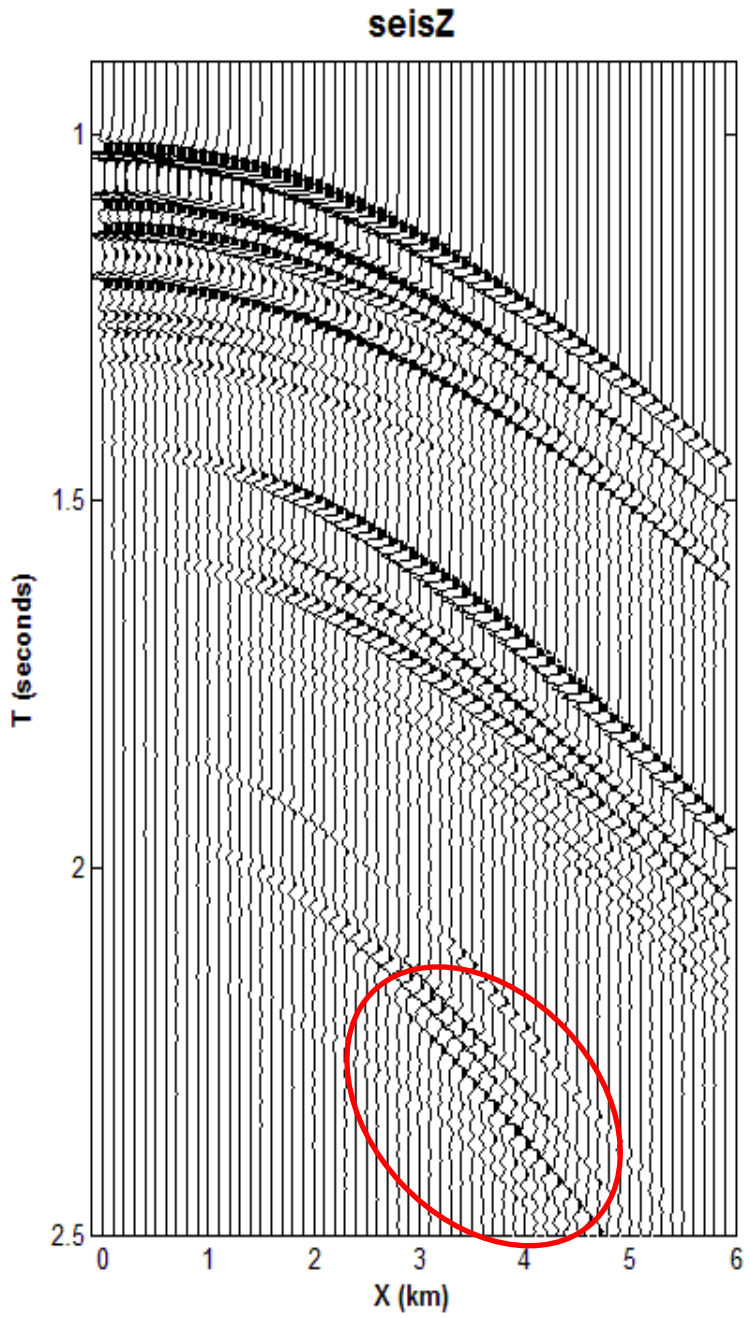

seisX
T (seconds)
X (km)
1
1.5
2
2.5
0
1
2
3
4
5
6

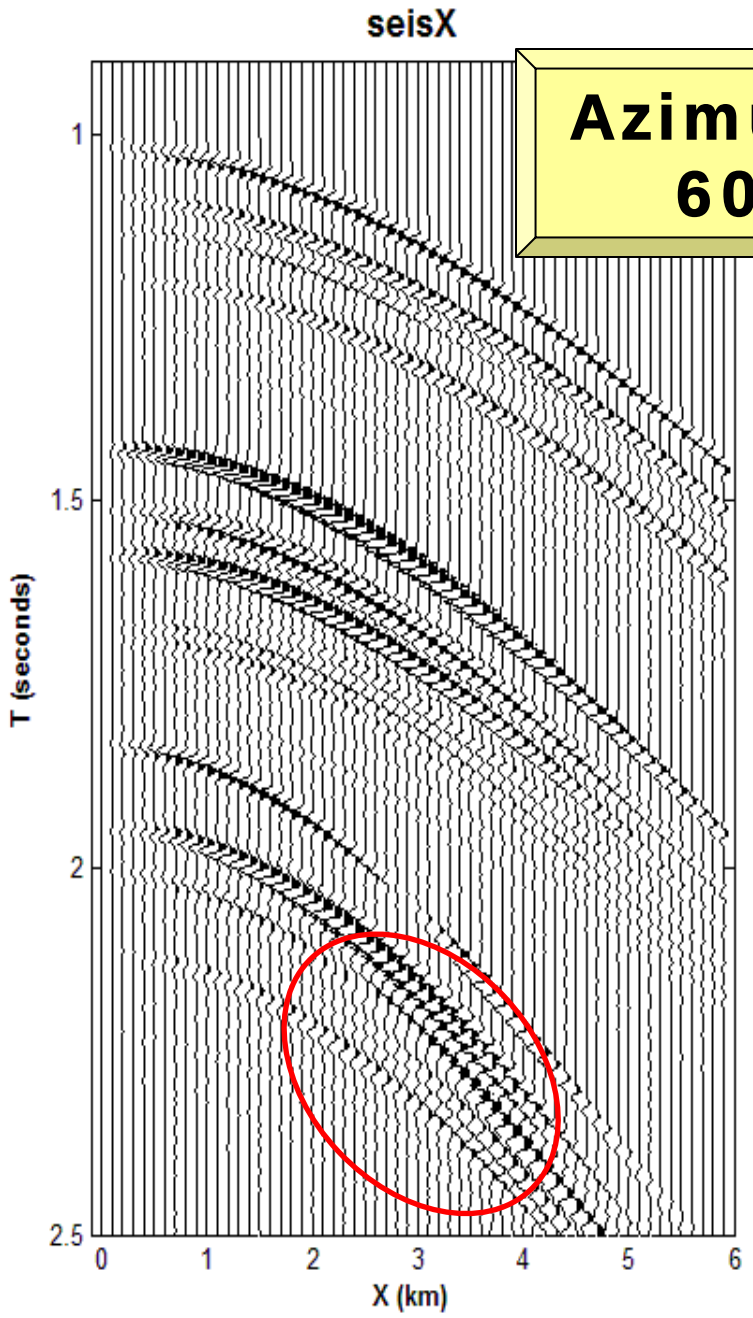
Azimuth 30


seisZ
T (seconds)
X (km)
1
1.5
2
2.5
0
1
2
3
4
5
6

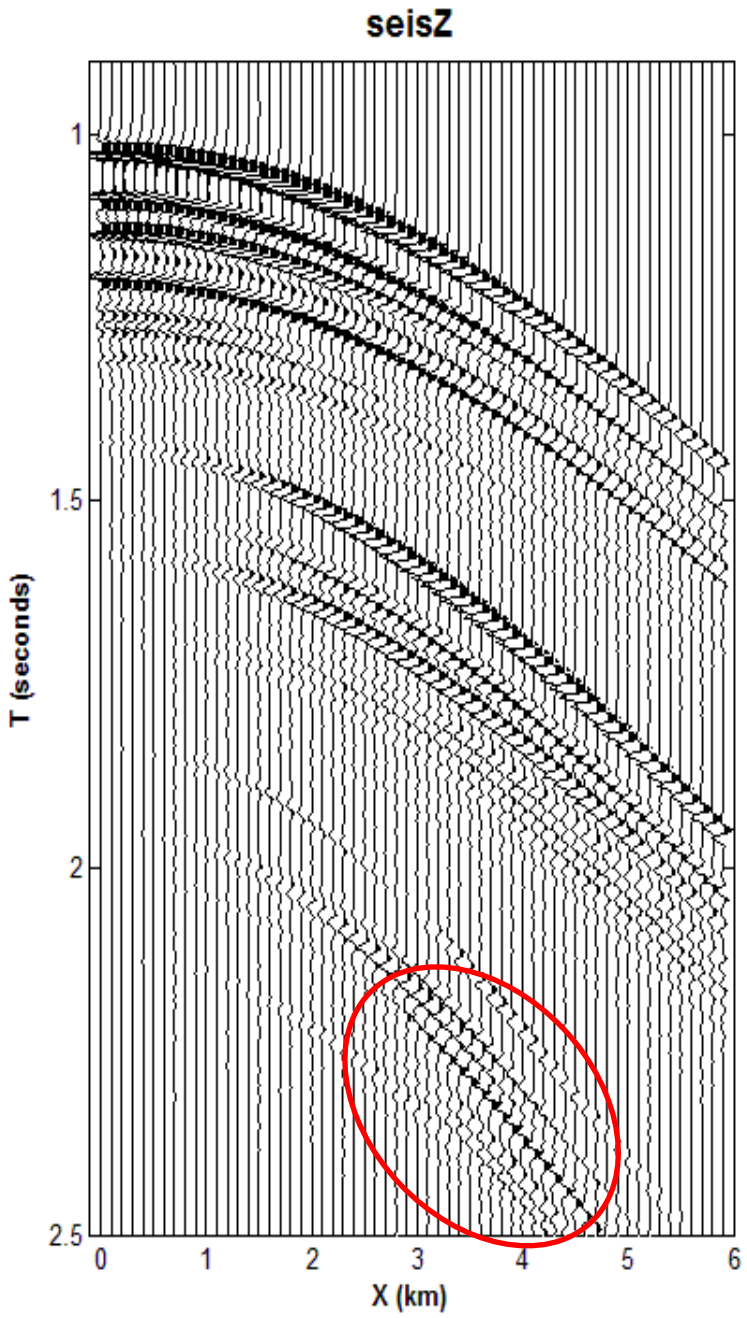

seisX
T (seconds)
X (km)
1
1.5
2
2.5
0
1
2
3
4
5
6

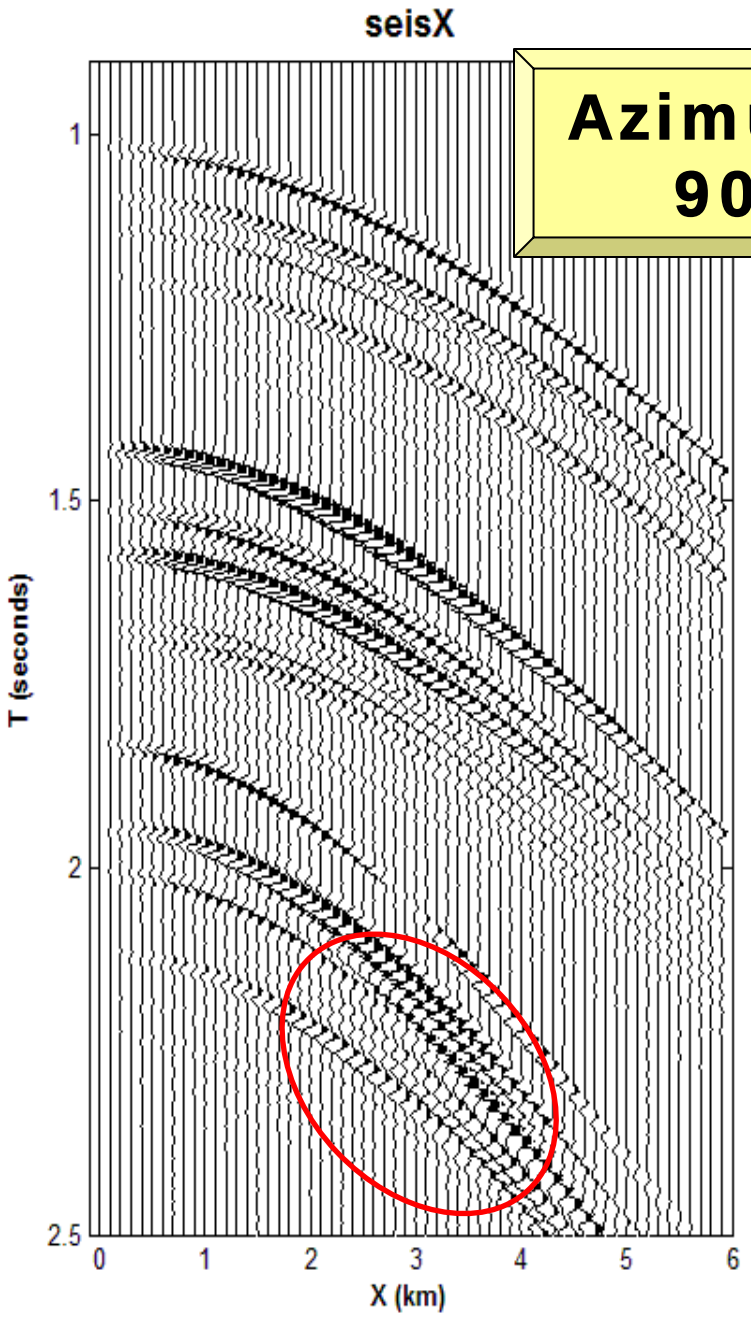
Azimuth 45


seisZ
T (seconds)
X (km)
1
1.5
2
2.5
0
1
2
3
4
5
6

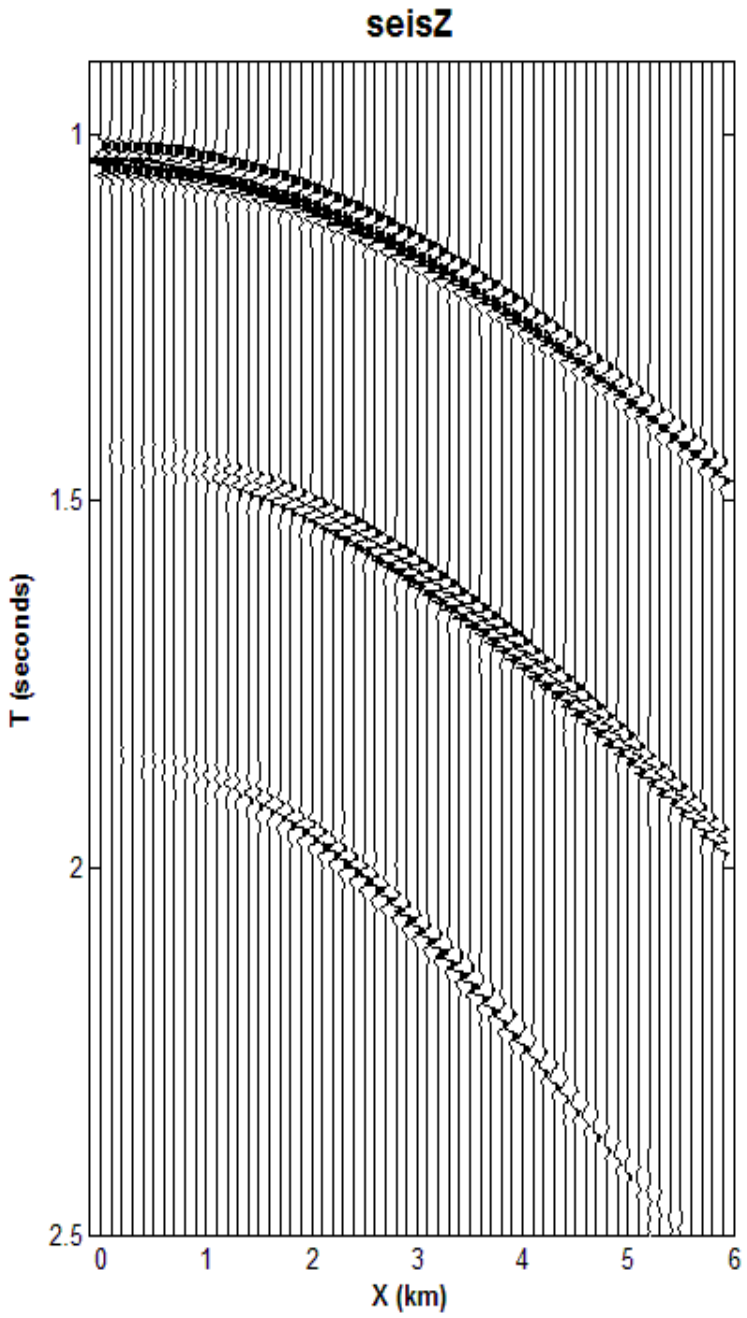

seisX
T (seconds)
X (km)
1
1.5
2
2.5
0
1
2
3
4
5
6

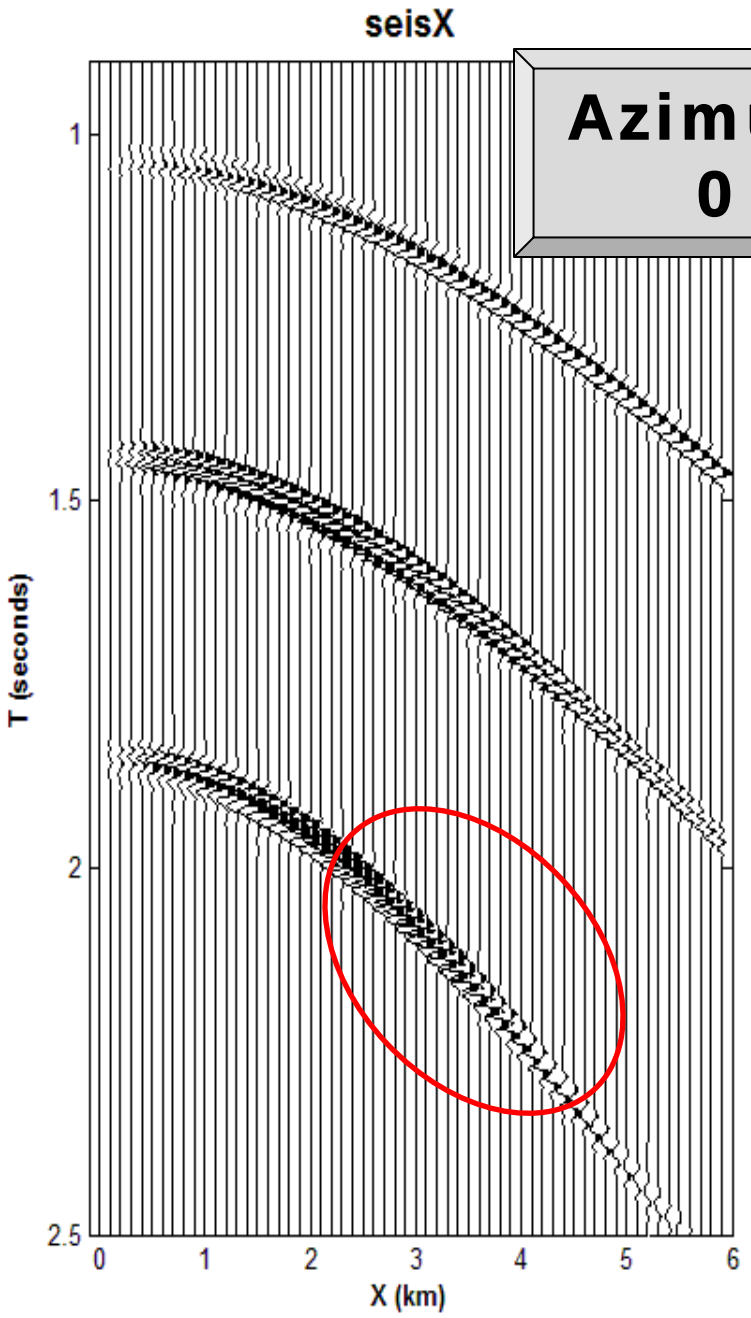
Azimuth 60


seisZ
T (seconds)
X (km)
1
1.5
2
2.5
0
1
2
3
4
5
6

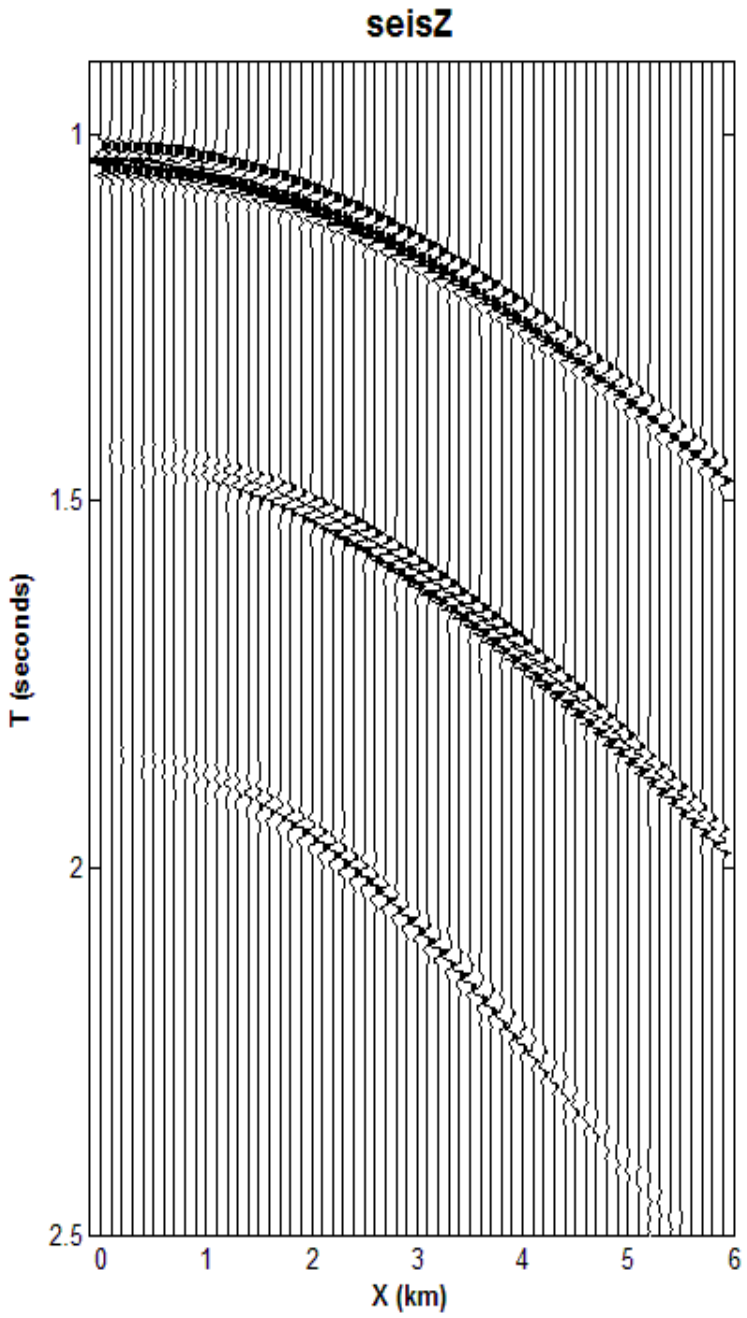

seisX
T (seconds)
X (km)
1
1.5
2
2.5
0
1
2
3
4
5
6

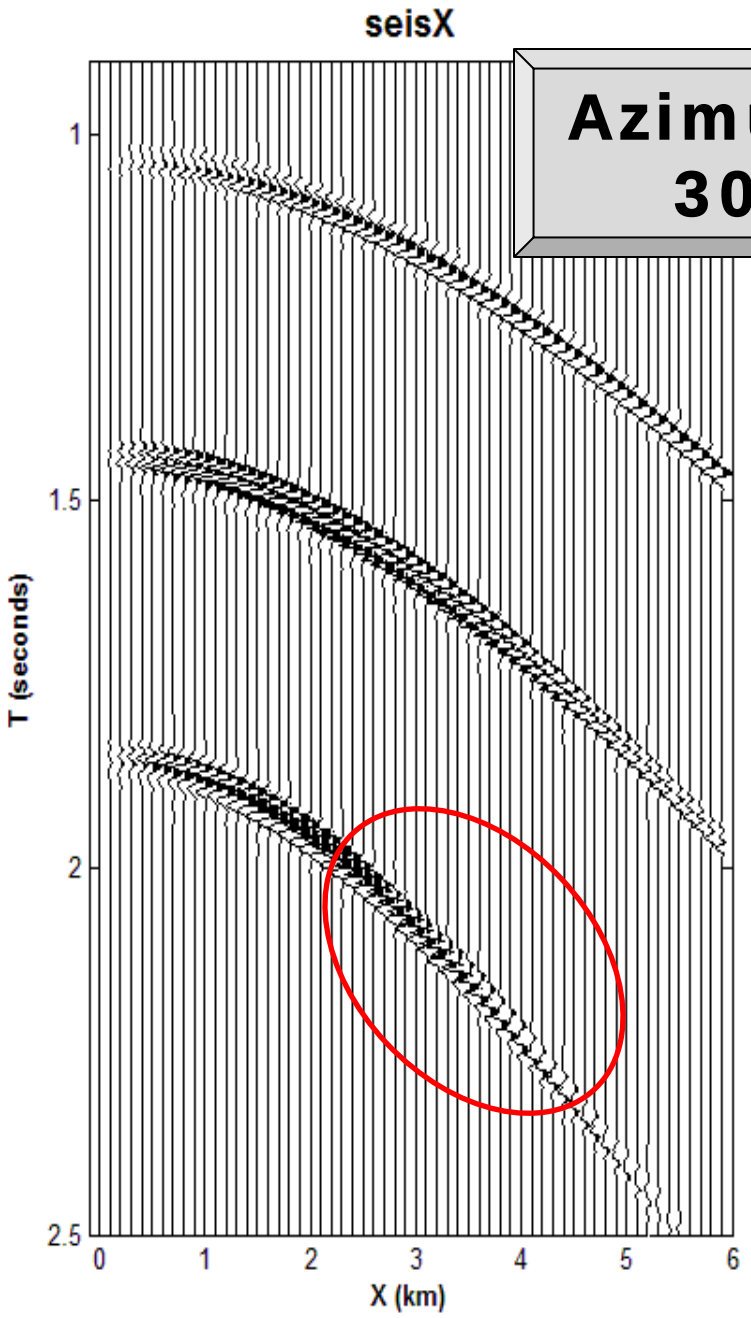
Azimuth 90


seisZ
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

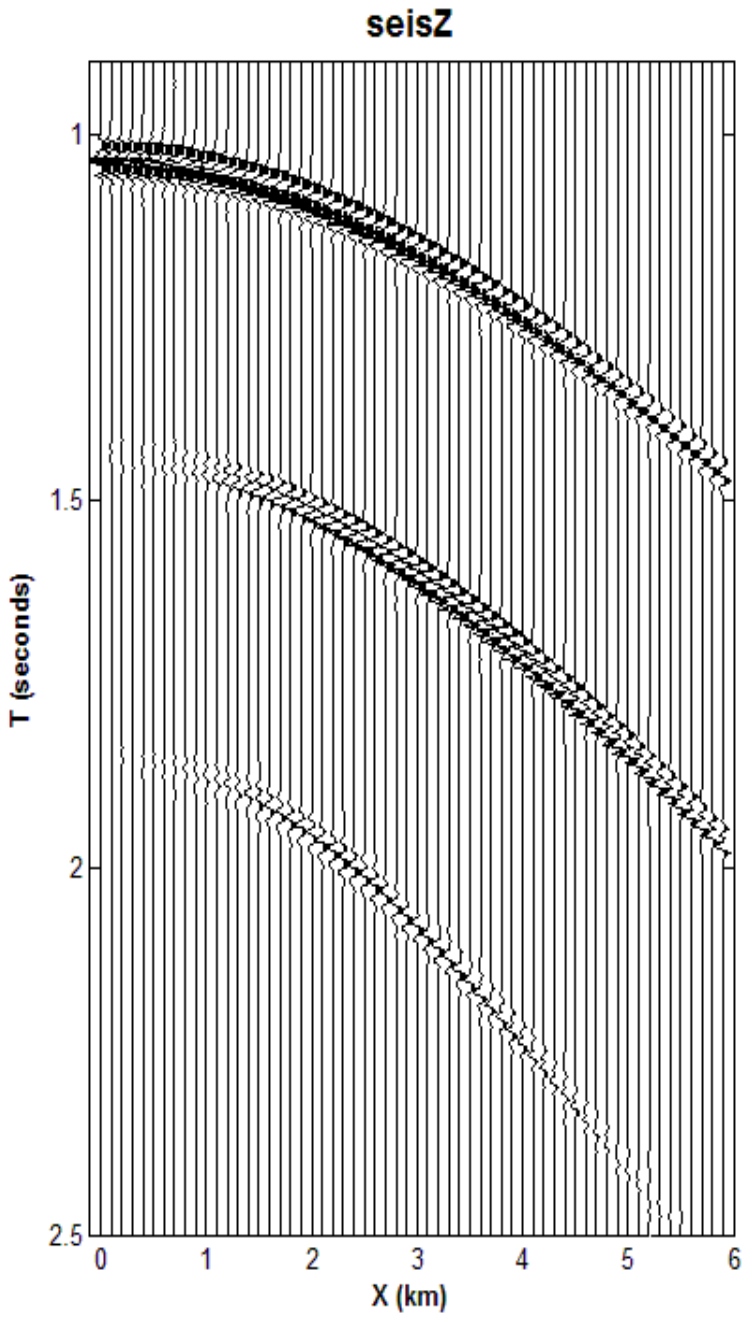

seisX
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

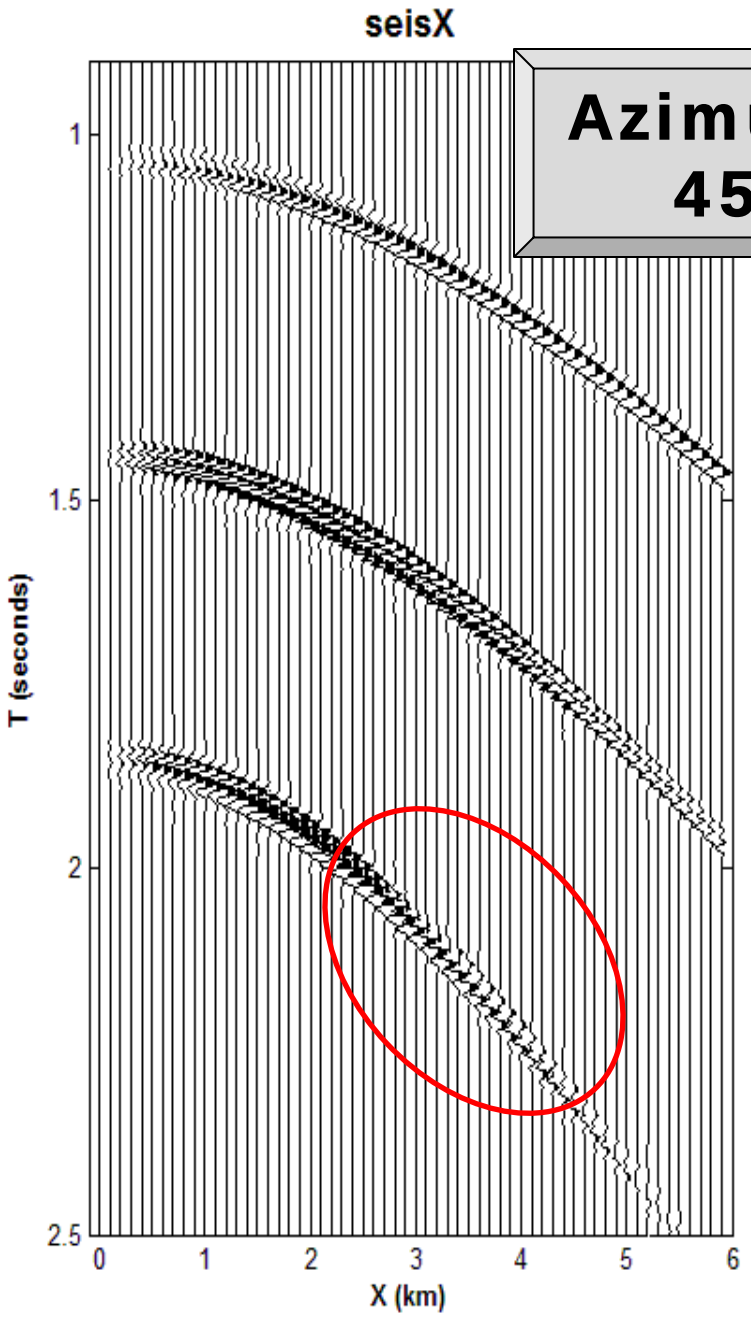
Azimuth 0


seisZ
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

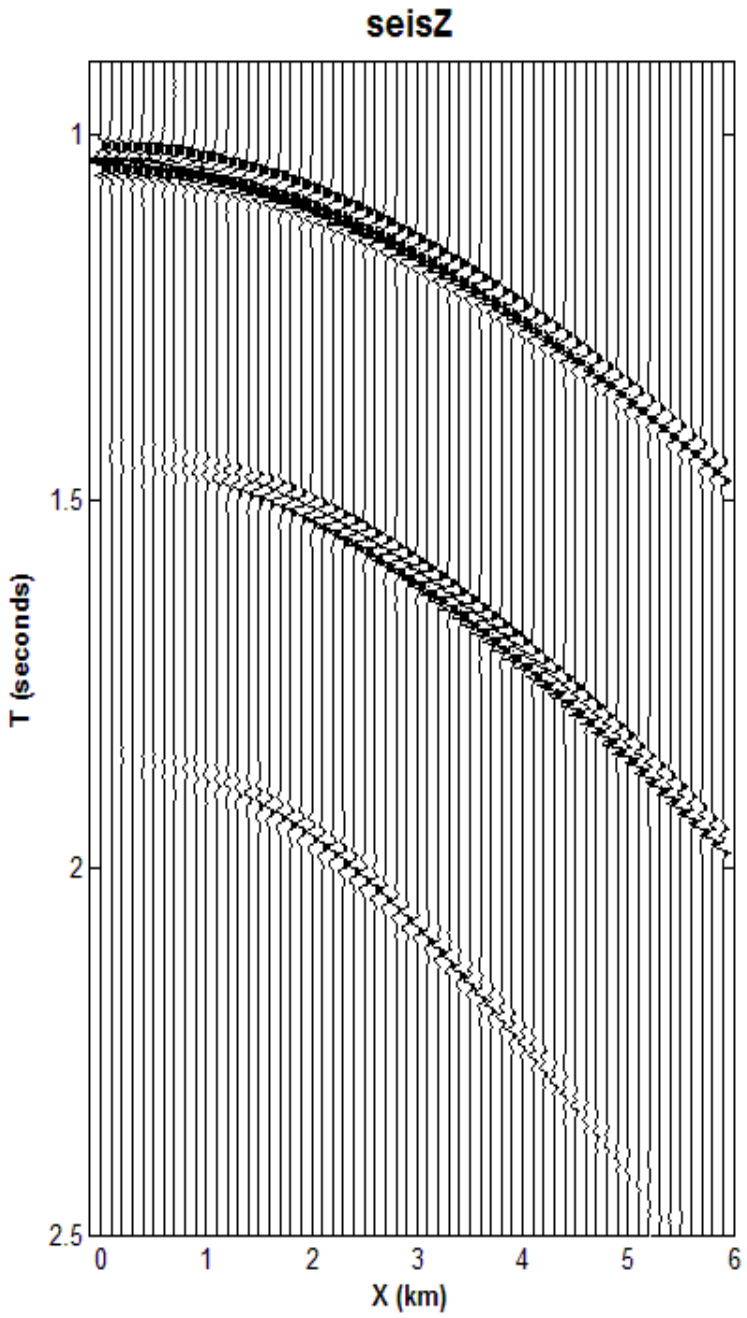

seisX
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

Azimuth 30


seisZ
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)


seisX
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

Azimuth 45


seisZ
T (seconds)
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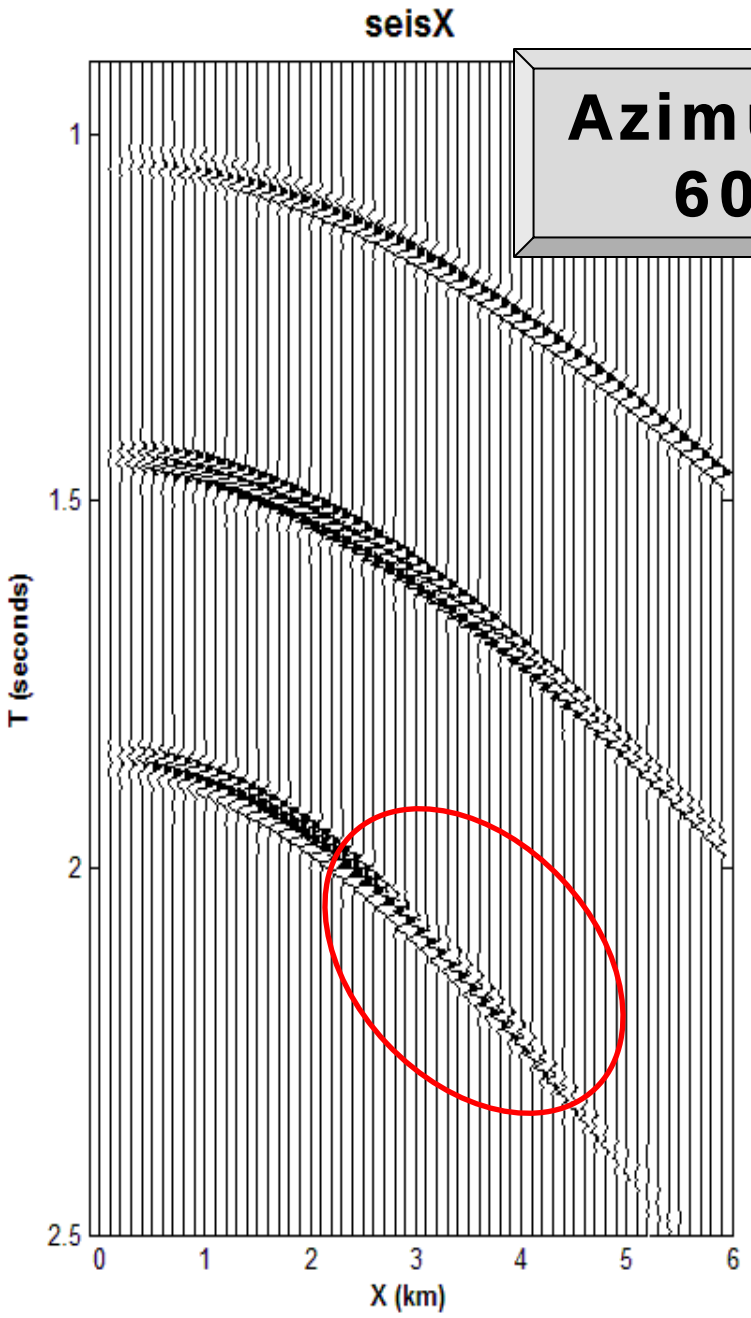
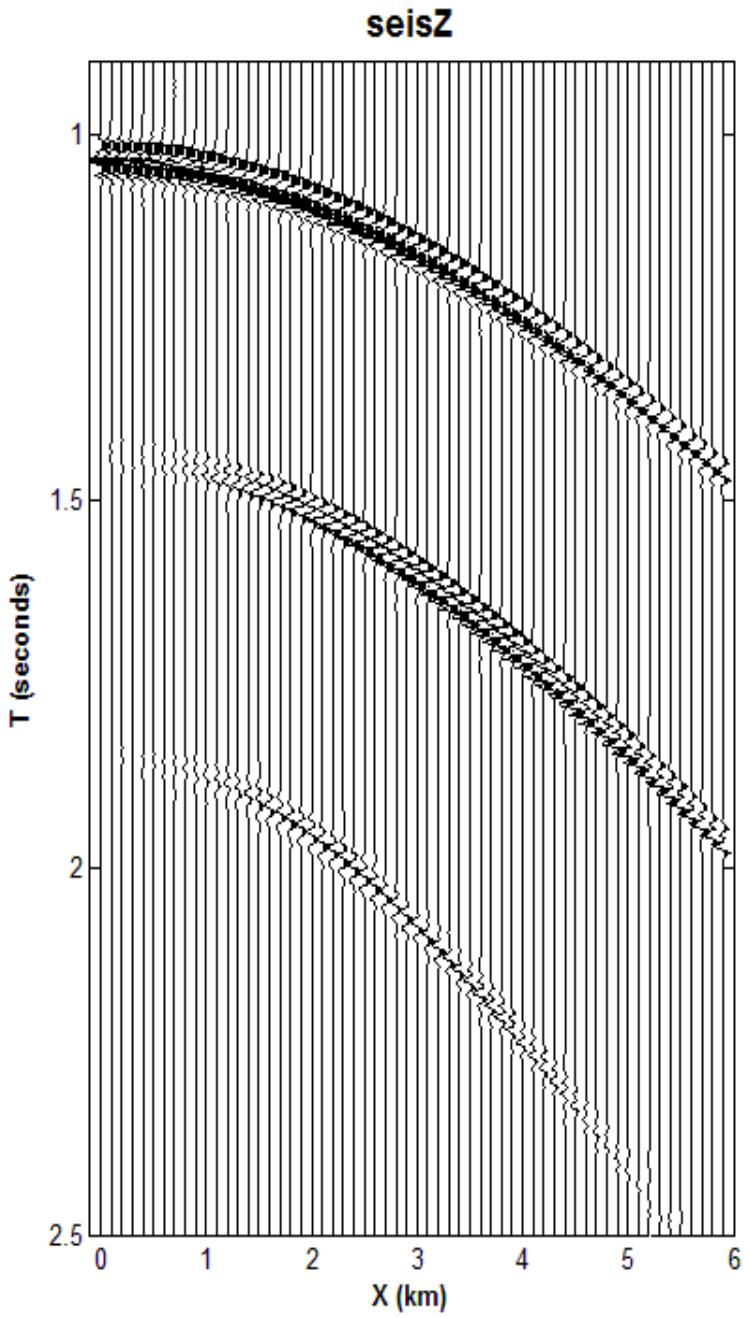
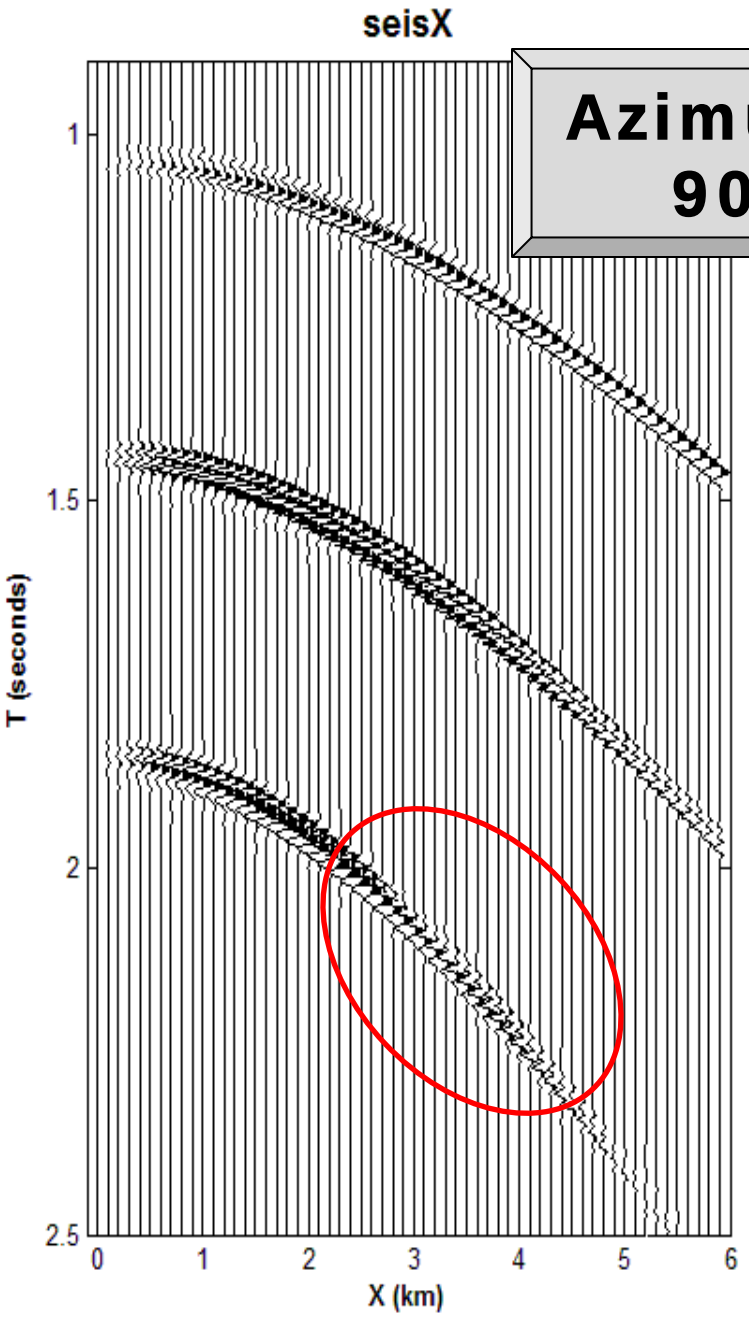
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

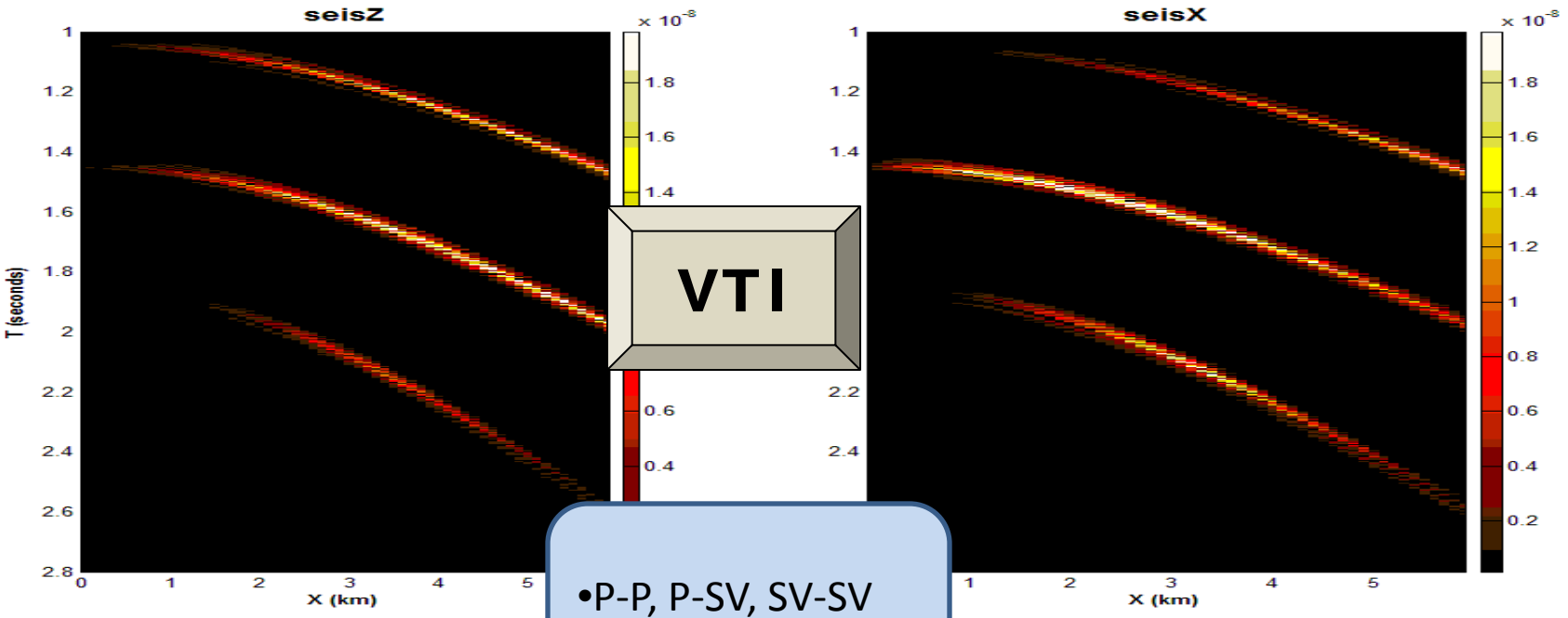

seisX
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

Azimuth 60

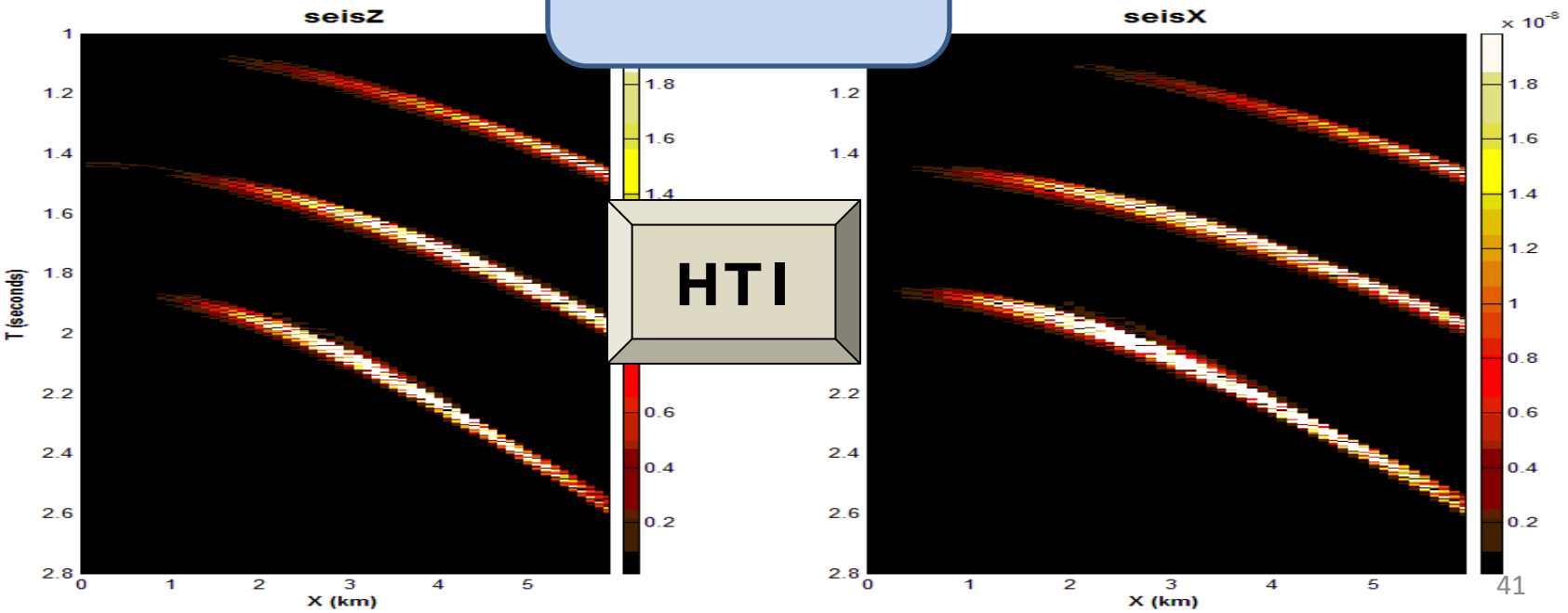

seisZ
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)


seisX
T (seconds)
1
1.5
2
2.5
0
1
2
3
4
5
6
X (km)

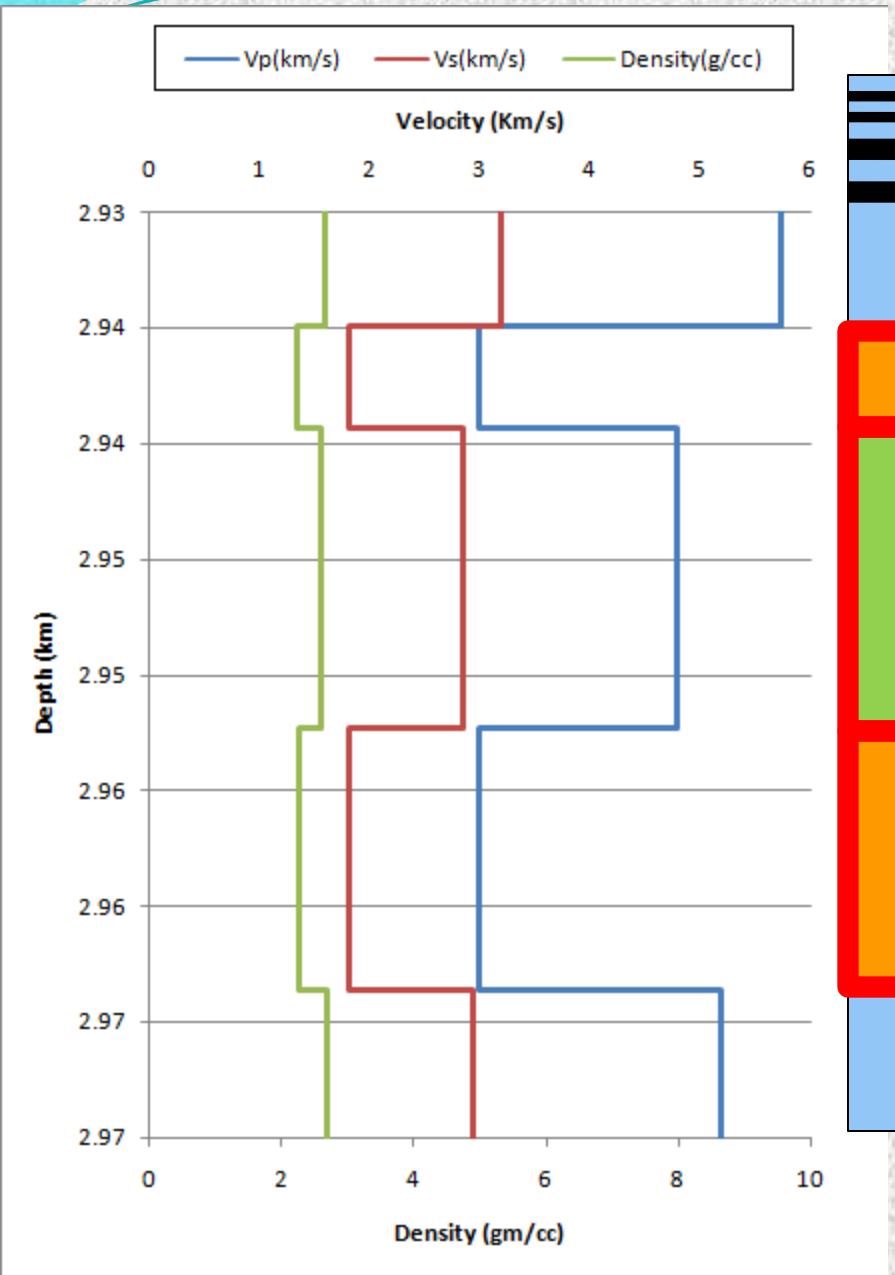
Azimuth 90

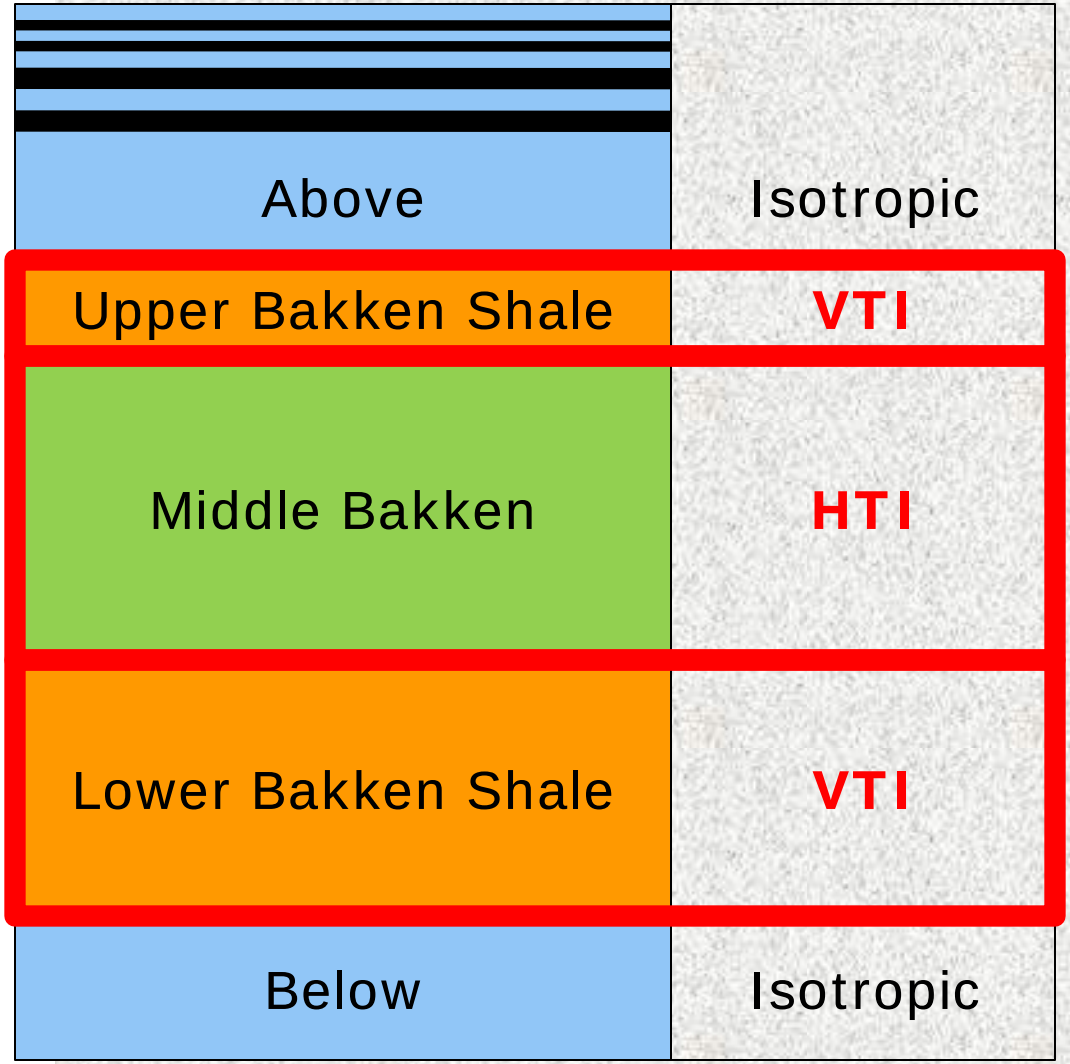


- P-P, P-SV, SV-SV
- offset ranges

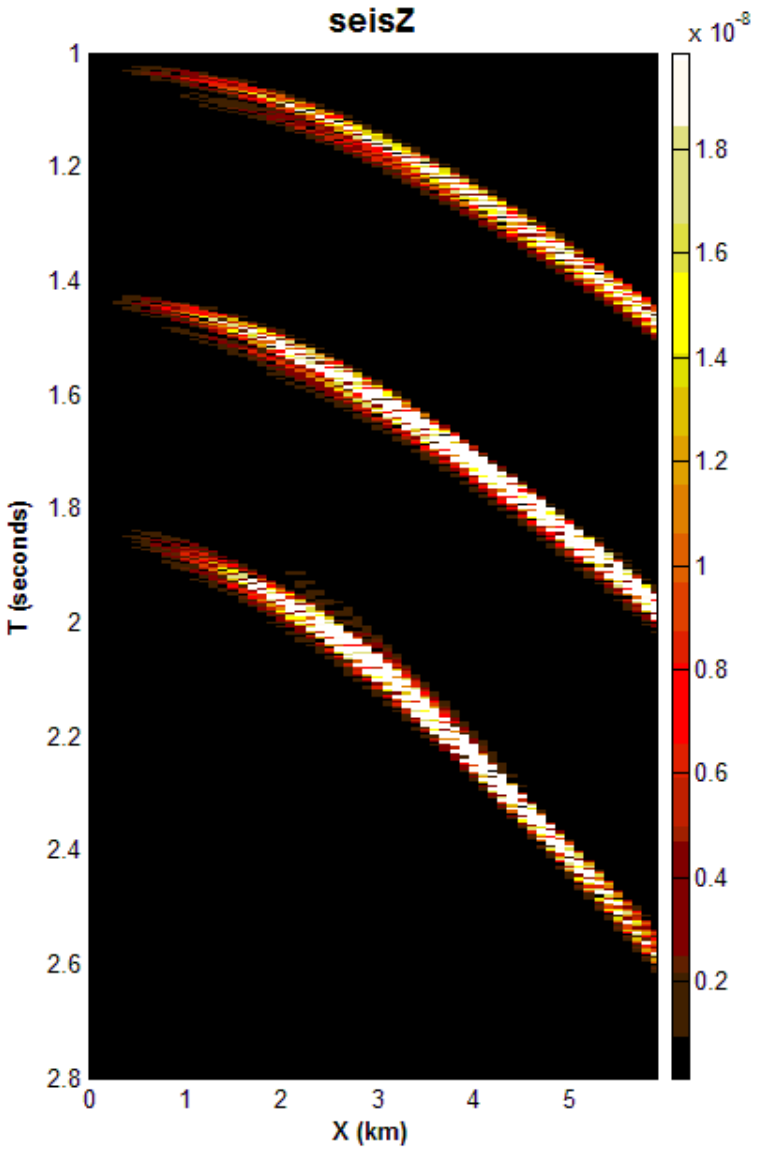


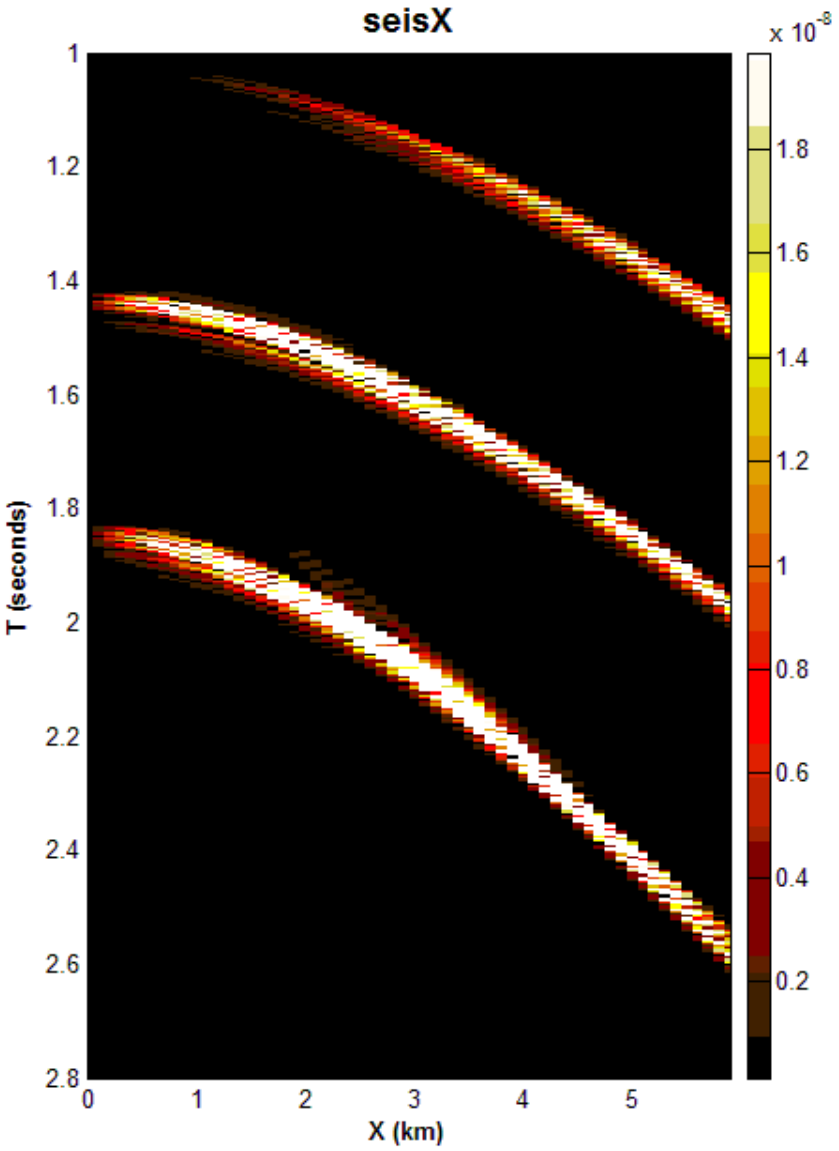
Modeling Step 4: VTI + HTI



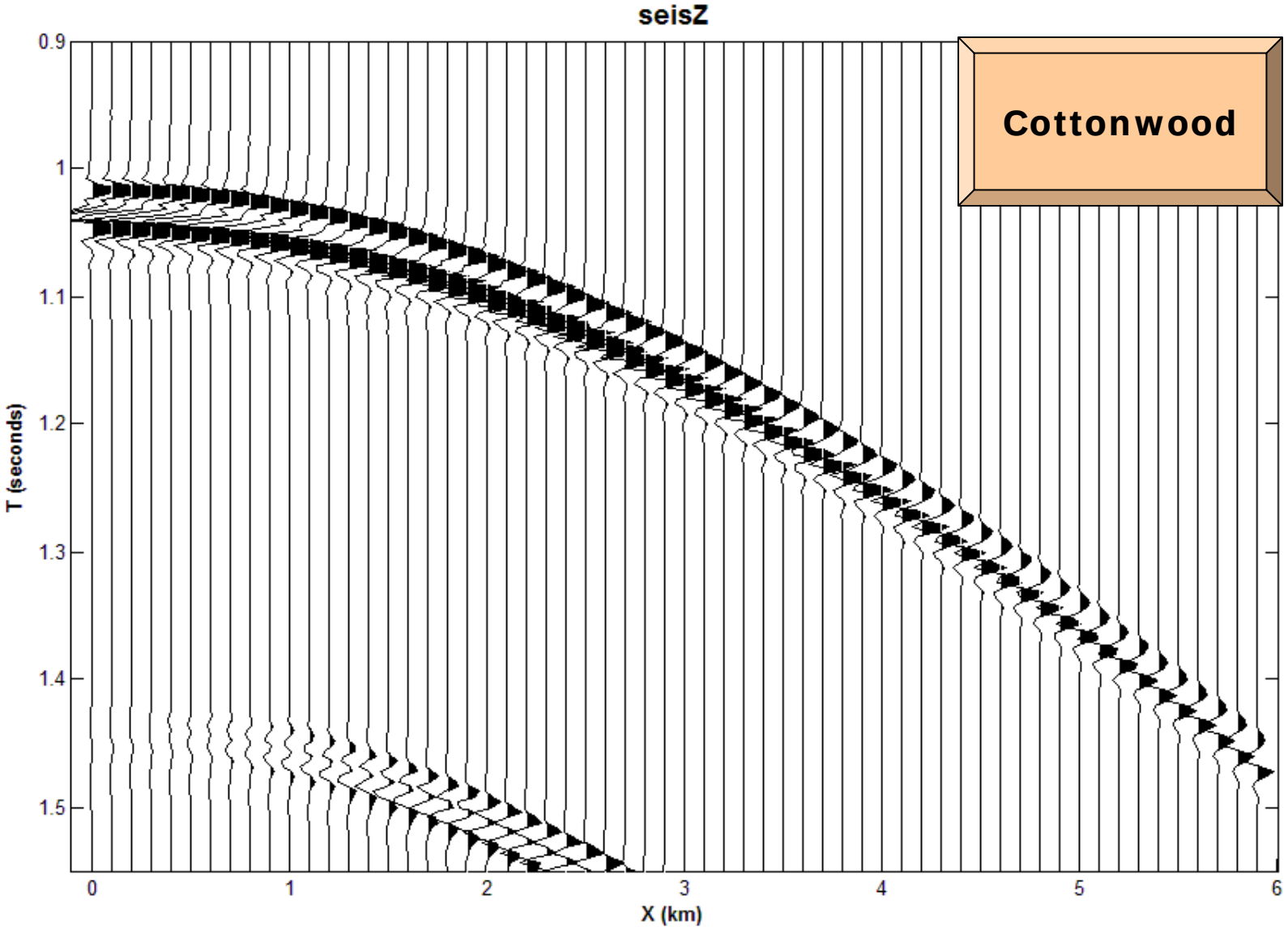


VTI + HTI: Difference Between Azimuth 0 and 90

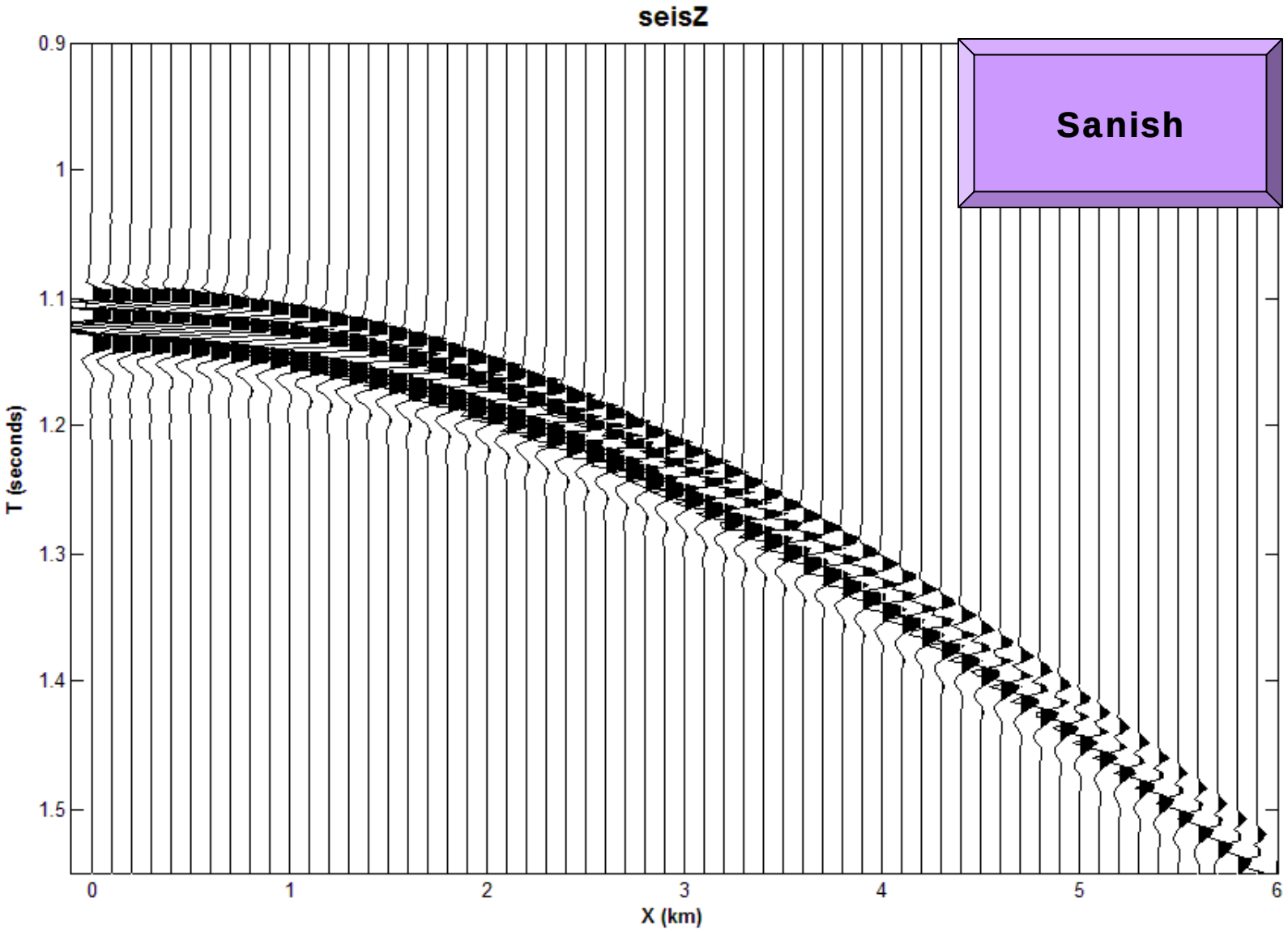




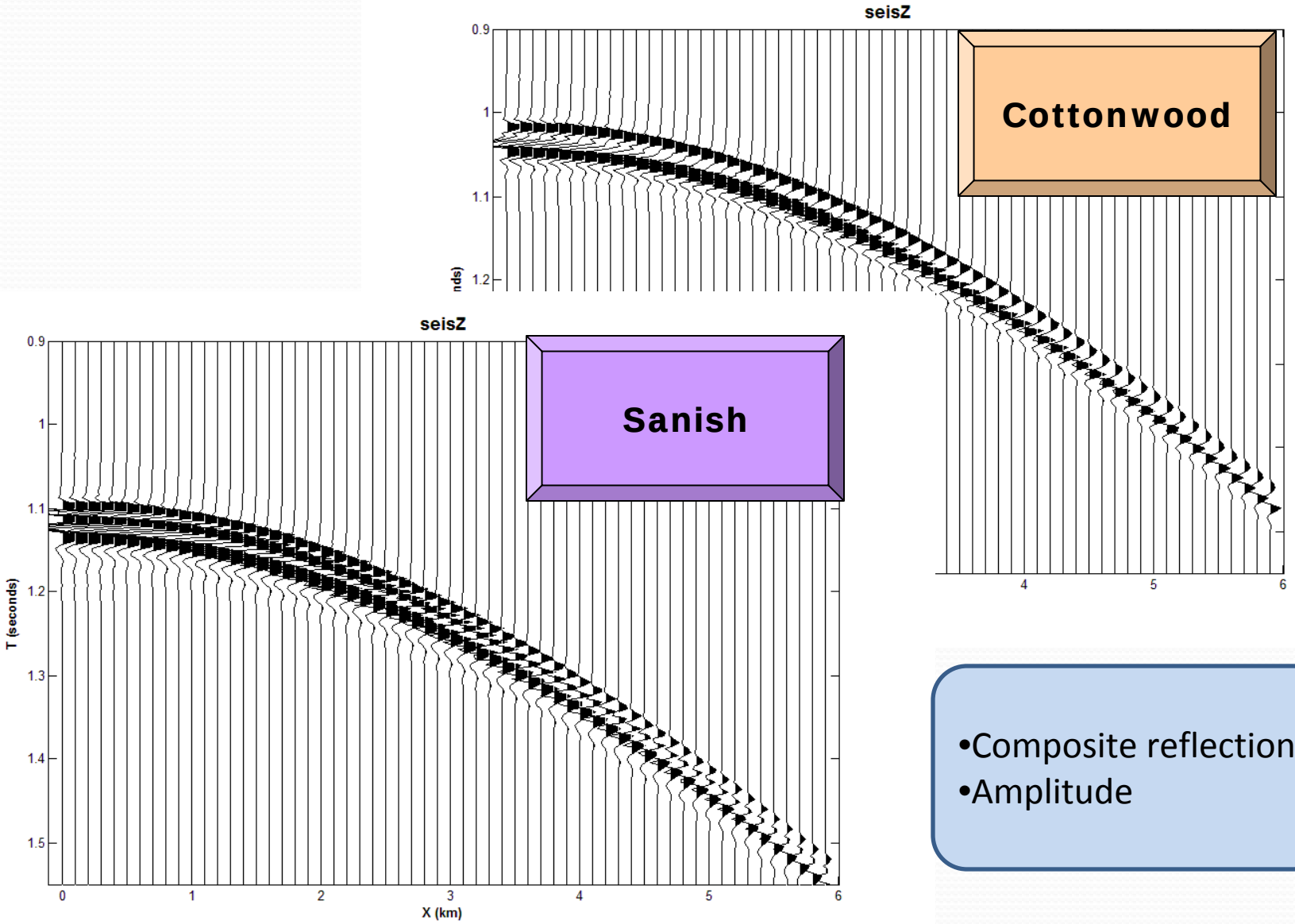
Cottonwood field : P wave Z component



Sanish field : P wave Z component

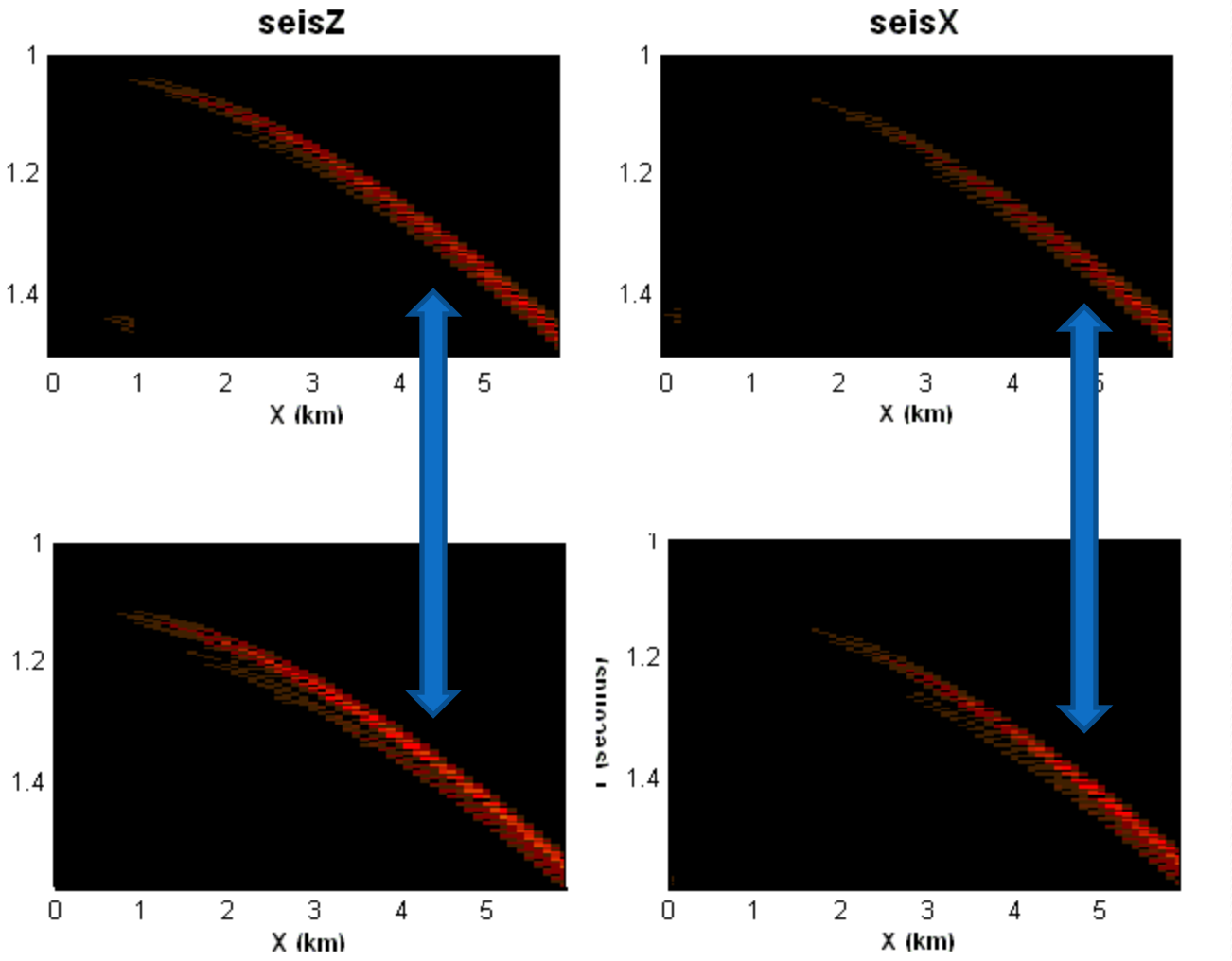


Comparison between Cottonwood and Sanish field



- Composite reflection
- Amplitude

Difference Between Azimuth 0 and 90



Cottonwood

Sanish

Brighter color → more difference between two azimuths

Outline

- Introduction
- Well log analysis
- Seismic modeling
- Summary
- Acknowledgements

Summary

❖The Upper and Lower Bakken shales are characterized by low density , low P and S wave velocities and low Vp/Vs 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.

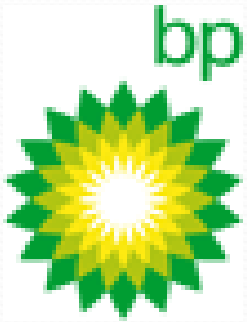
❖ The presence of fracture results in azimuthal anisotropy, which can be observed from wide azimuth seismic data. For P wave, the anisotropy is more pronounced at mid to far offset seismic data.

❖Bakken thickness variation contributes a lot to the difference in seismic responses between Sanish and Cottonwood field.

Summary

- On going and future work
  - Sensitivity analysis
  - Comparison between Cottonwood and Sanish field
  - AVO
  - Field data
  - Relate differences in seismic response to productivity

Acknowledgements



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- Samik Sil
- Diego Valentin
- Effie Jarrett
- Margo Grace

Thank You