Understanding fracture orientation by removing polarization distortion for direct shear waves

Terence Campbell (Ph.D. Candidate, 2012)
Supervisor: Robert Tatham

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

UT-AUSTIN EDGER FORUM

The problem

THE PROBLEM

In general, a polarized shear wave undergoes significant distortion of that polarization upon reflection regardless of the symmetry of the propagating media (even in purely isotropic media).

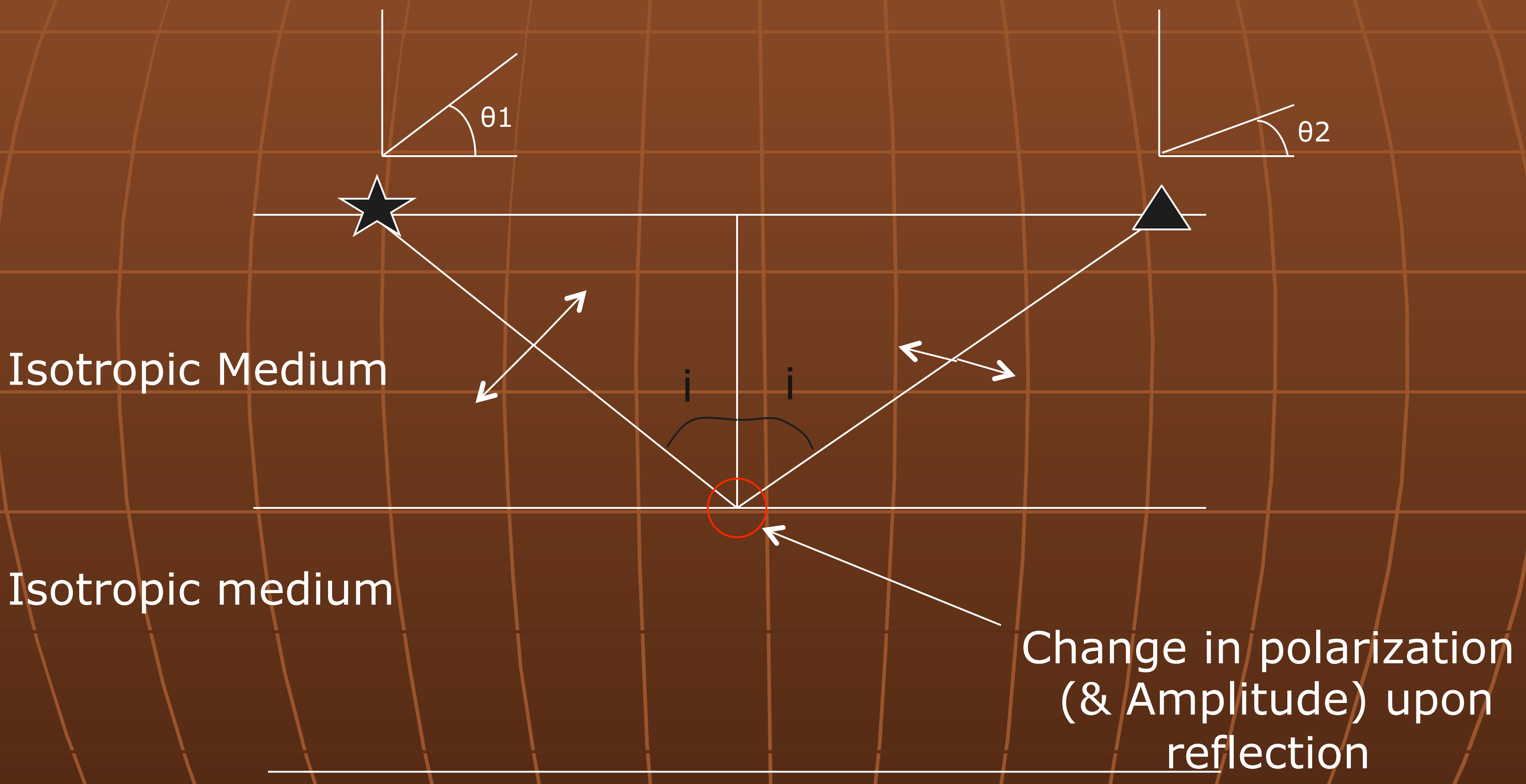
THE CONSEQUENCES

This distortion complicates analysis of the reflection data for extracting medium properties from polarization information

Talk Outline

- S waves
- Polarization distortion
- Addressing the problem
- Previous work
- Reflection polarization vs. incidence angle
- Real Data
- Future Work
- Questions

Polarization distortion isotropic media



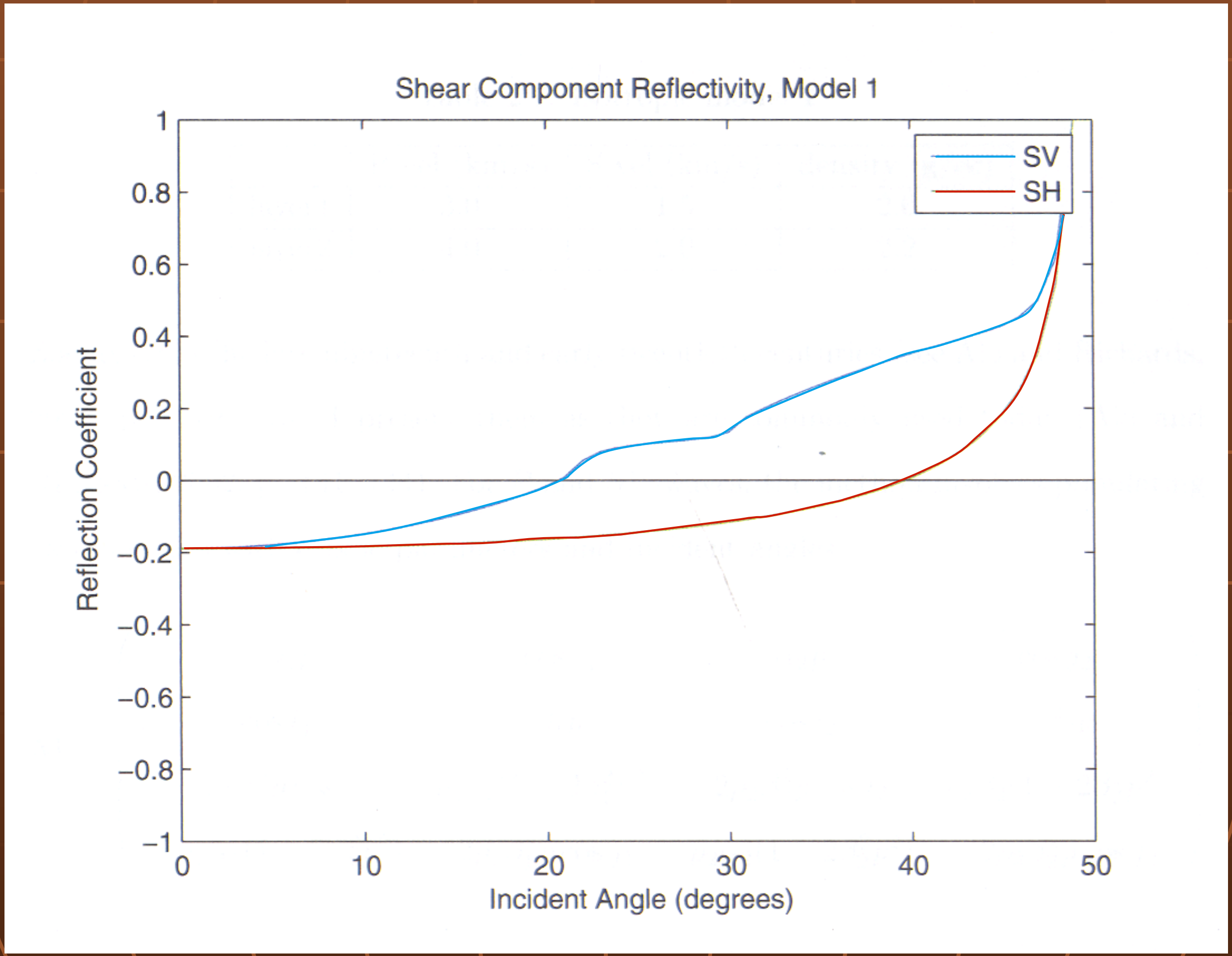
THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Isotropic model

P wave Velocity – 3.0 km/sec
S wave velocity - 1.5 km/sec
Density - 2.0 g/cc

P wave Velocity – 4.0 km/sec
S wave velocity - 2.0 km/sec
Density - 2.2 g/cc

Rss vs Incidence Angle



JACKSON
SCHOOL OF GEOSCIENCES

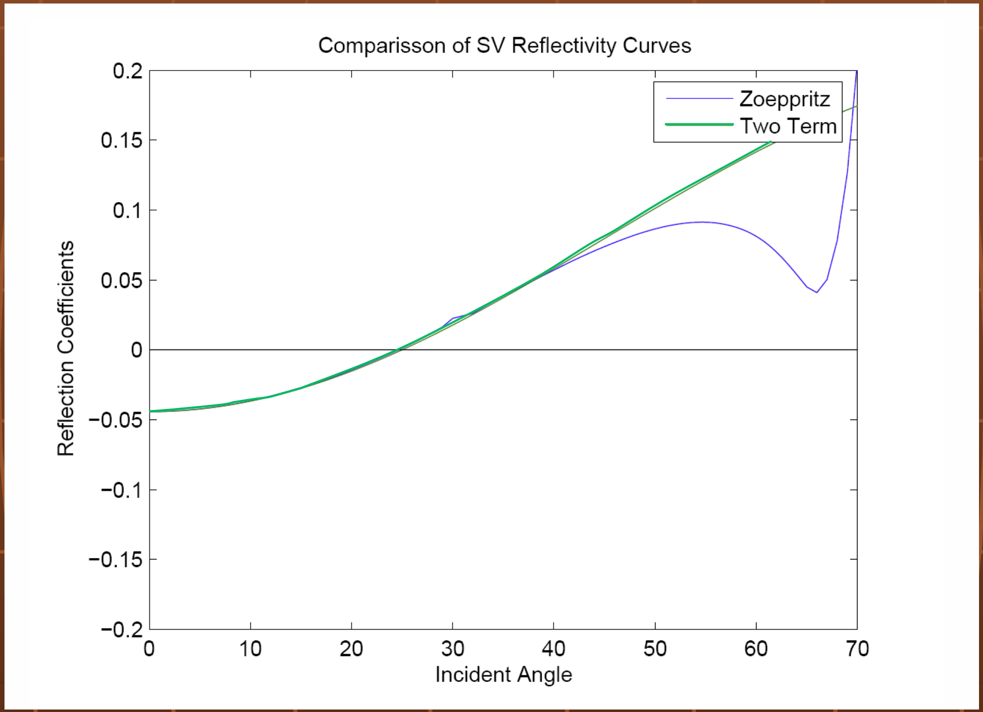
Approximations to simplify Zoeppritz equations

- The coefficient of the second term is that combination of elastic properties which can be determined by analyzing the offset dependence of event amplitude in conventional multichannel reflection data
- Assumes small contrasts in density and velocity

	Receiver		
Source	P	S_v	S_h
P	$R_p + (R_p - 2R_s)\sin^2\theta$	$-2R_s \sin\theta$	—
S_v	$-2R_s \sin\theta$	$-R_s + \left[7R_s + \frac{1}{2}\left(\frac{\Delta\rho}{\rho}\right)\right]\sin^2\theta$	—
S_h	—		$-R_s + \frac{1}{2}\left(\frac{\Delta V_s}{V_s}\right)\sin^2\theta$

Spratt (1993) shows other reflection coefficients for different sources and different receivers

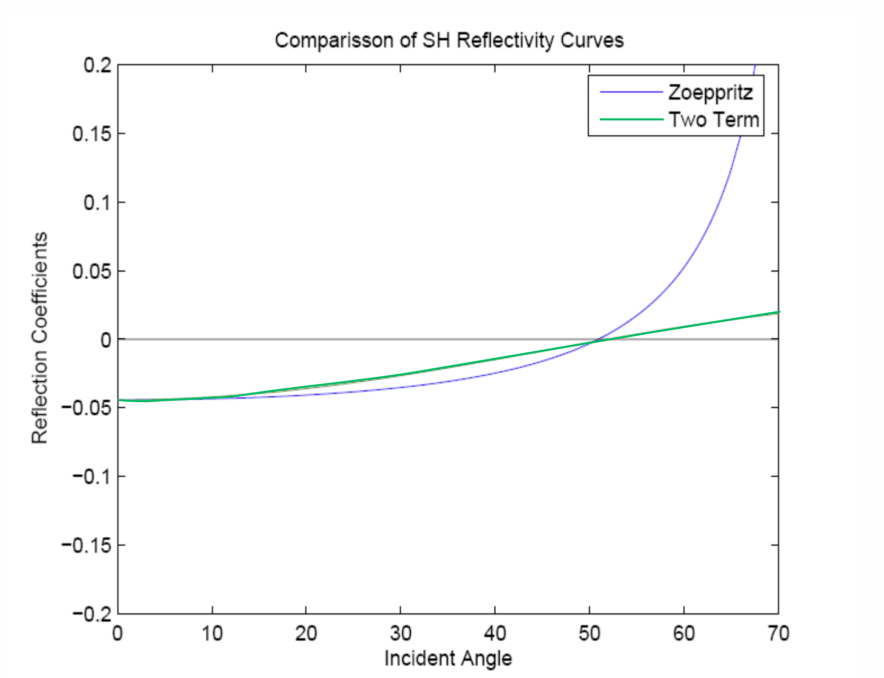
Comparing Zoeppritz equation to the two term linear approximation



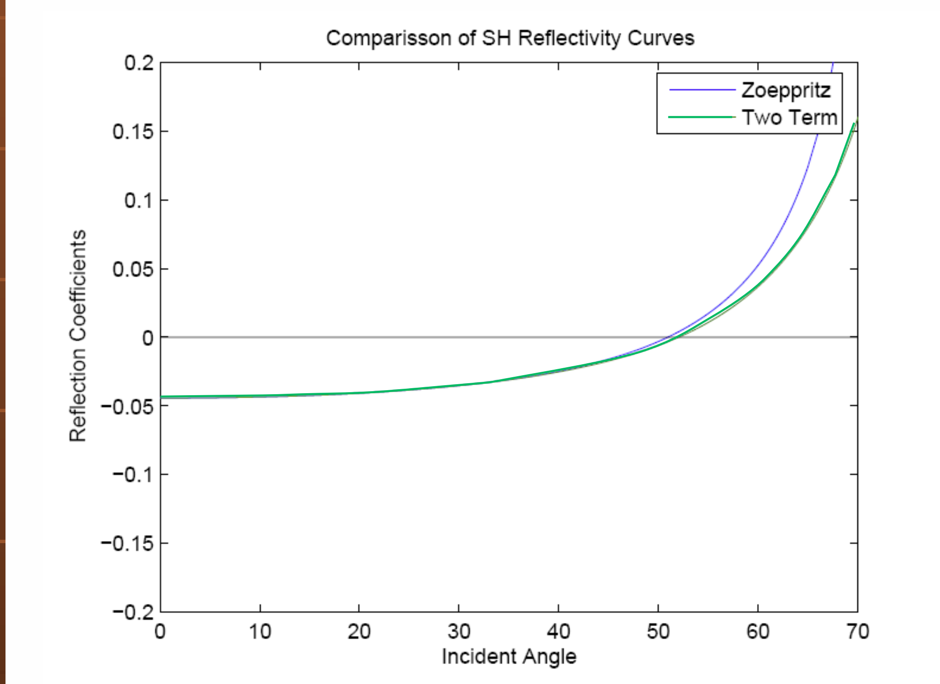
Comparing the full Zoeppritz equations to a two term $\sin^2$ approximation, describing *SV* motion (Spratt, 1993)

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Comparing Zoeppritz equation to Spratt's and Lyons linear approximation



Comparing the full Zoeppritz equations to a two term Sin^2 approximation, describing *SH* motion. There is poor agreement between the two approximations



Comparing the full Zoeppritz equations to a two term tan^2 approximation, describing *SH* motion. There is excellent agreement between the two through an incident angle of 50 *(*Lyons, 2006*)*

Approximation to simplify Zoeppritz equations

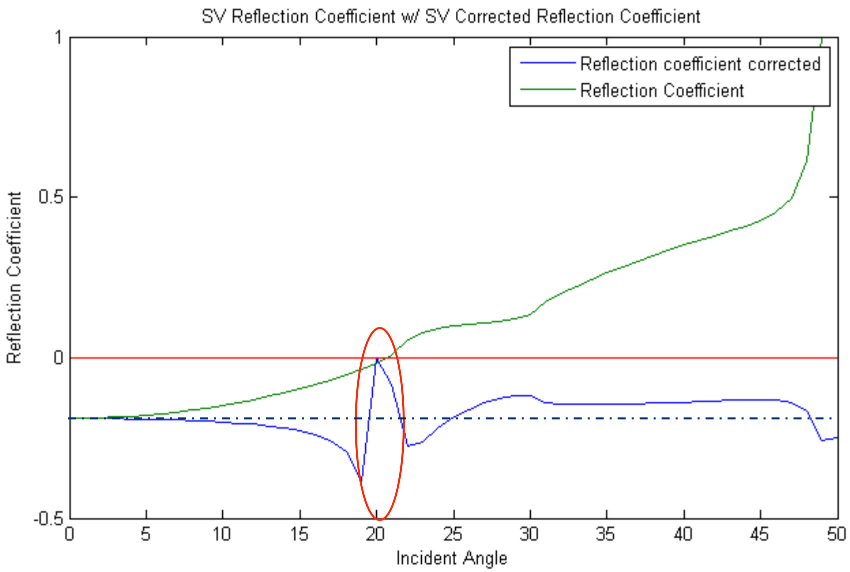
- Calculate a gradient value for Spratt's approximation correct SV AVO with $[A + B \sin^2(\Theta)]$ form
- Assume zero crossing at 20 deg A=1, to leave normal incidence unchanged therefore:
- $[1 + B \sin^2(20)] = 0$; $B_{sv}=-8.5486$
- Calculate a gradient value for Lyons's approximation correct SH AVO with $[A + B \tan^2(\Theta)]$ form
- Assume zero crossing at 40 deg A=1, to leave normal incidence unchanged therefore:
- $[1 + B \tan^2(40)] = 0$; $B_{sh}=-1.4203$;

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

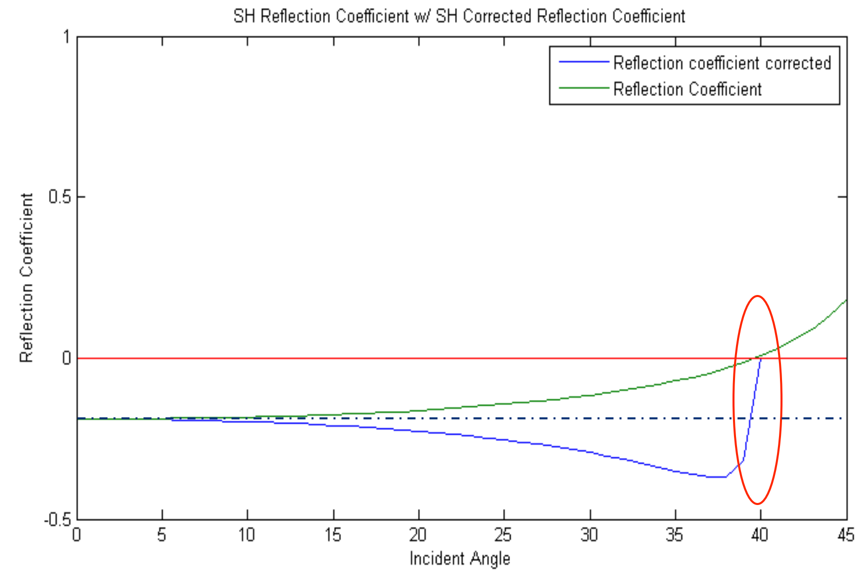
Corrected reflection coefficient to minimize amplitude change

$SS_{SVcorrected} = SS_{SV} *(1/(1+Bsv*\sin^2\theta))$

$SS_{SHcorrected} = SS_{SH} *(1/(1+B_{SH}*\tan^2\theta))$



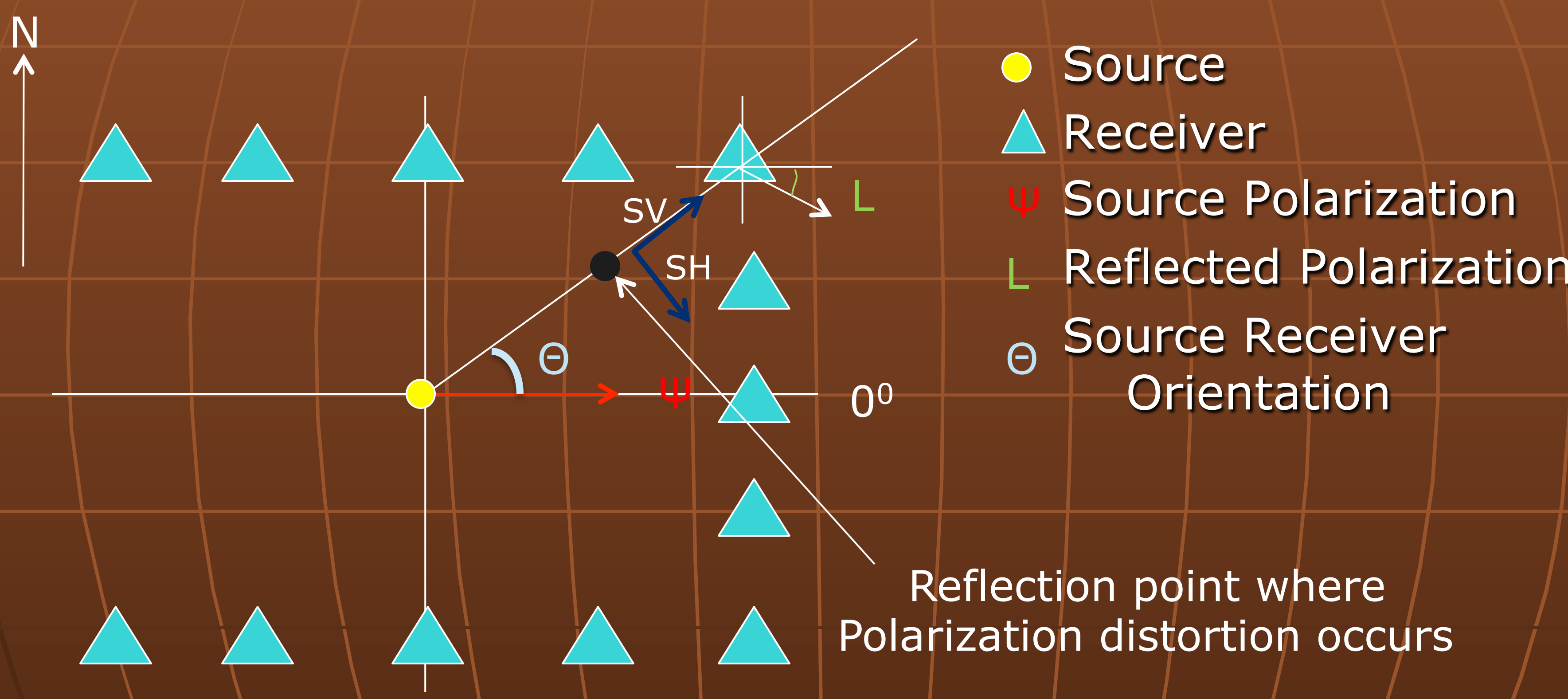
Singularity at 18-22 degrees



Singularity at 38-42 degrees

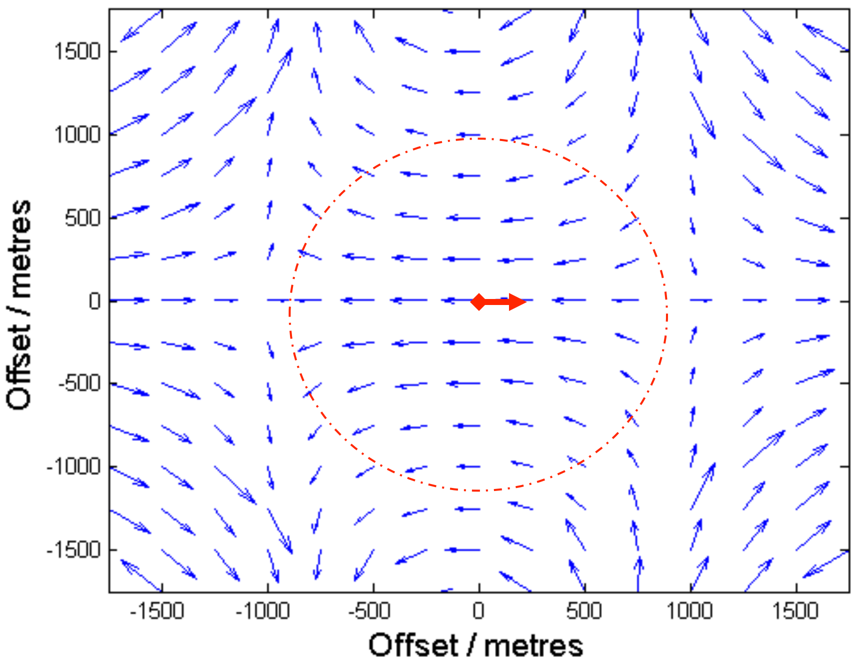
THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Theoretical Survey Design

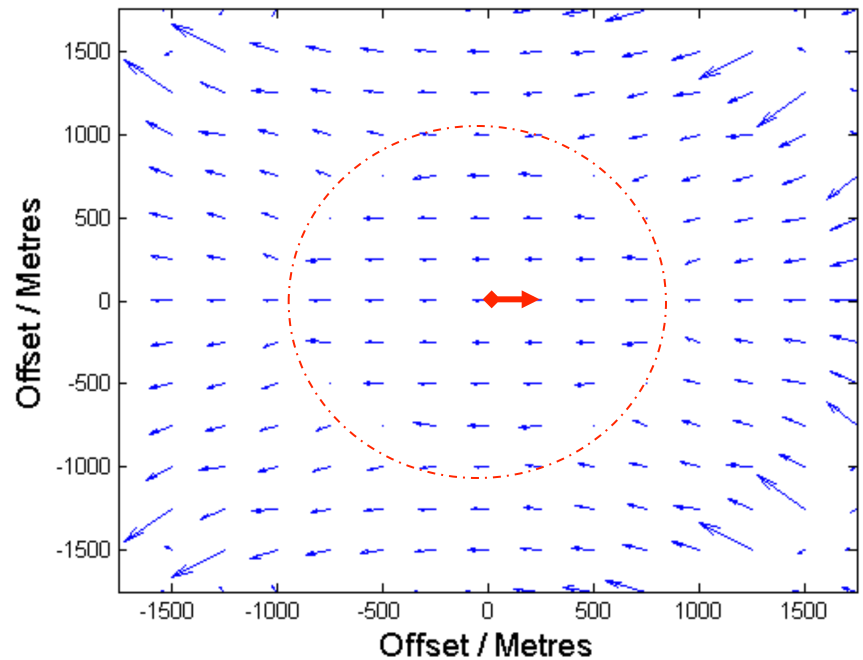


$$L = \arctan\left[\cos(\Theta-\Psi)SV / \sin(\Theta-\Psi)SH\right] + (\Theta-90)$$

Polarization plot (3D survey)



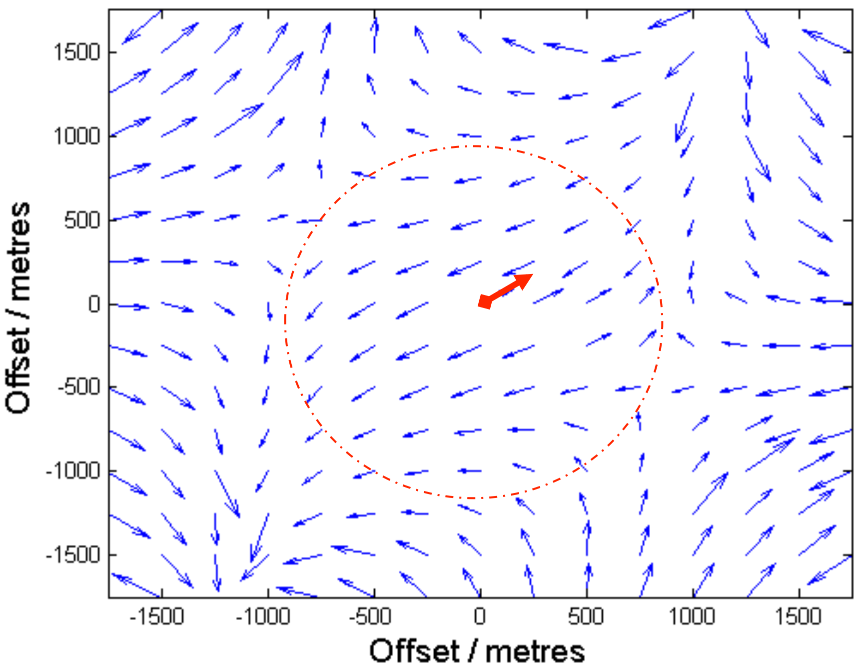
$L = \arctan [\cos(\Theta-\Psi)SV/\sin(\Theta-\Psi)SH] + (\Theta-90)$

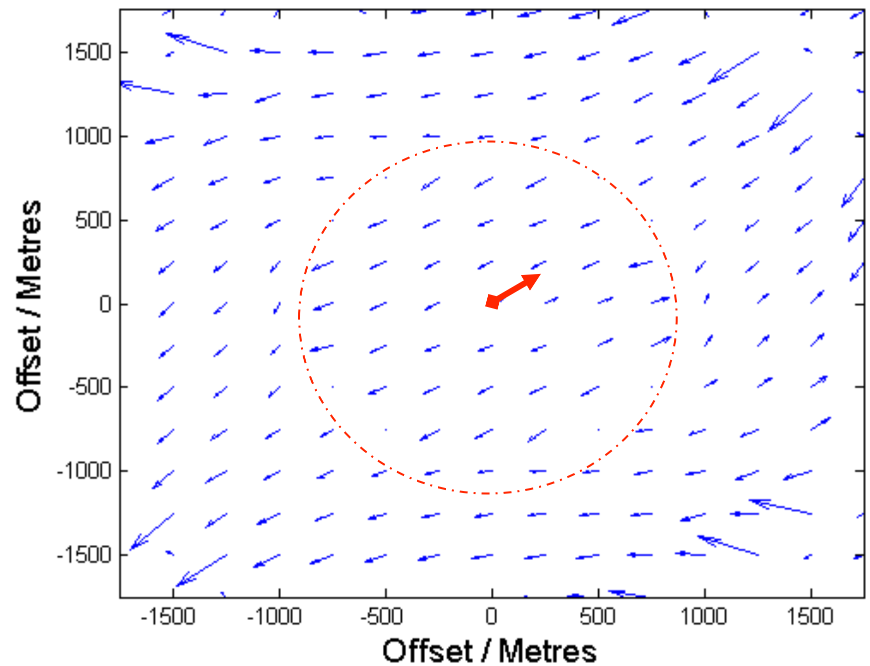


$L = \arctan [\cos(\Theta-\Psi)Sv_{corrected} /\sin(\Theta-\Psi)SH_{corrected}] + (\Theta-90)$

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Polarization plot (3D survey)





Source polarized 30^0 North of East

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Sensitivity Analysis

- Sensitivity analysis performed to understand changes in SV and SH reflection coefficients with changes in Density and S-wave velocity
- SH reflection coefficient changes but they are insensitive to changes in incidence angles
- SV reflection coefficient is very sensitive to changes in density and incidence angles
- Zero crossing for SV and SH are relatively constant to changes in shear wave velocity

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Diagram of Polarization distortion in Isotropic / HTI media

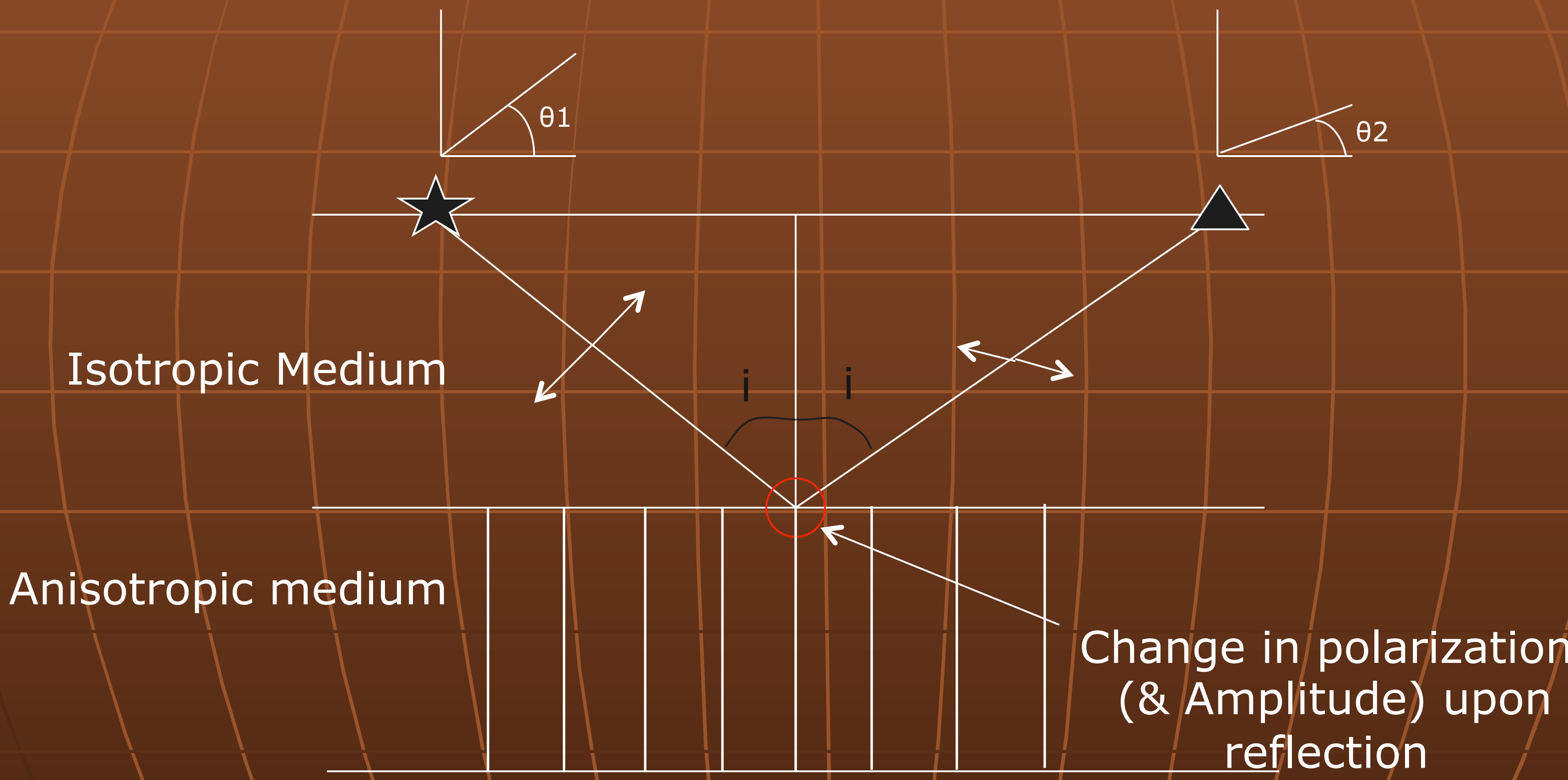


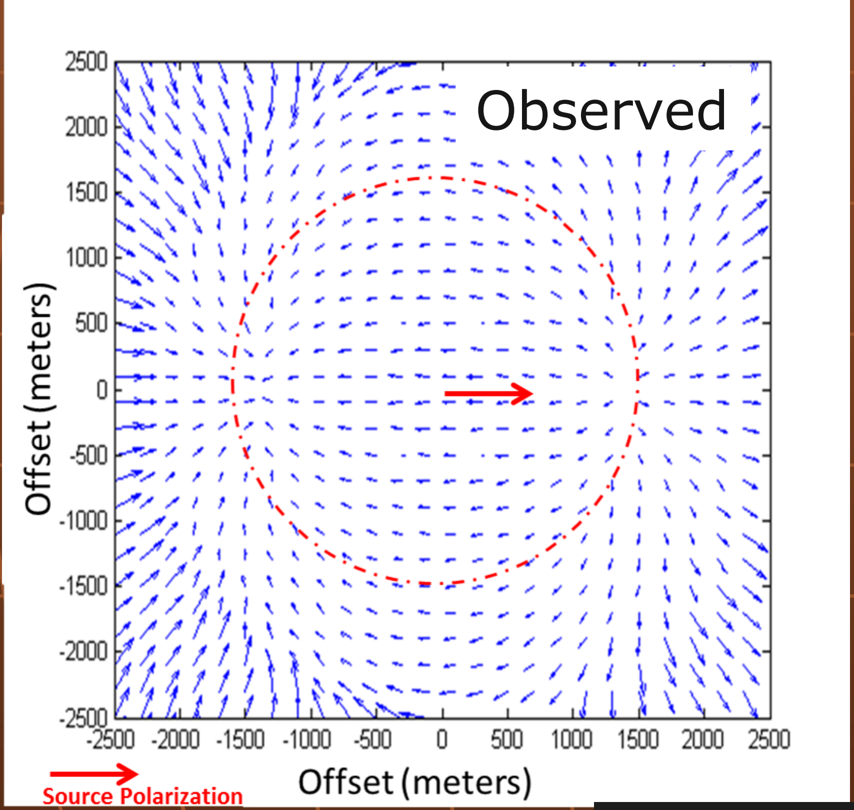
Diagram of Isotropic - HTI model

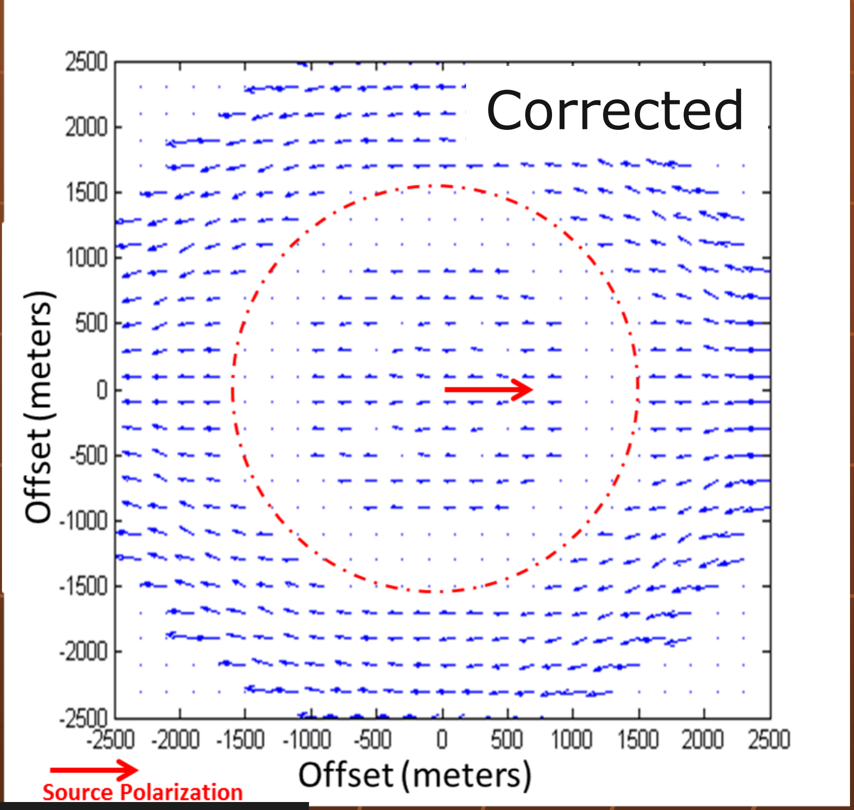
P wave Velocity – 3.0 km/sec
S wave velocity - 1.5 km/sec
Density - 2.0 g/cc

Vp(0)=4.0km/sec
Vs(0)=2.0km/sec
ϵ=0.50
δ=0.10
γ=0.02
Fracture Strike=East
ρ=2.2g/cc

- Use Ruger's 1996 equations for Isotropic /HTI medium to determine zero crossing for sources parallel and normal to fractures

Polarization plot (3D survey) fractures parallel to source

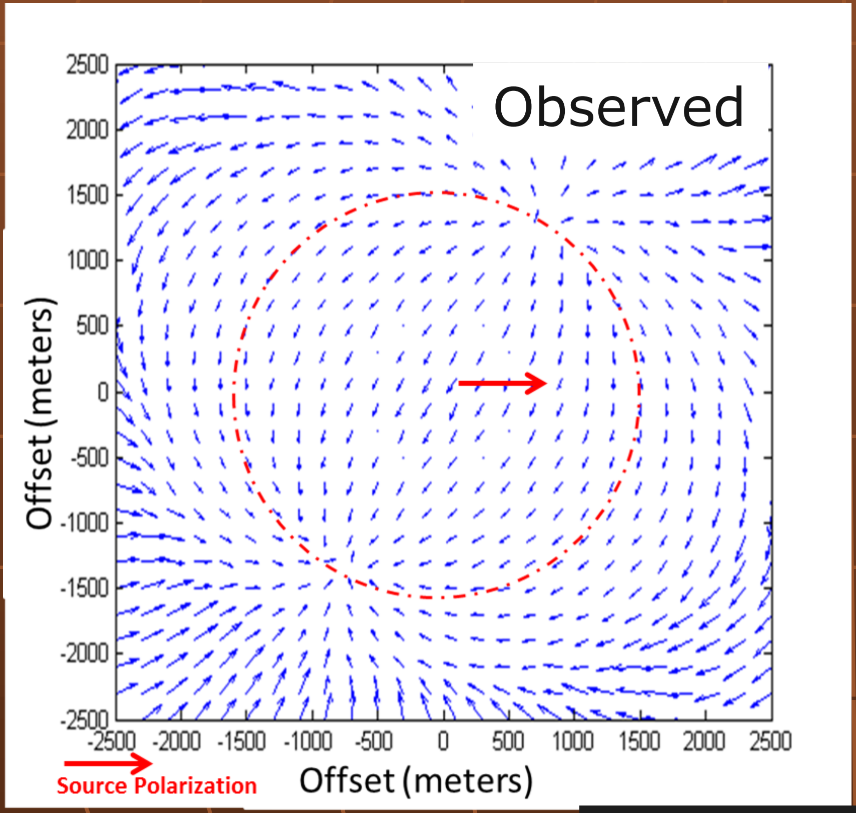


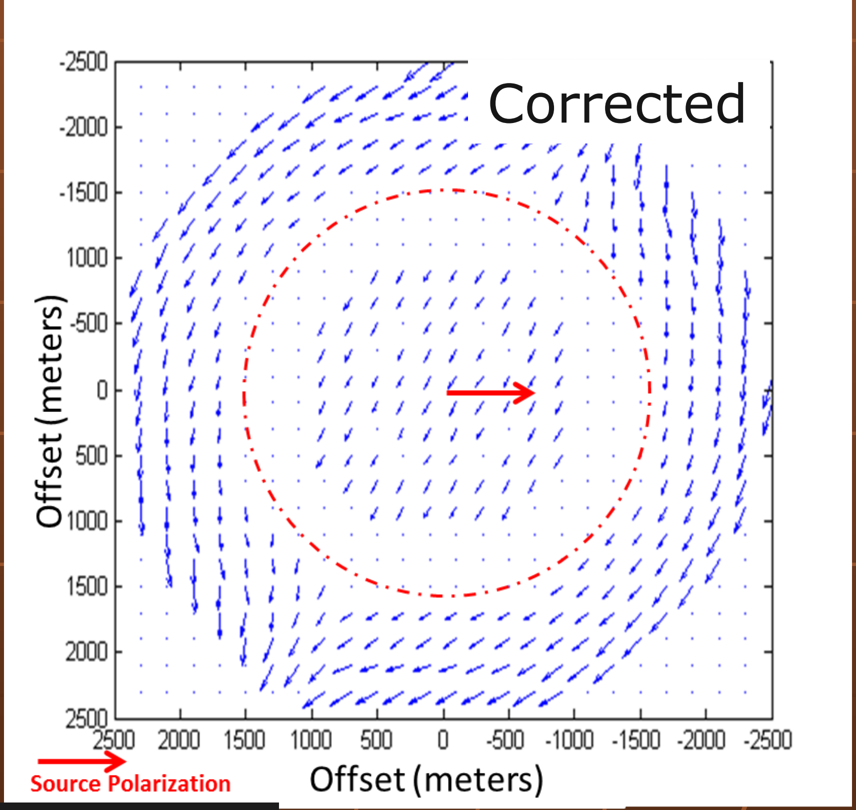


Gamma = 2%

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Polarization plot (3D survey) fractures 30^0 to source

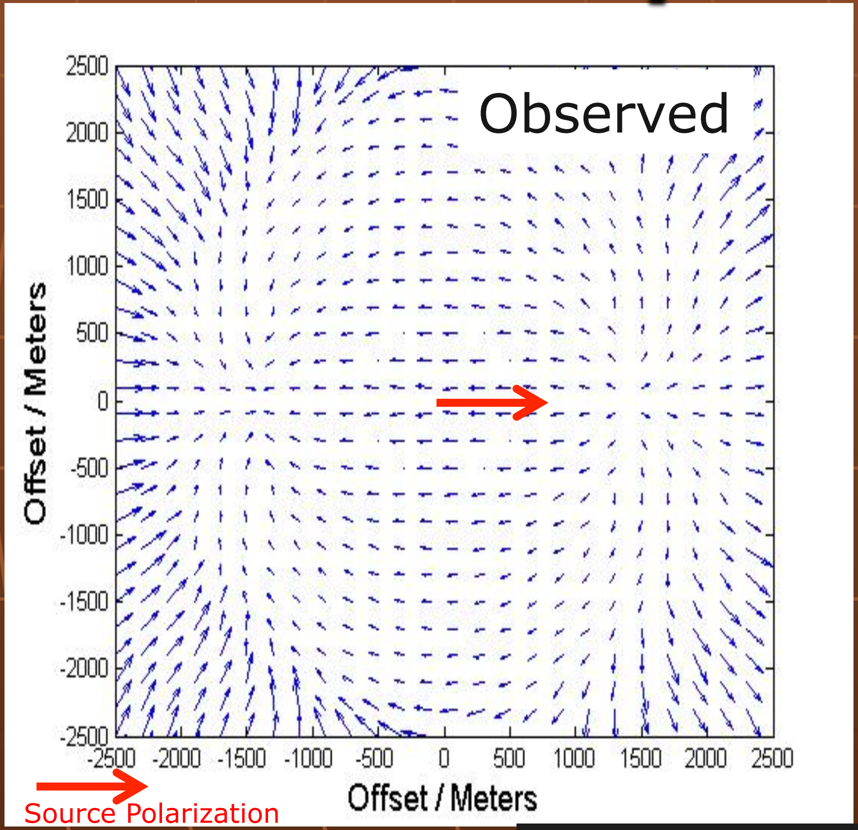


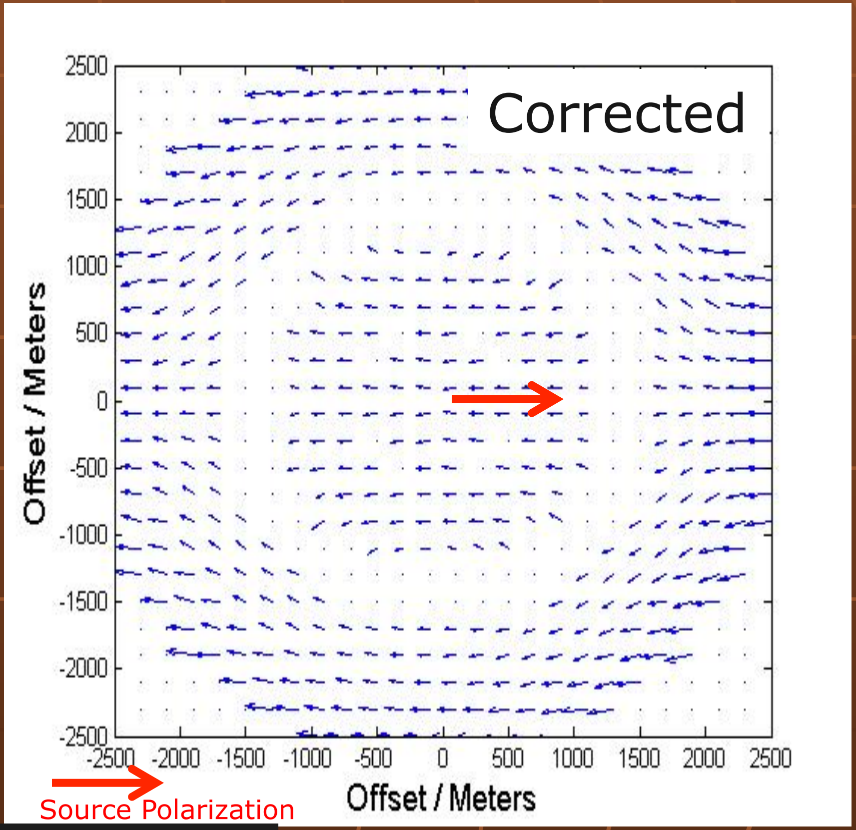


Gamma = 2%

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Polarization plot (3D survey) fractures parallel to source





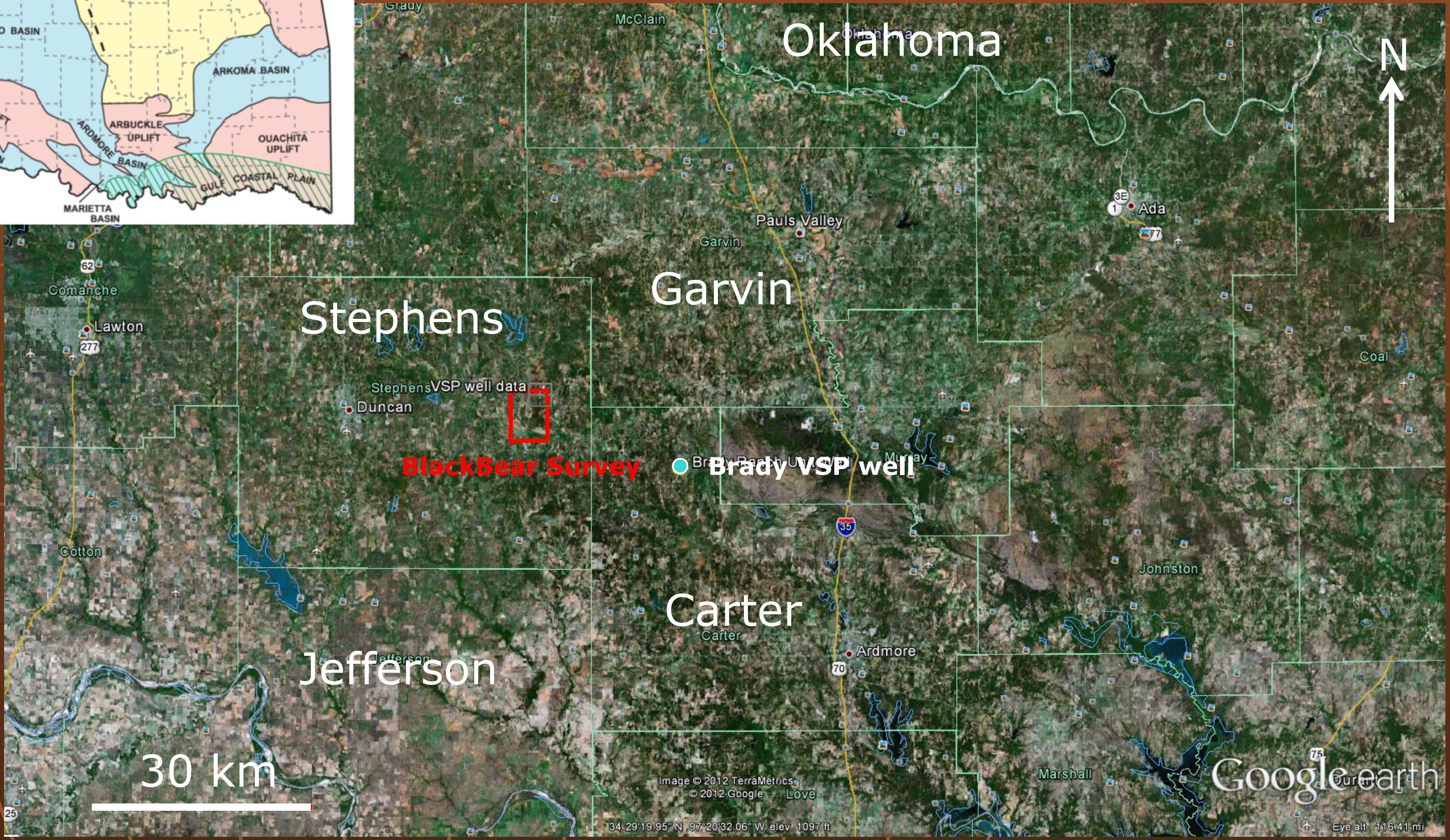
Gamma = 10%

Isotropic - HTI model Analysis

- Gamma larger than 10% uncorrected data properly defines the orientation
- Gamma > 2%, regardless of the source orientation, corrected polarization are all properly oriented
- Gamma < 1%, observed and corrected polarizations have no real differences from the simple isotropic/isotropic case; shear wave splitting seems to not occur

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Black-Bear Creek Oklahoma,



Data Courtesy
Exploration Geophysics
Laboratory (EGL)

JACKSON
SCHOOL OF GEOSCIENCES

Analysis of 3D 9C Seismic Data Set (Blackbear field)

- 3D 9C Data set
- Stephens County Oklahoma
- Sycamore fracturing (Carbonates)
- Acquisition 1998

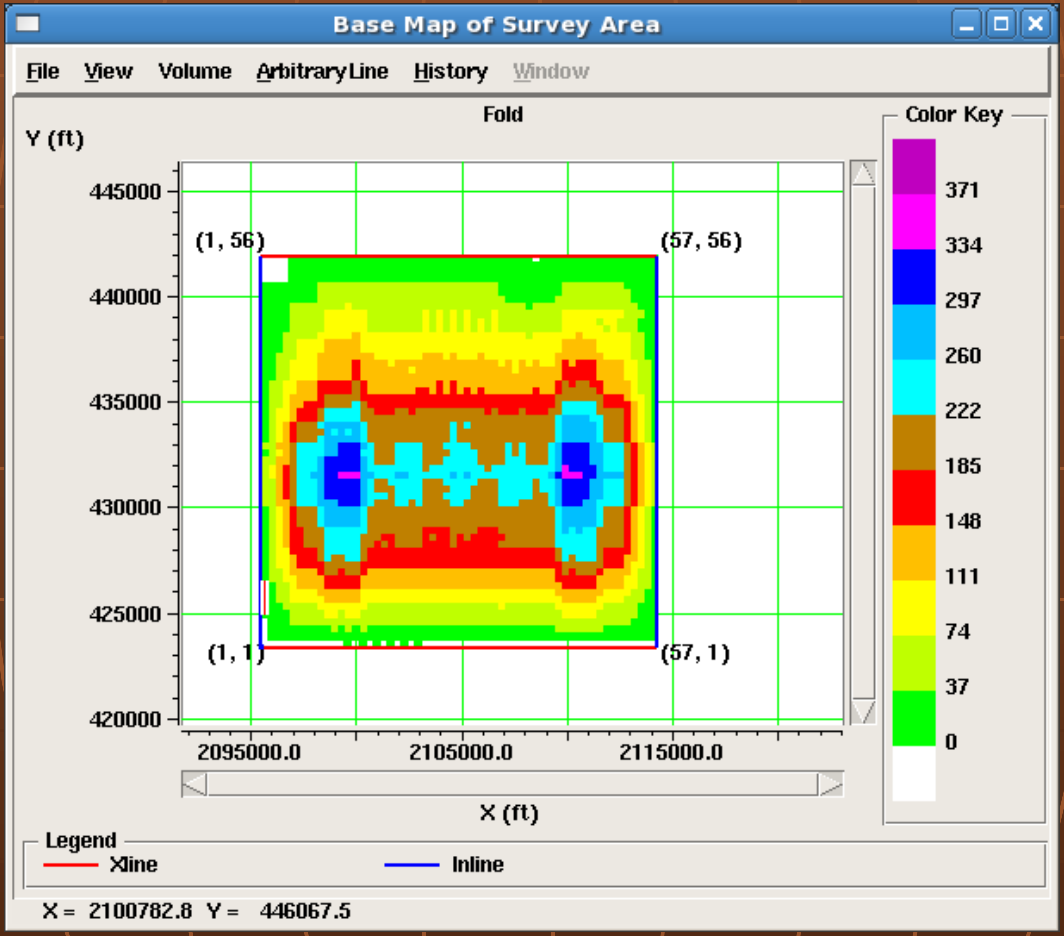
THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Zones of interest Sycamore and Hunton Carbonates

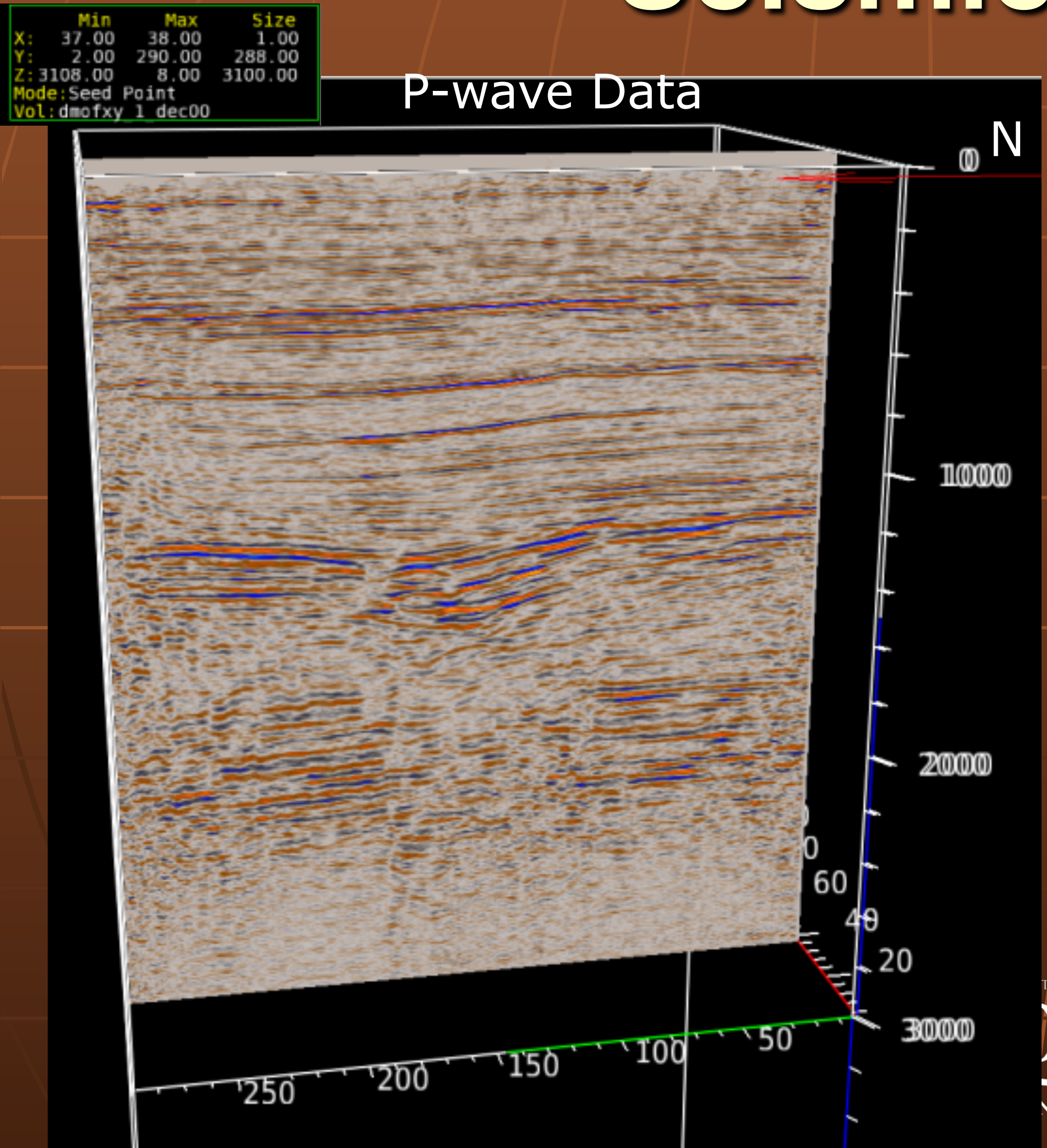
- Silurian Hunton Group rocks, generally limestone and dolomite,
- Depths 5,000 - 13,000 ft
- Productivity of this play are its proximity to a major hydrocarbon source--the overlying Woodford Shale--and its widespread reservoir and trap development

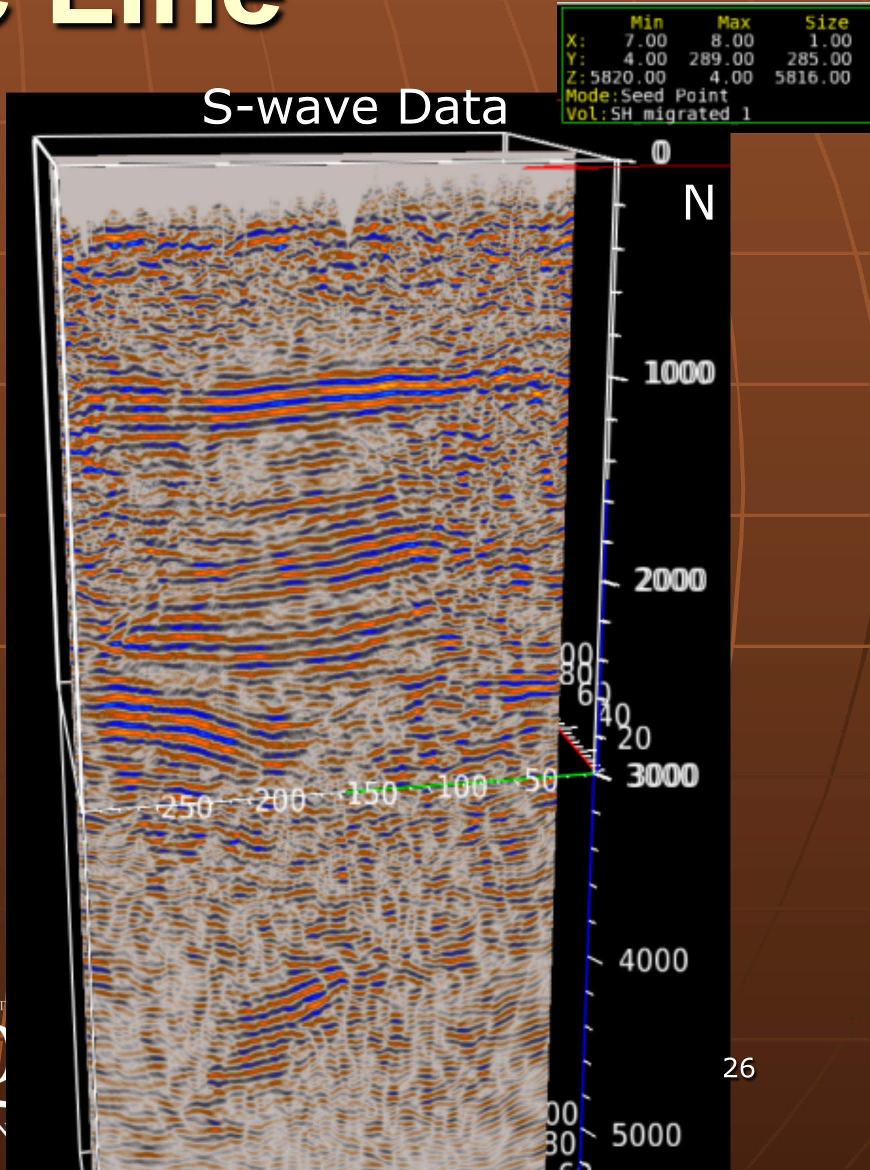
THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Fold Maps of S-wave Inline & Crossline Source

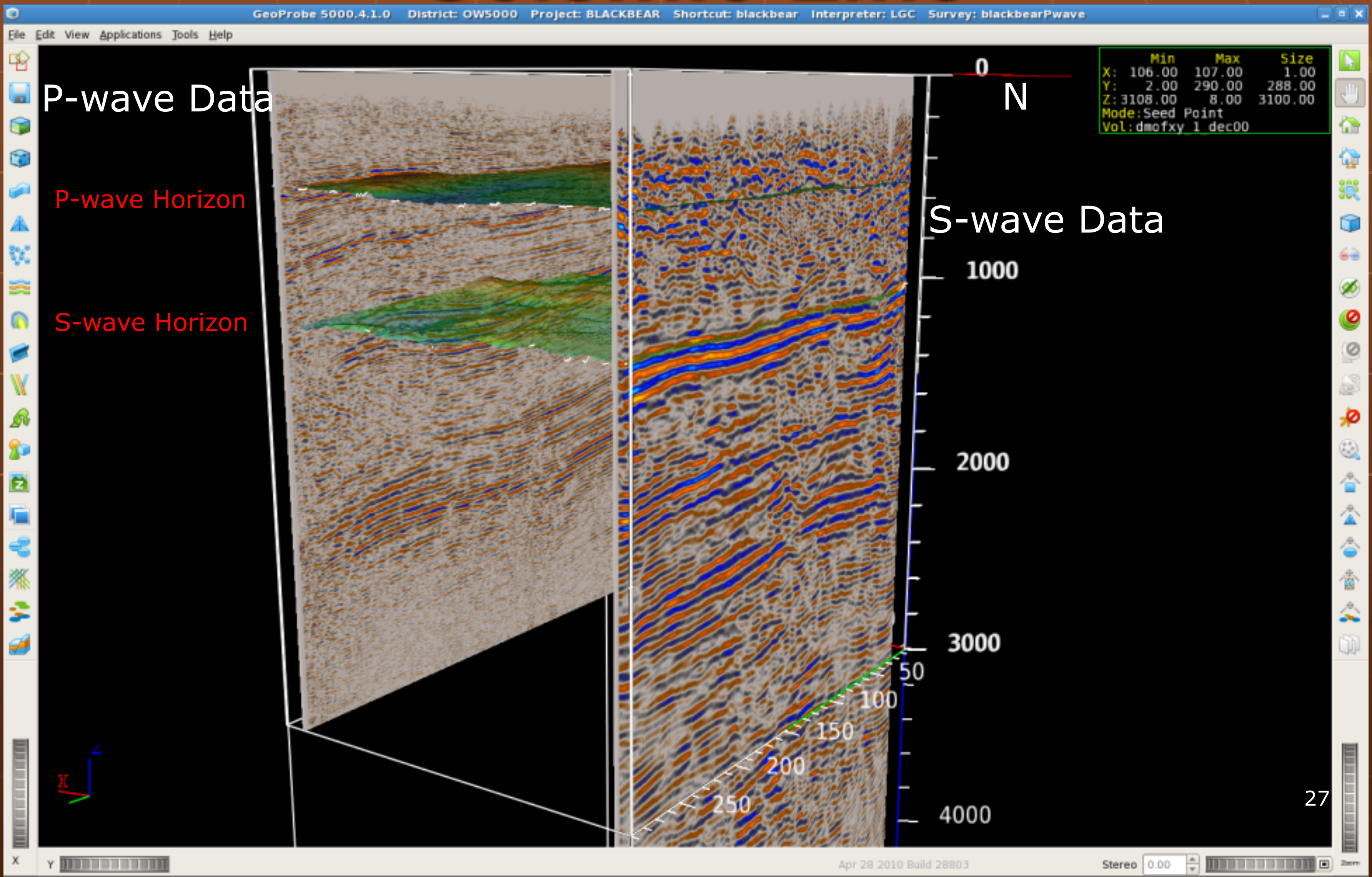


BlackBear S-wave and P-wave Seismic Line

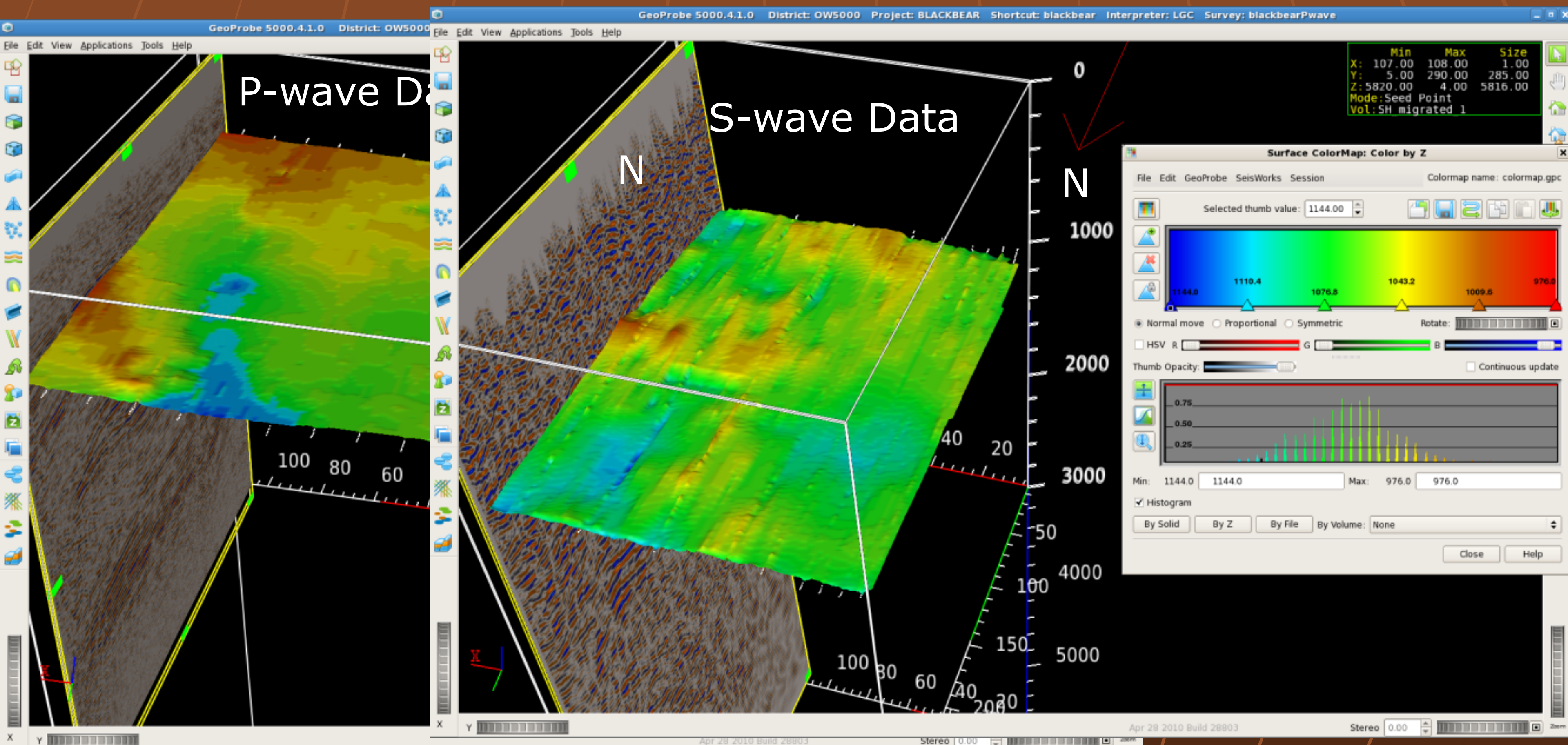




BlackBear S-wave and P-wave Seismic Line

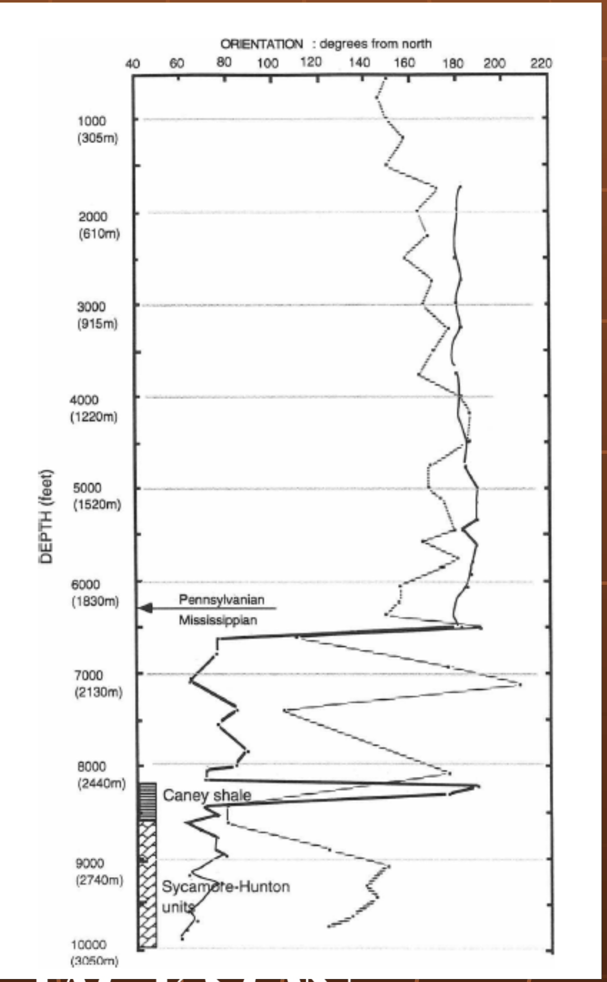


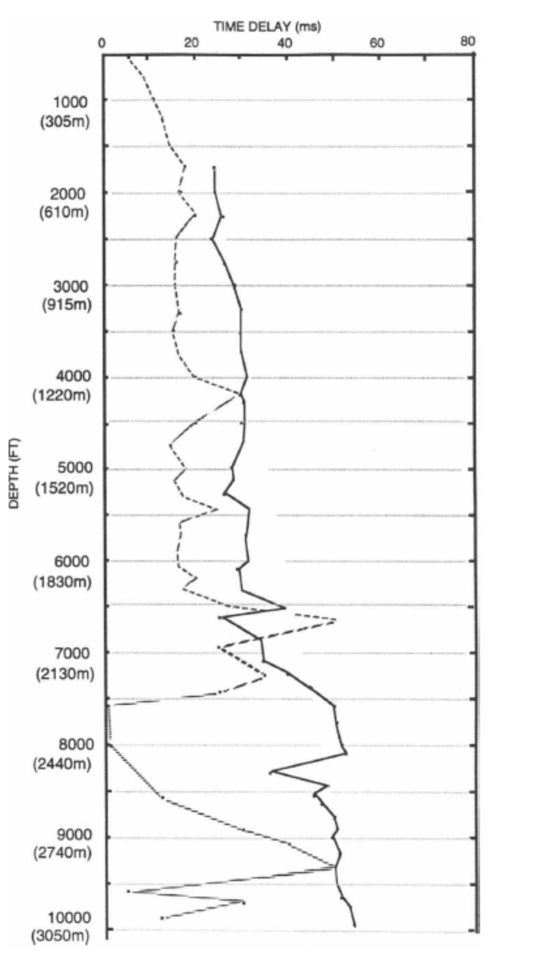
BlackBear S-wave and P-wave Seismic Line



Previous Well Data showing HTI Anisotropy

- The VSP indicate three changes in the orientation of azimuthal anisotropy east-northeast, east-southeast, and north-south orientations
- Synchronous rotation (SR) from angles of 0^0 to 180° at one degree increments
- Dashed curve is the result of applying SR at each depth level, and the solid curve is the result of applying downward continuation plus SR

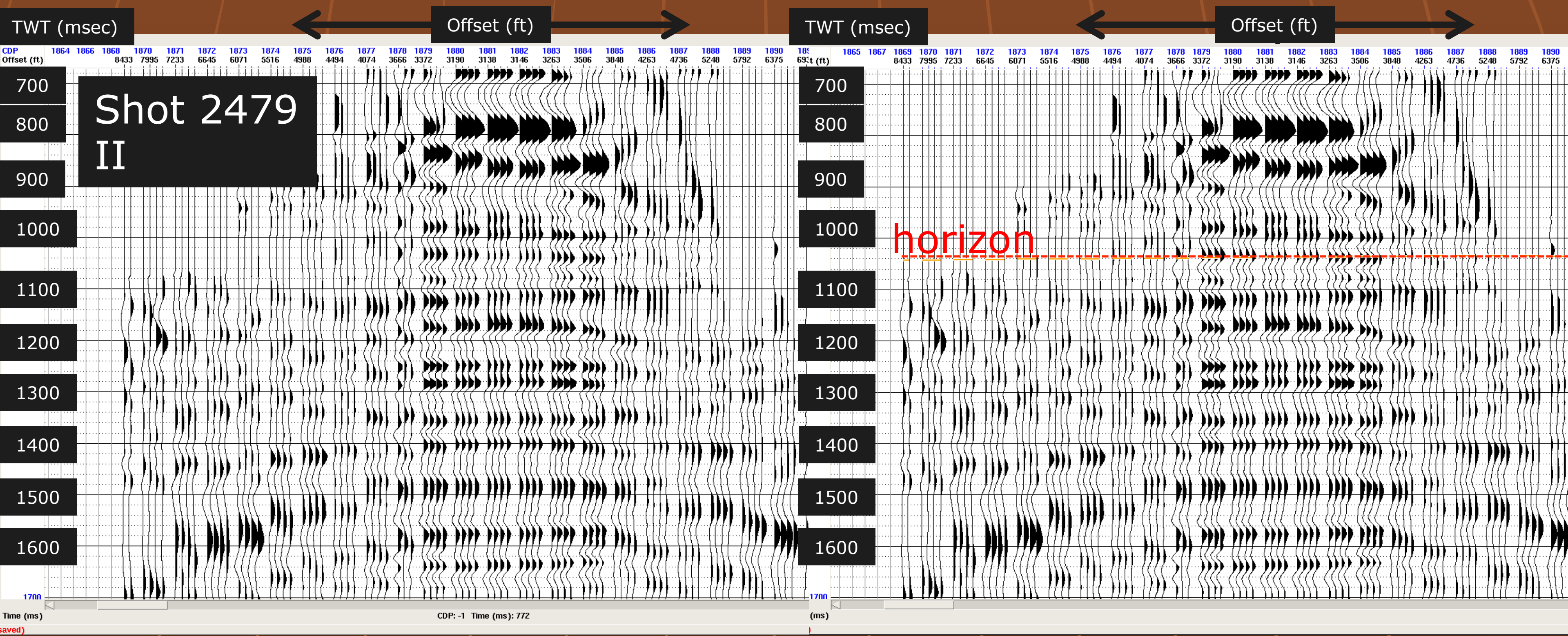




JACKSON
SCHOOL OF GEOSCIENCES

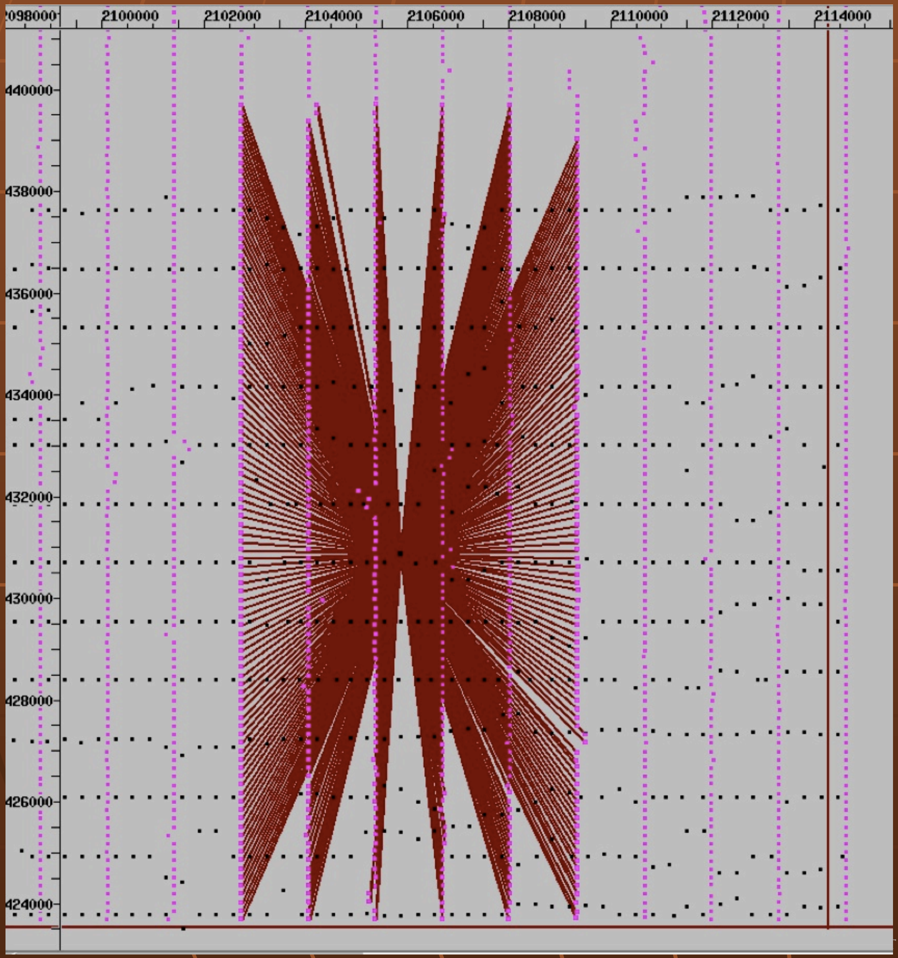
Beckham 96

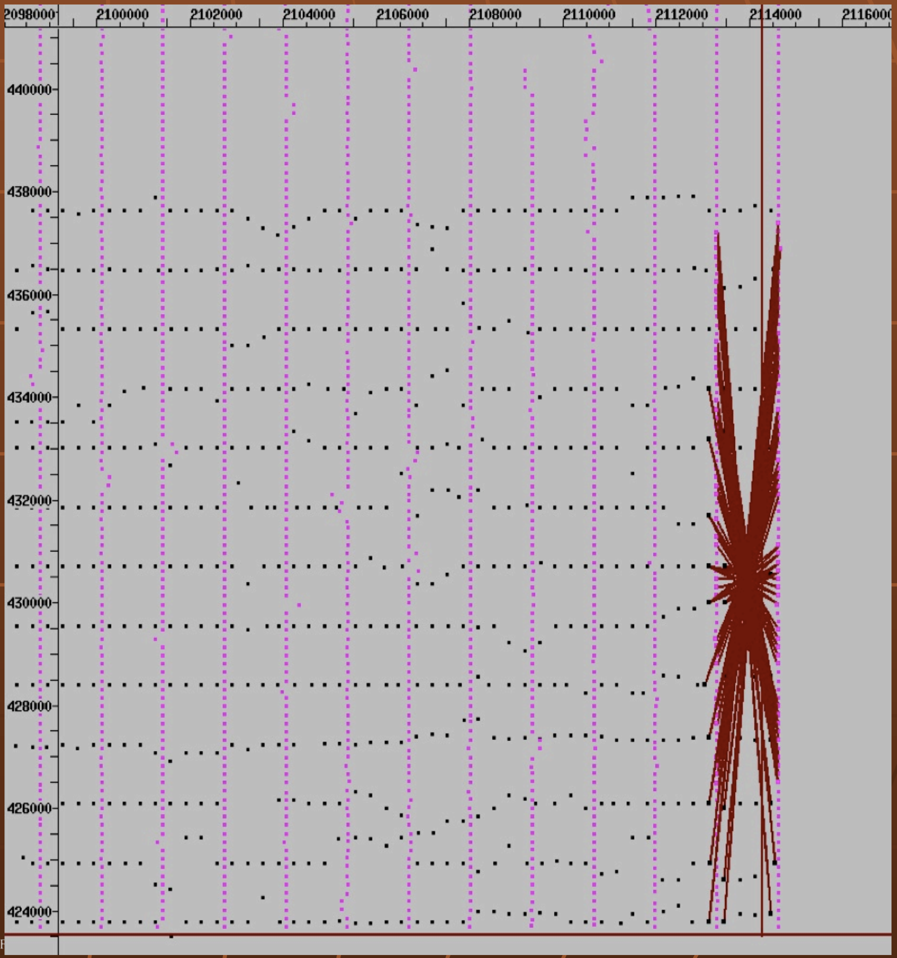
Prestack Data used to correct for Polarization Distortion



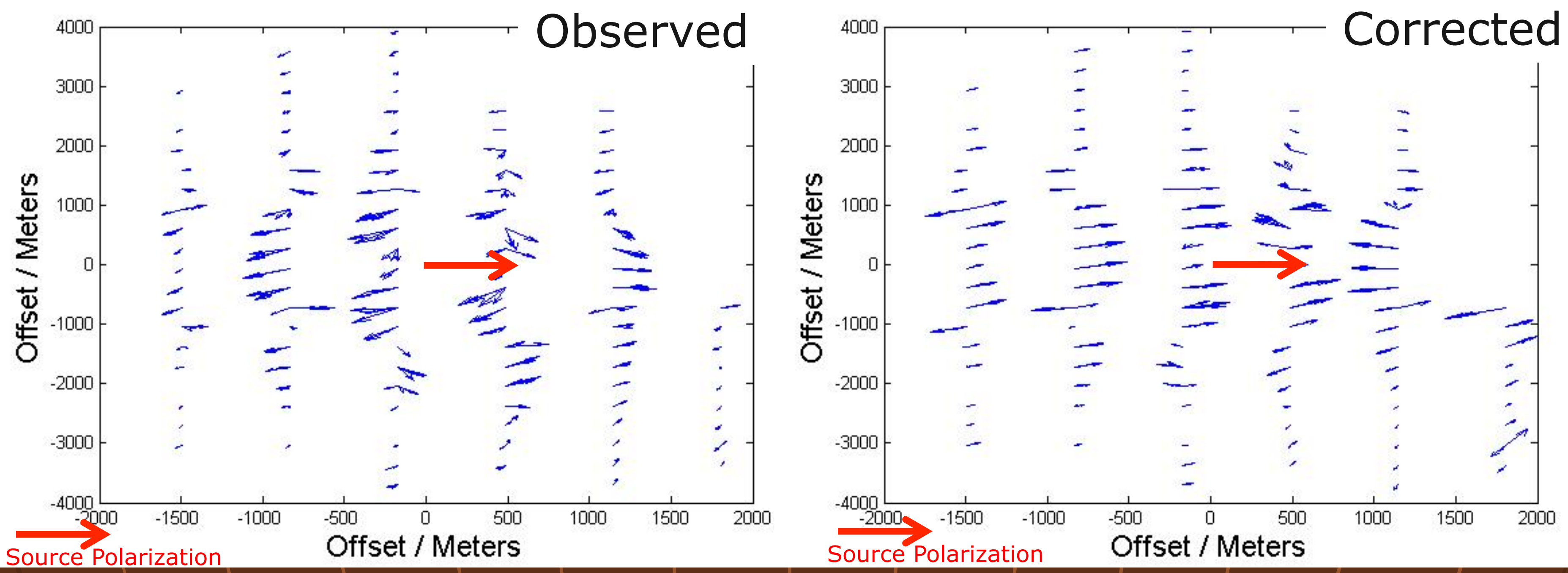
THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Shot Gather Analysis for Black-bear field





Center of Survey Shot Correct and Uncorrected Plots



THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

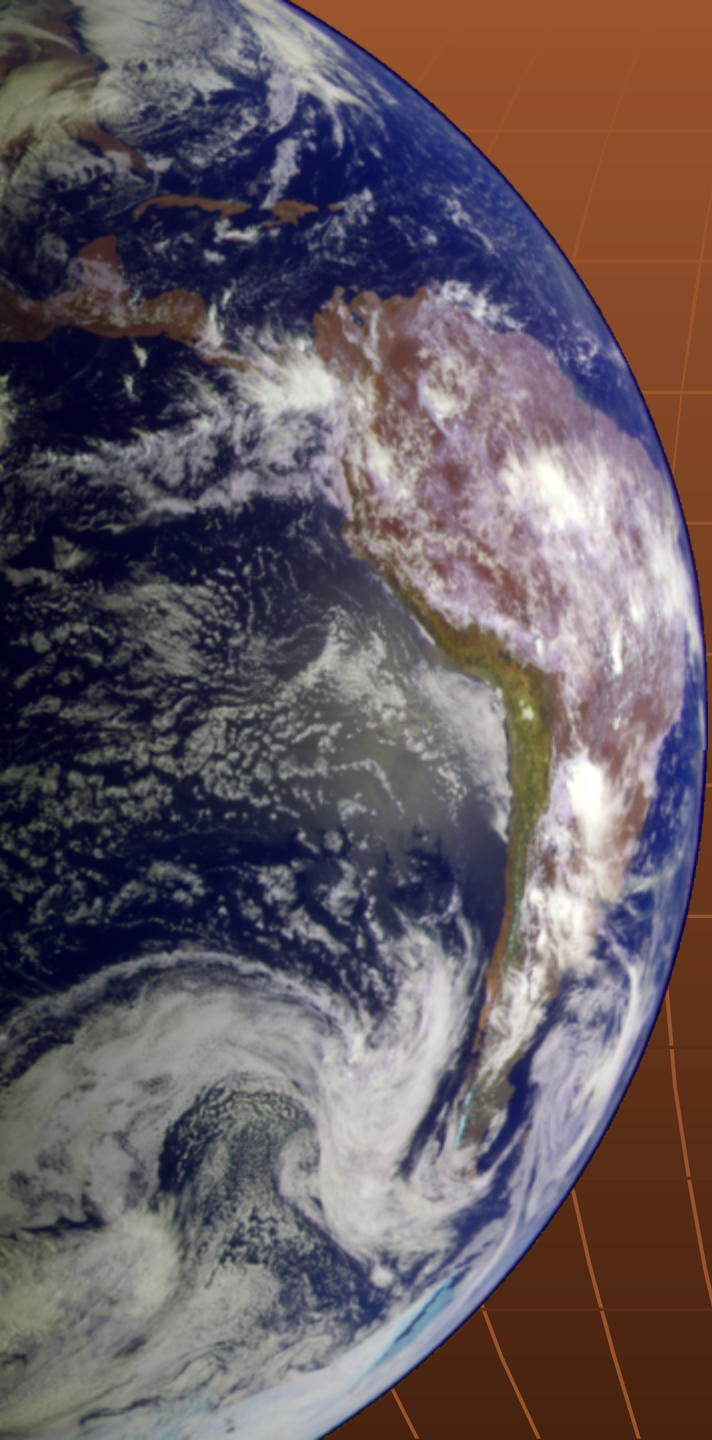
Next Steps

- Apply correction to HTI anisotropy which may be applicable to real data
- Develop a process to incorporate correction for land data in pre-processing phase
- Possible land seismic data improvements for fracture characterization

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Conclusions

- Reflection process alters polarization of direct shear waves
- Anisotropic Analysis is important in Fracture characterization for reservoir architecture
- Potential extension to Alford Analysis to non-normal angles of incidence



Thank you

Questions

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Special Thanks to our Sponsors

UT-AUSTIN EDGER FORUM

Anadarko

bp

BRIGHAM Exploration Company

CIMAREX

devon

ConocoPhillips

CNPC BGP

Chevron Human Energy

drillinginfo® Open To Explore™

HALLIBURTON | Landmark Software & Services

DAWSON® Dawson Geophysical Company

Blackbear Survey Parameters

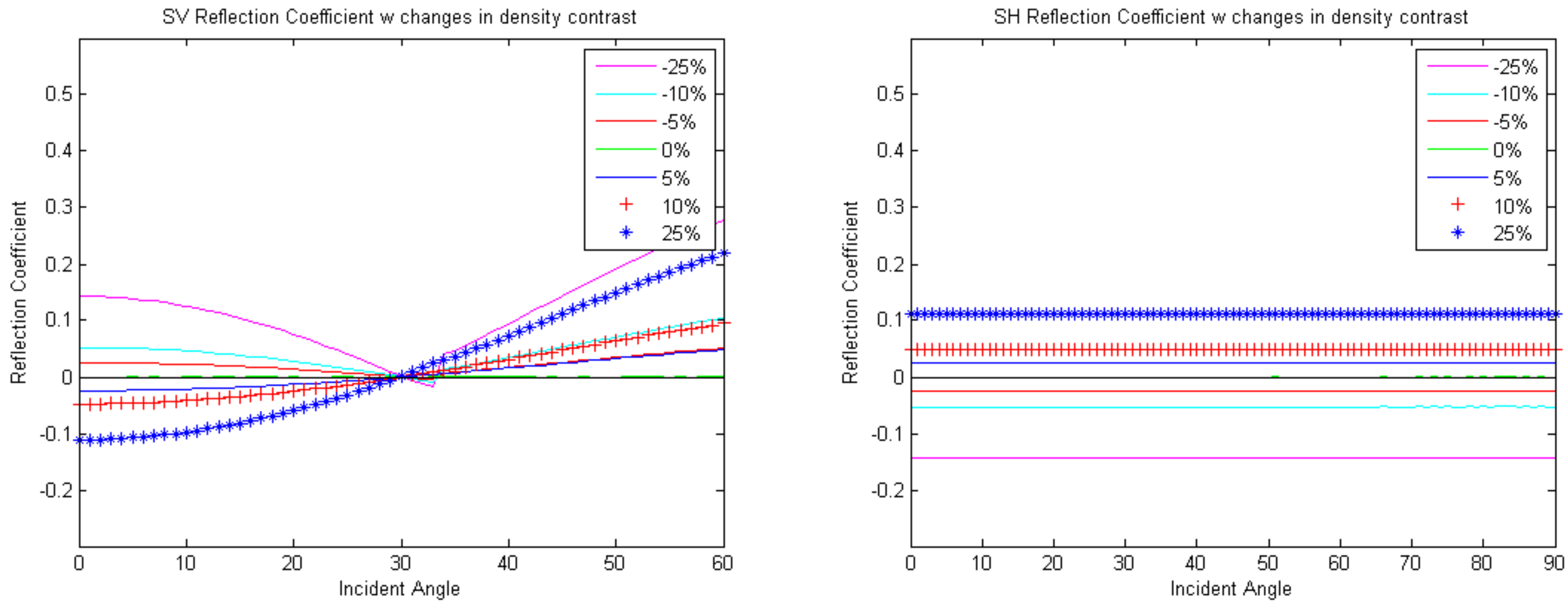
- S-wave record length – 6sec
- P-wave Sampling Rate – 4ms
- S-wave Sampling Rate – 8ms
- Station Lines – 15
- Total Lines – 2220
- Live Stations / Line – 148
- Station Spacing – 165 ft
- Station Line Spacing – 1320 ft
- Shot Lines – 21
- Total Shots – 1197
- Fired Shots - 1197
- Shot Spacing – 330ft
- Shot Line Spacing 1155ft
- Maximum Channels - 672
- Areal Extent 16.42 sq miles
- Bin Width 165 ft
- Bin Height – 82.50 ft
- Maximum Offset – 9912ft
- S-wave source Array –

  6-48 Hz 16sec sweep

  8 sweeps

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Sensitivity Analysis

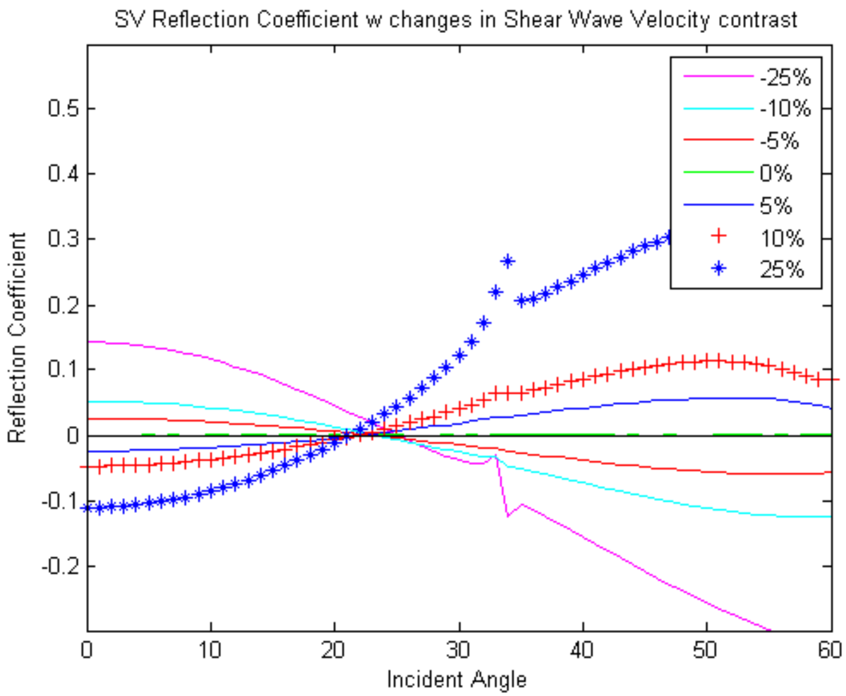


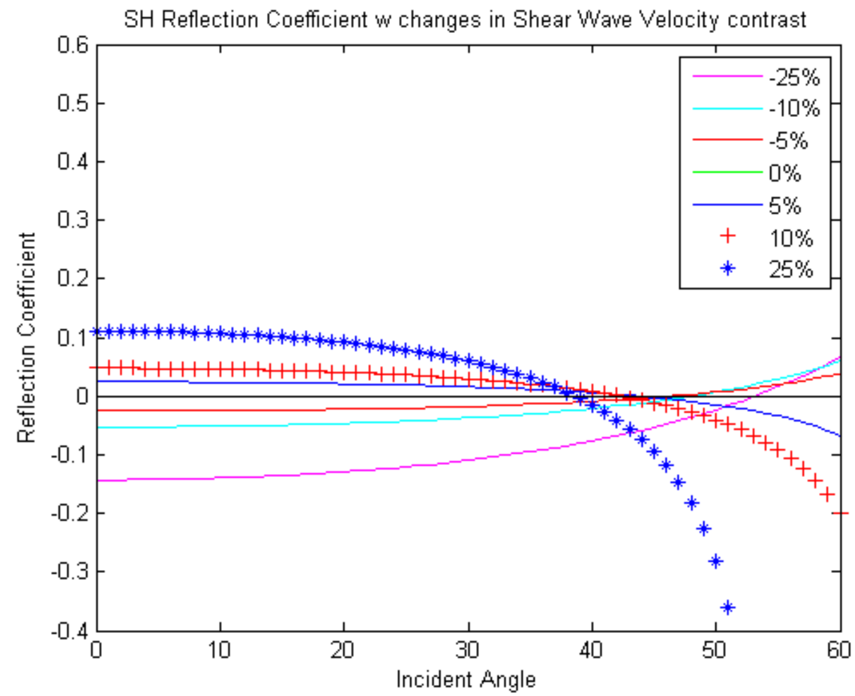
V_p/V_s=1.8 Density variation +/- 25%

V_p and V_s remains constant

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Sensitivity Analysis





Initial V_p/V_s=1.8, Density 2.2g/cc Shear wave velocity +/- 25%
V_p and density remains constant