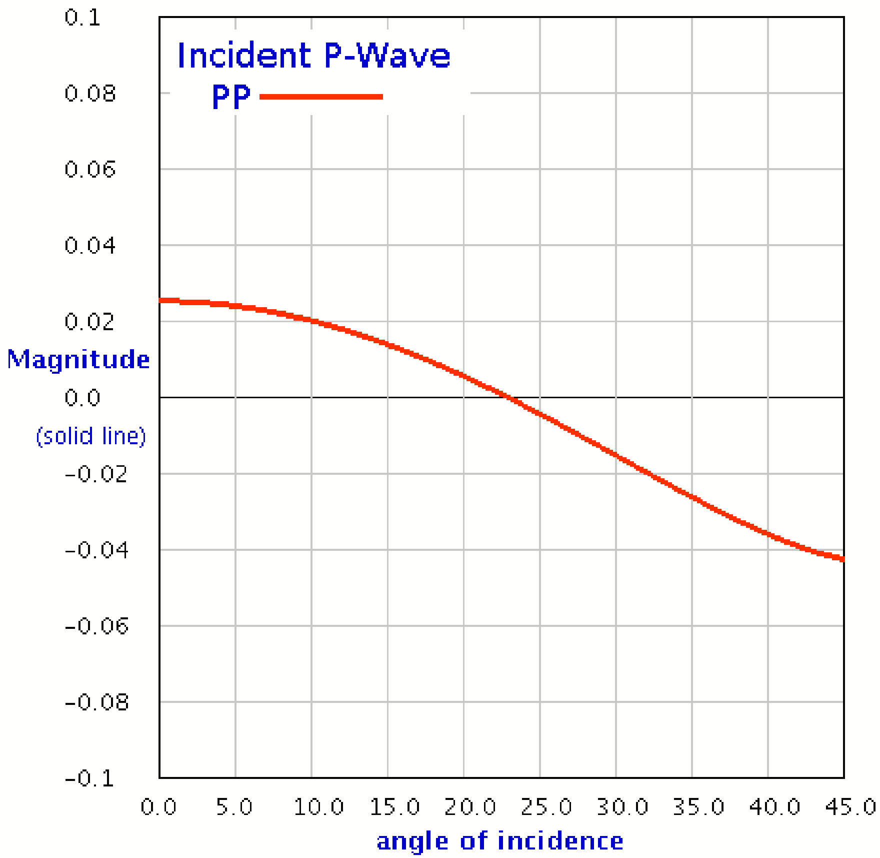
The Shear Difference: Insightful Perspectives and a Proposal

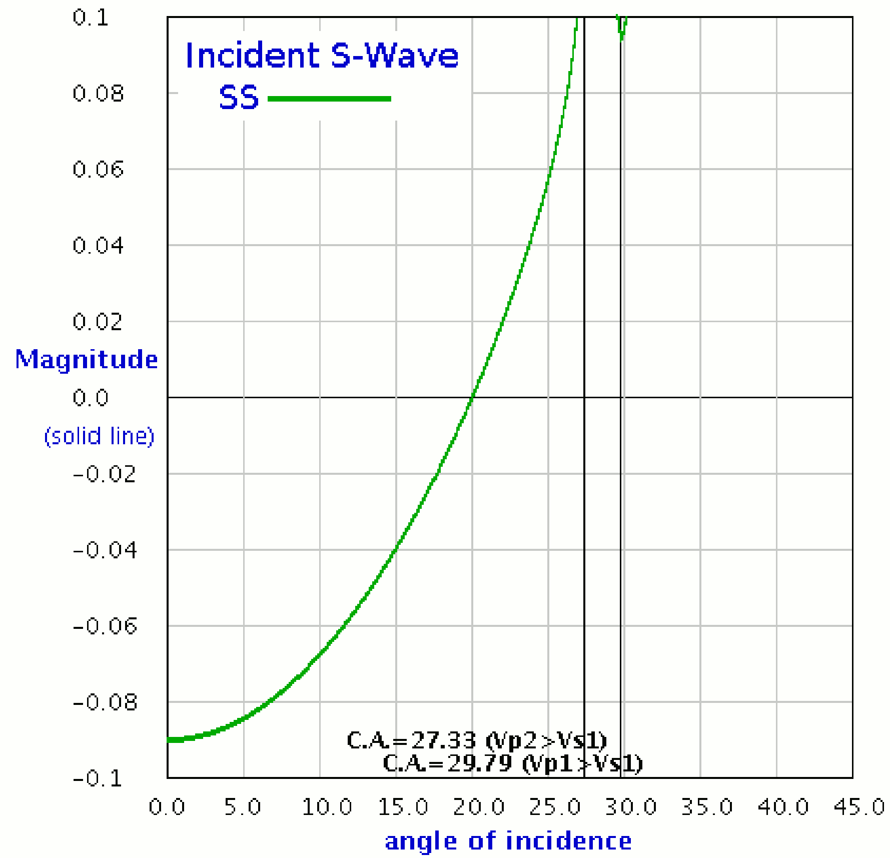
Robert Windels
Michael O'Brien

RCP Meeting
Colorado School of Mines – April 2010

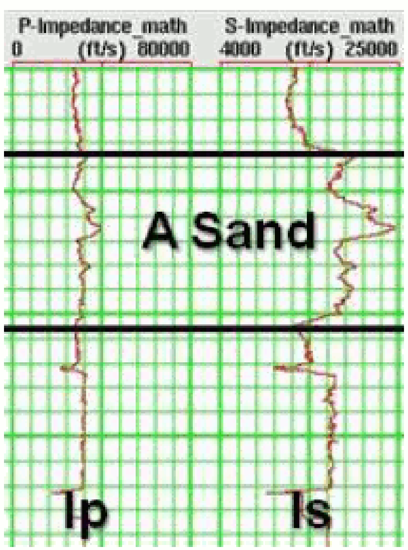
CREWES Zoeppritz Explorer 2.0

www.crewes.org





Overburden	Vp	3374
	Vs	1676
	Rho	2.584
A Sand	Vp	3651
	Vs	2067
	Rho	2.511



From Singh, 2009

Allied Geophysics, Inc.

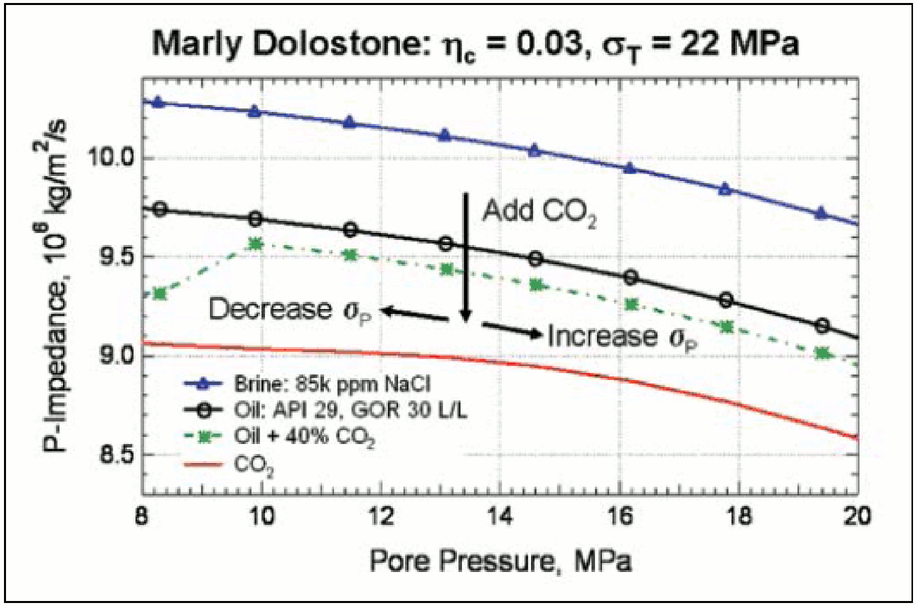


Figure 5. *Rock physics modeling can predict the amount of P-wave acoustic impedance change that CO_2 will introduce into a reservoir. Rarely do the predicted changes of S-waves match reality.*

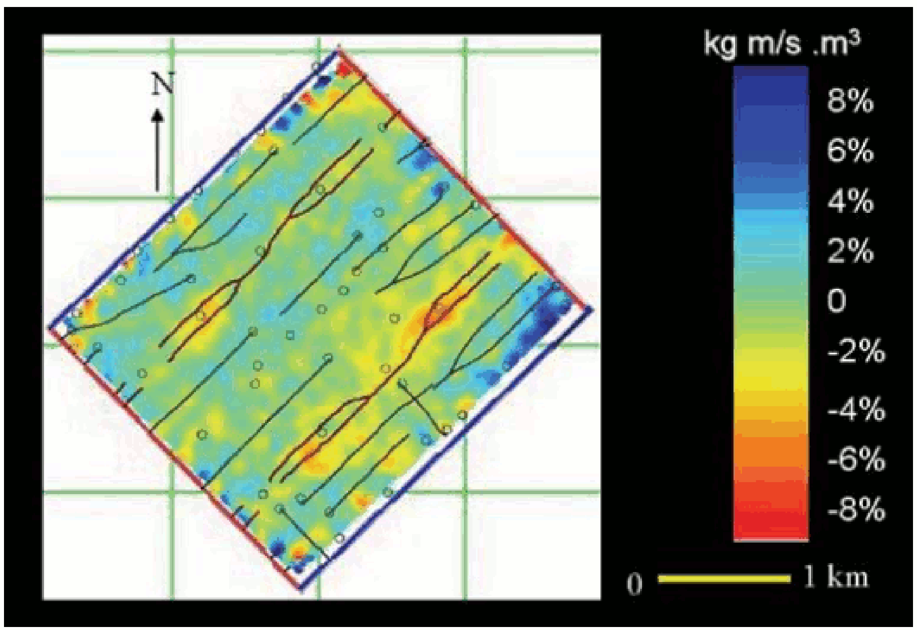


Figure 6. *Weyburn Field (RCP's study area) showing acoustic impedance changes in a 30-m thick reservoir at 1450 m after a year of injection from four twin-leg horizontal wells.*

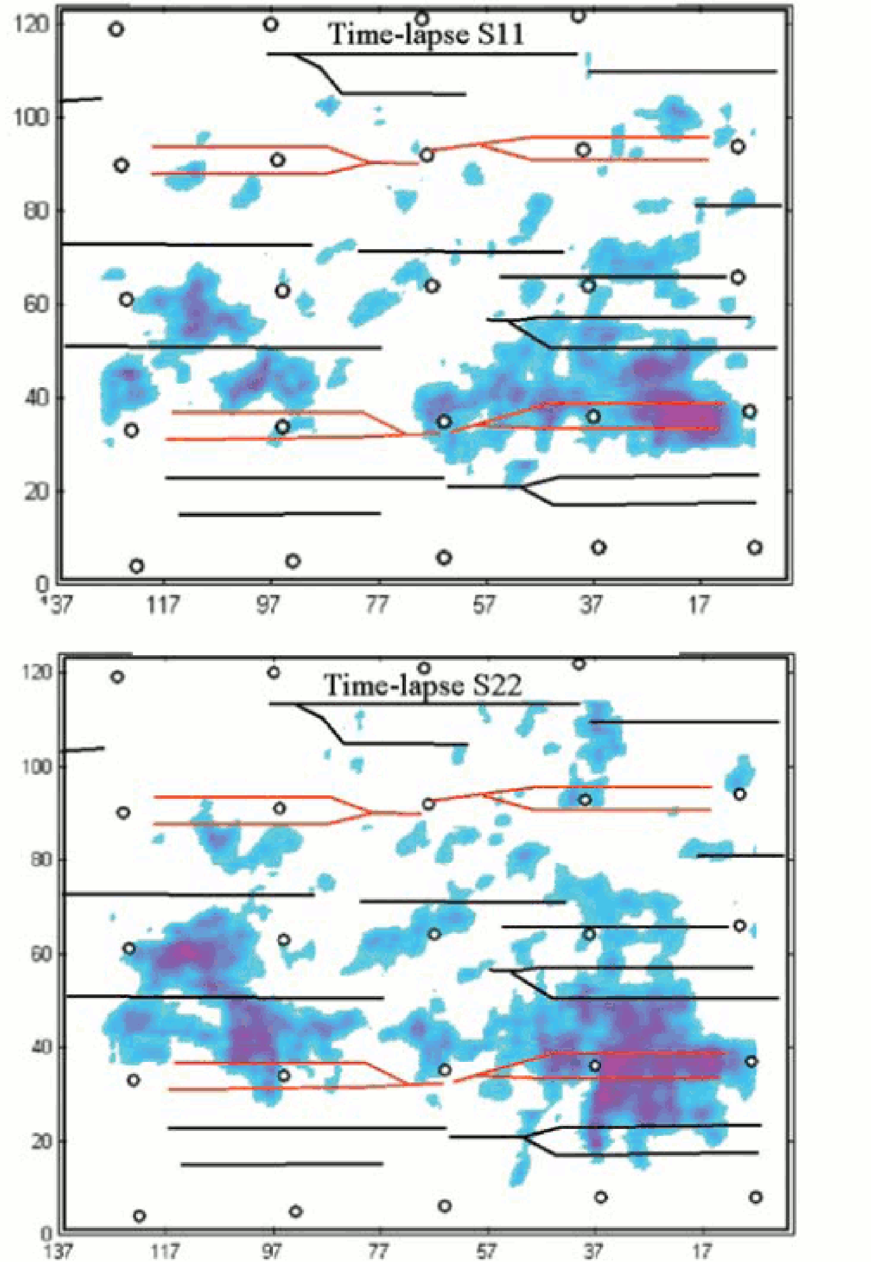
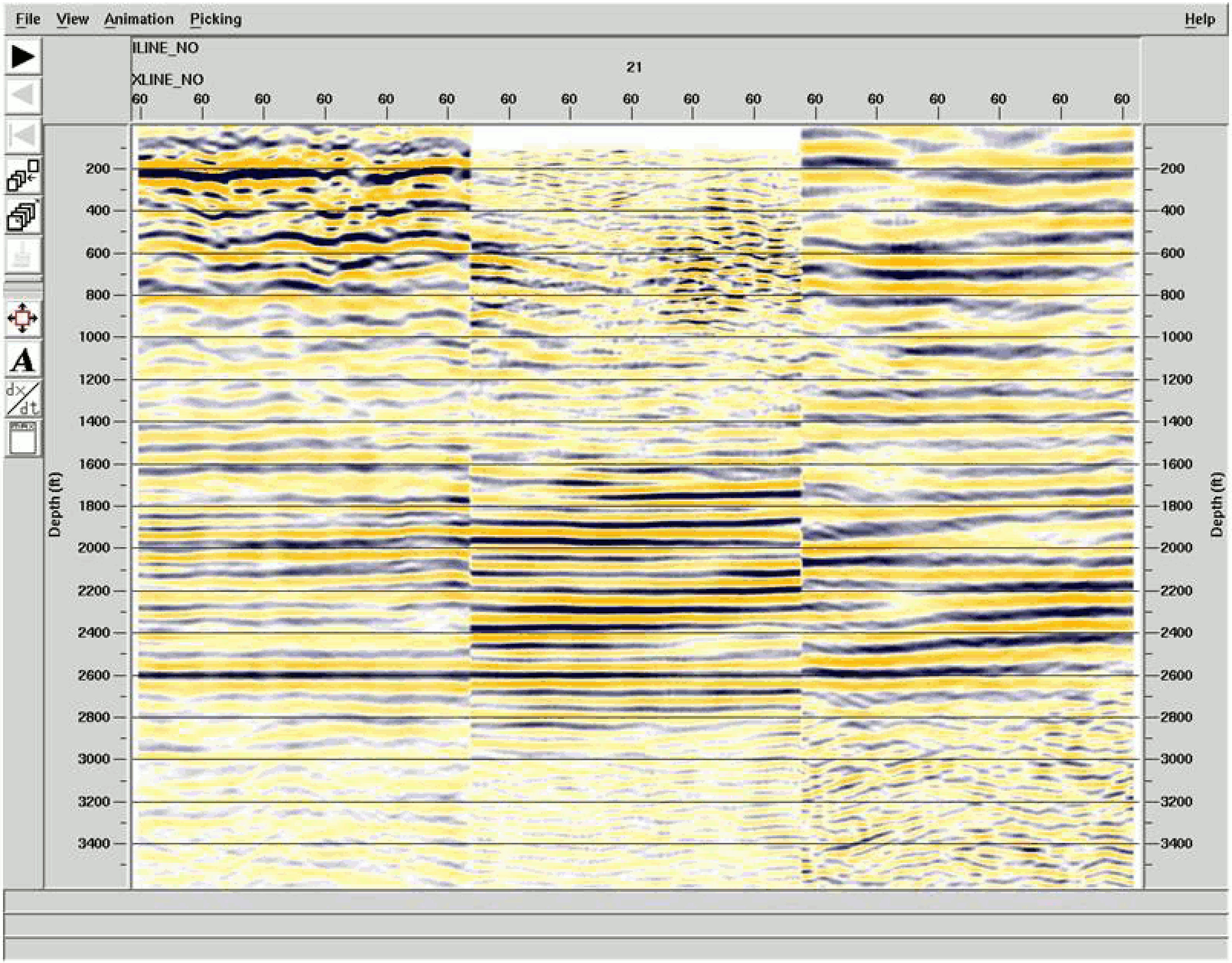


Figure 7. *S-wave amplitude changes from S-wave data at Weyburn Field. The largest changes occur on the S22 component, indicating anisotropic changes in the horizontal stress field due to a rise in fluid pressure associated with the formation of the tertiary flood bank. A noise threshold has been applied, and the changes shown are only those that exceed one standard deviation.*

T. Davis, The Leading Edge, Jan., 2010



Baseline PP Stack
Stretched 2 X

Baseline SS11 105°
Stack
Not Stretched

Baseline PS1 105°
Stack
Stretched 1.5 X

Borrowed from Robert Windels, October, 2009

Objectives

Study S-wave data quality issues in a Postle-like setting.

Assess the ability of time-lapse seismic to image the CO_2 flood.

To understand discrepancies between S-wave and P-wave images.

Project Activities

Build a 3D earth model with geology similar to Postle field.

Calculate full-waveform synthetic seismic data in the model.

Process the data using the best ideas for producing high quality images.

The hard parts

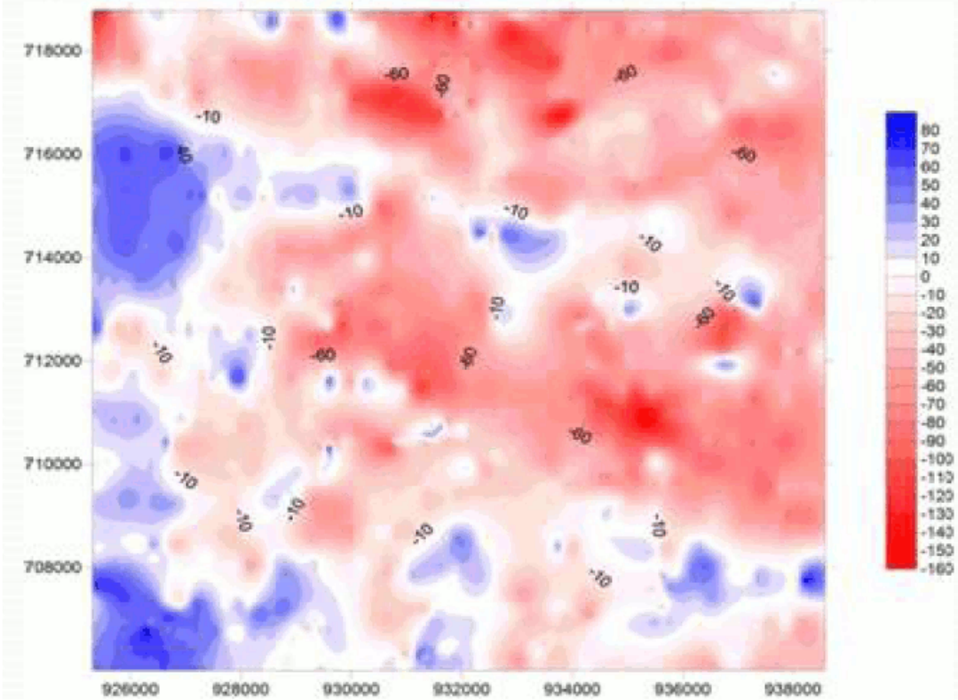
Build a 3D earth model with geology similar to Postle field.

Calculate full-waveform synthetic seismic data in the model.

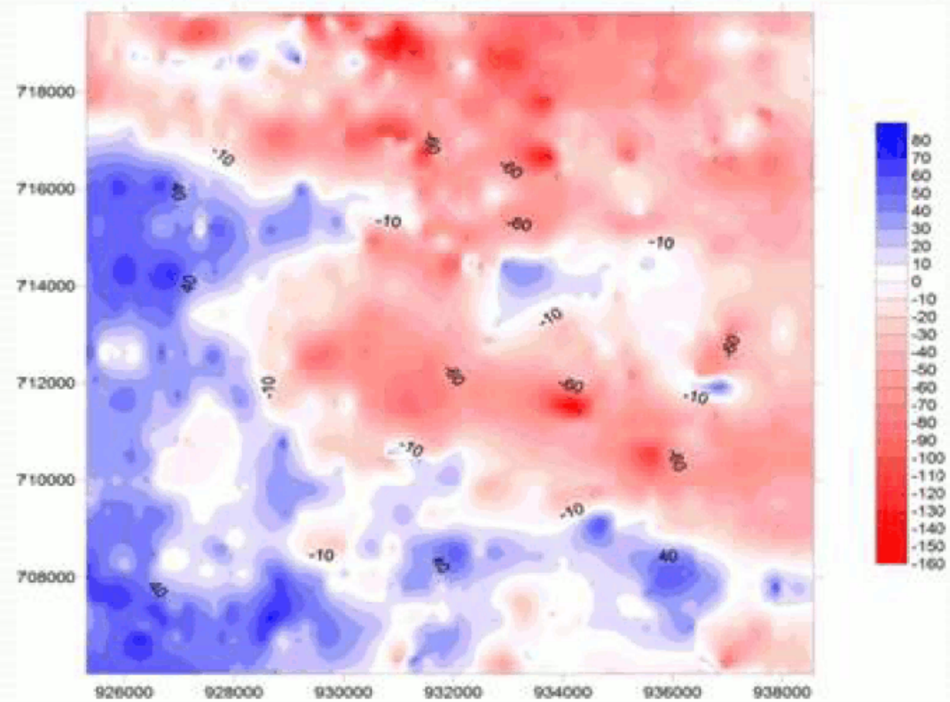
Process the data using the best ideas for producing high quality images.

Data quality issues

240 ms S-wave statics



Baseline survey
Source residual statics



Monitor survey
Source residual statics

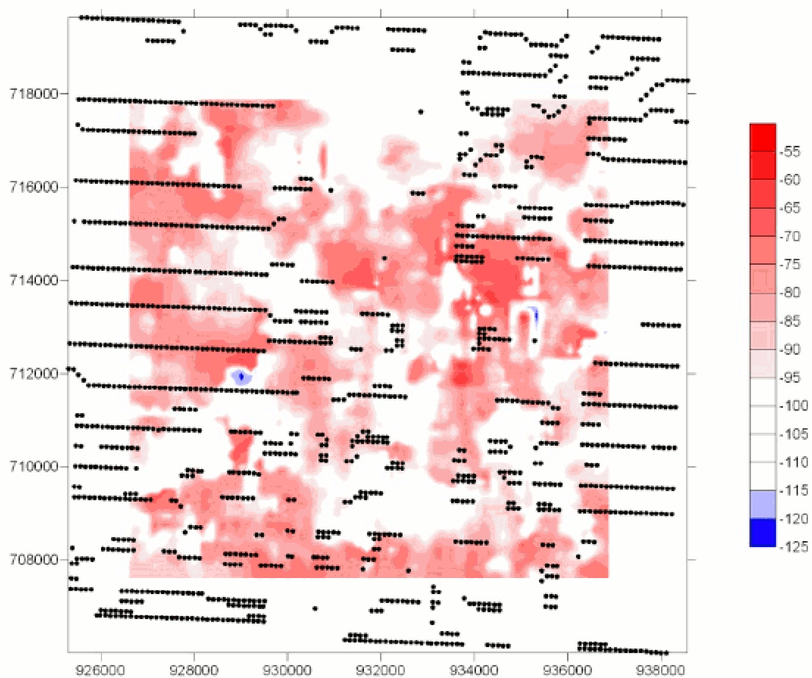
From Robert Windels, October, 2009

FAIRFIELD INDUSTRIES

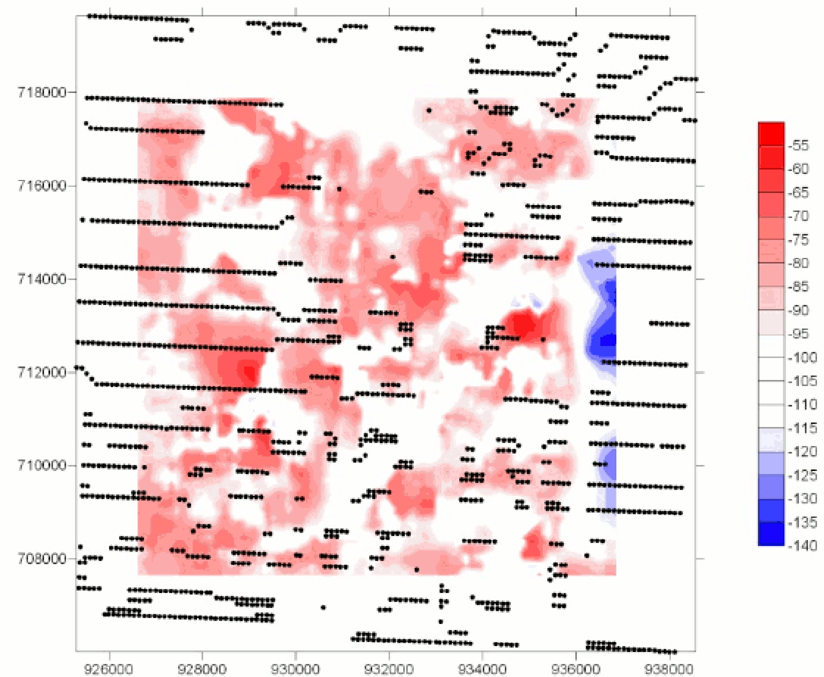
Data quality issues

S-wave polarization direction changes

Baseline and Time Lapse Survey – PHI – direction of fast Shear Waves



Base Line Survey



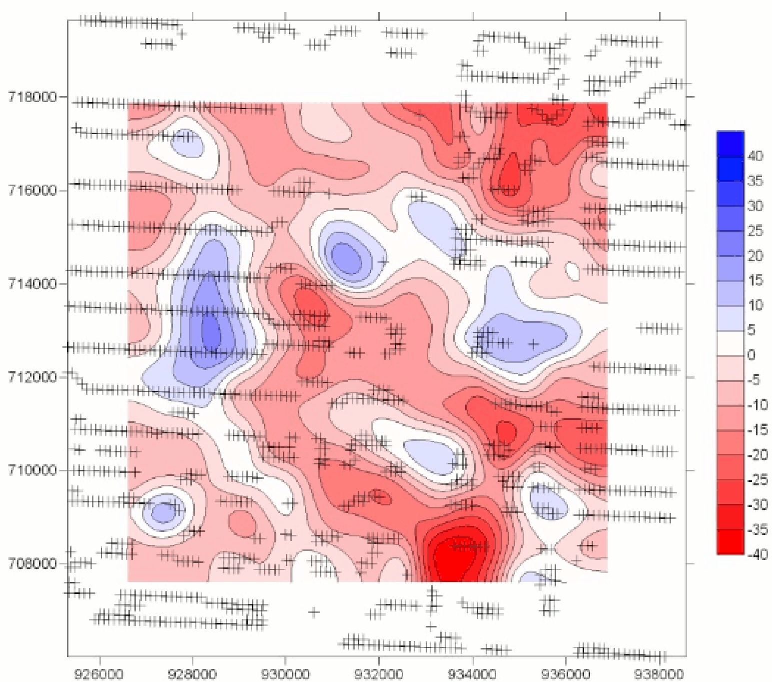
Time Lapse Survey

From Robert Windels, February, 2010

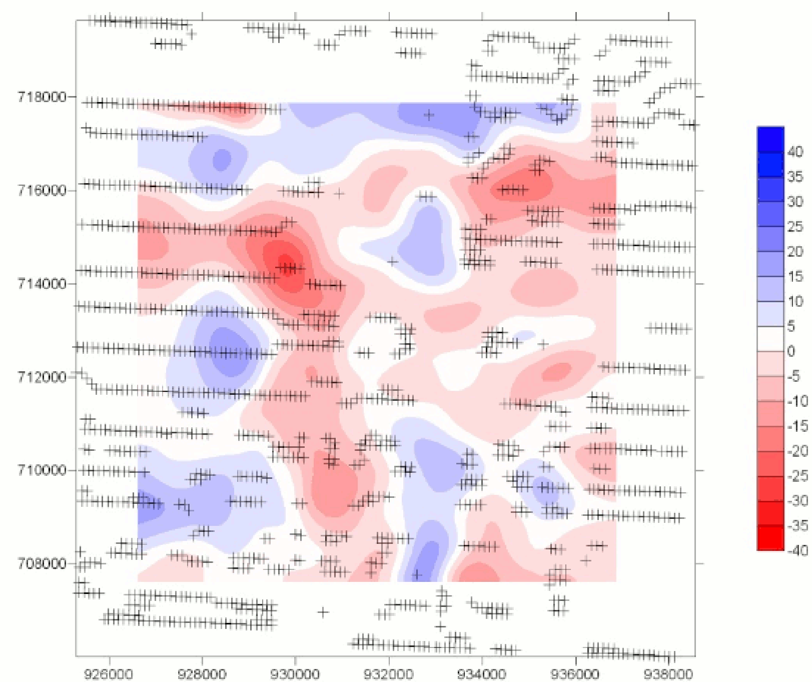
<u>Data quality issues</u>

40ms S-wave splitting in near surface

Baseline and Time Lapse Survey – LAG S1 – S2



Base Line Survey

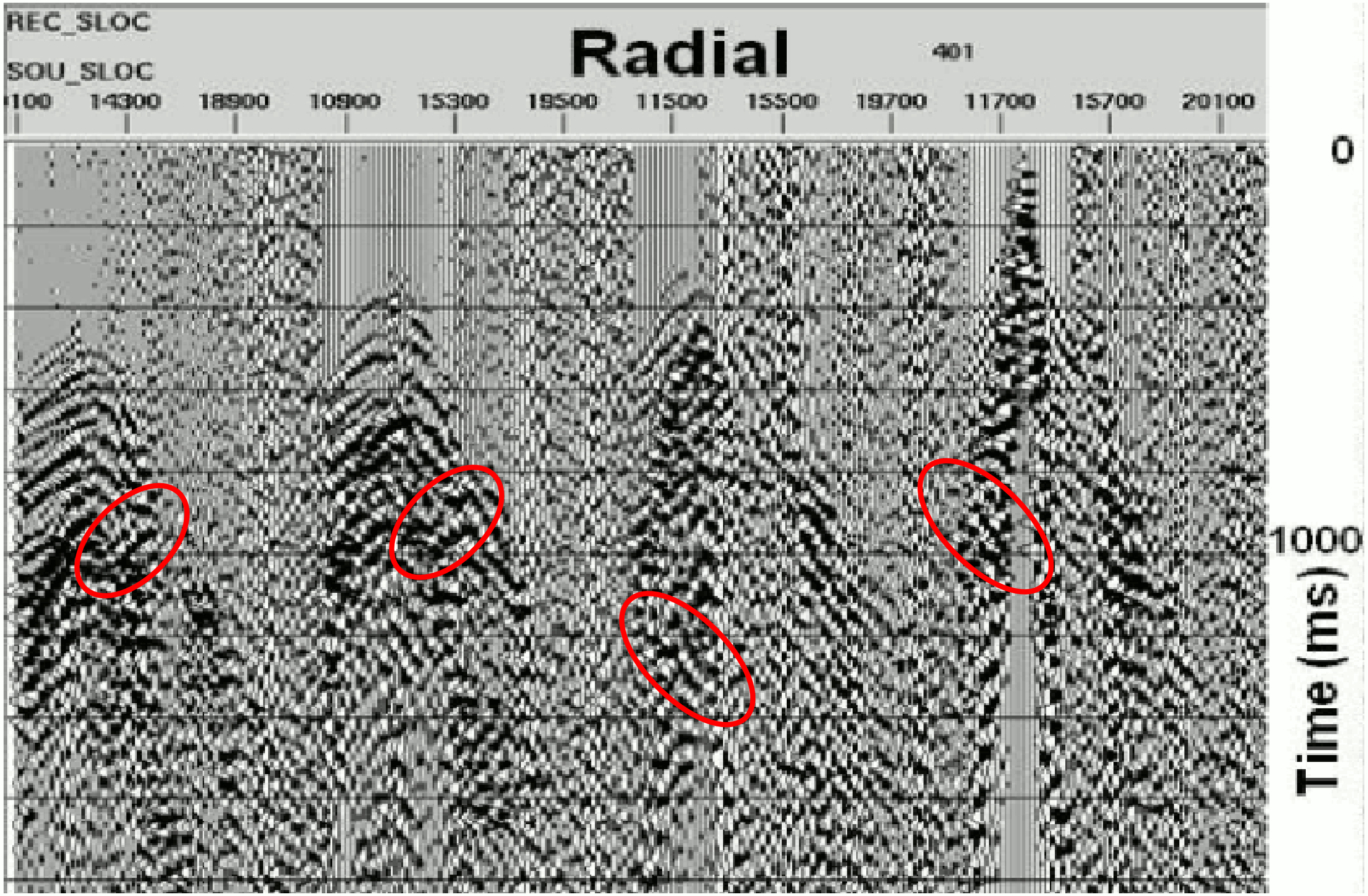


Time Lapse Survey

From Robert Windels, February, 2010

Data quality issues

Surface wave scattering

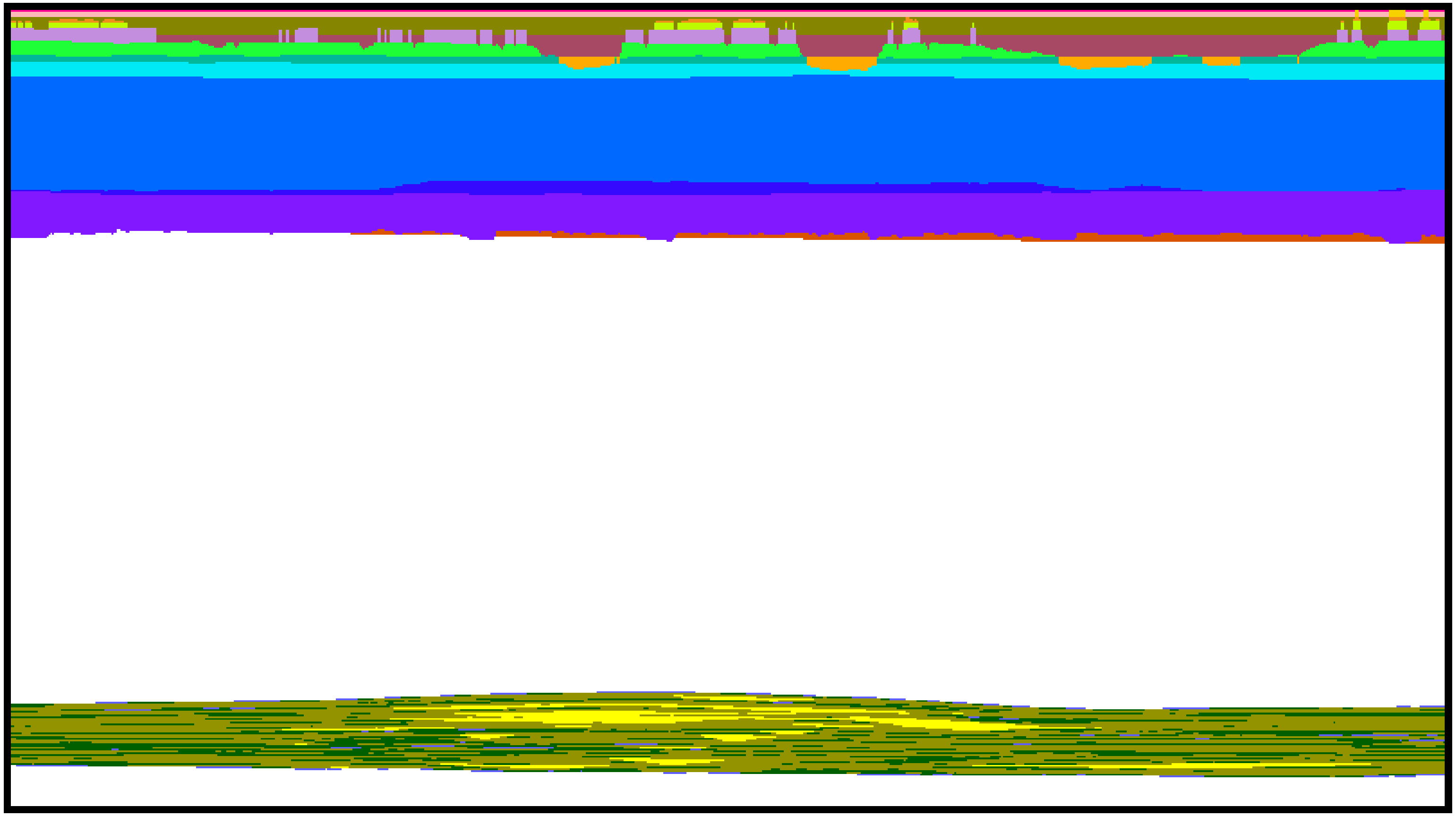


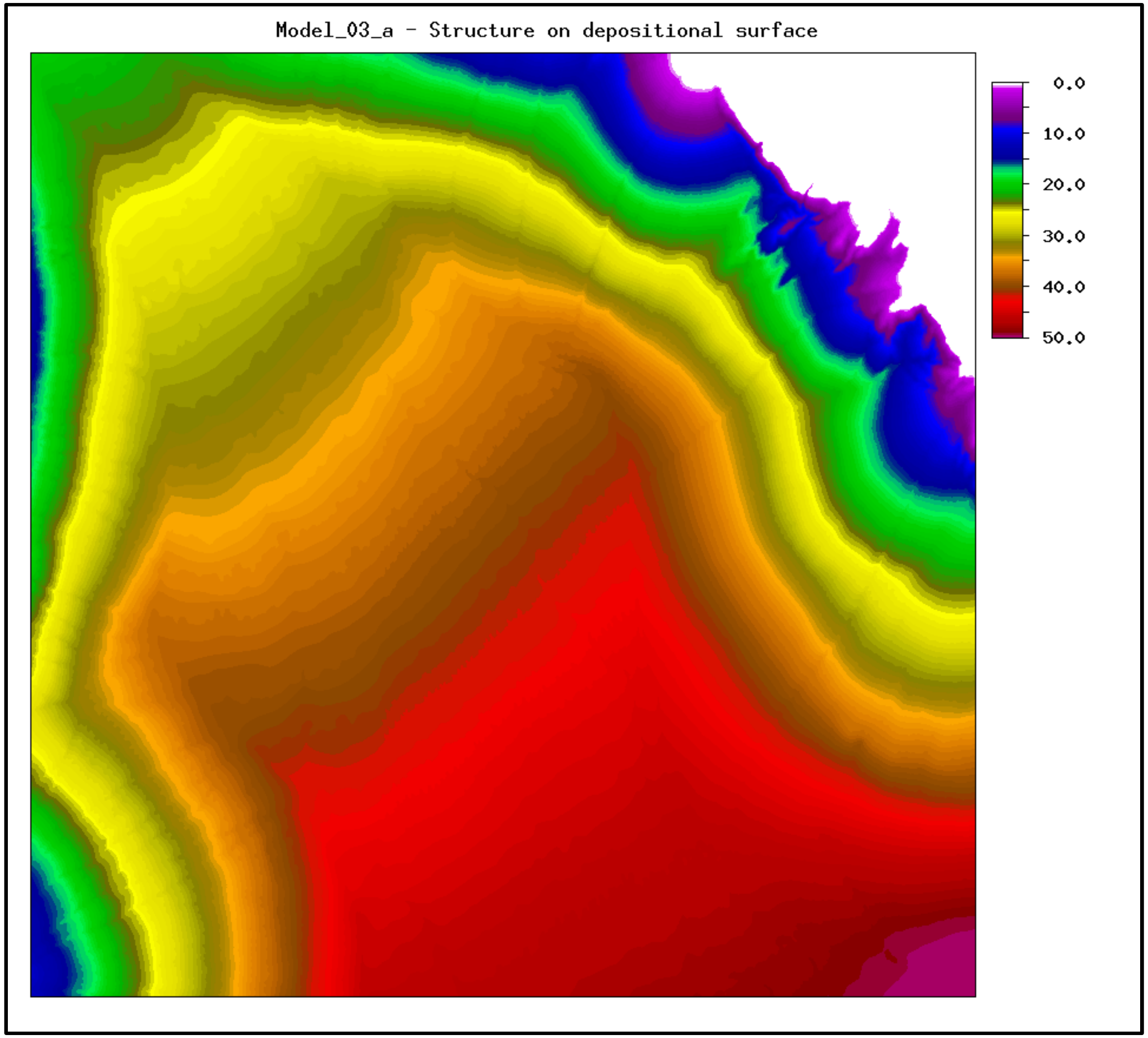
Geologic influences on seismic data quality

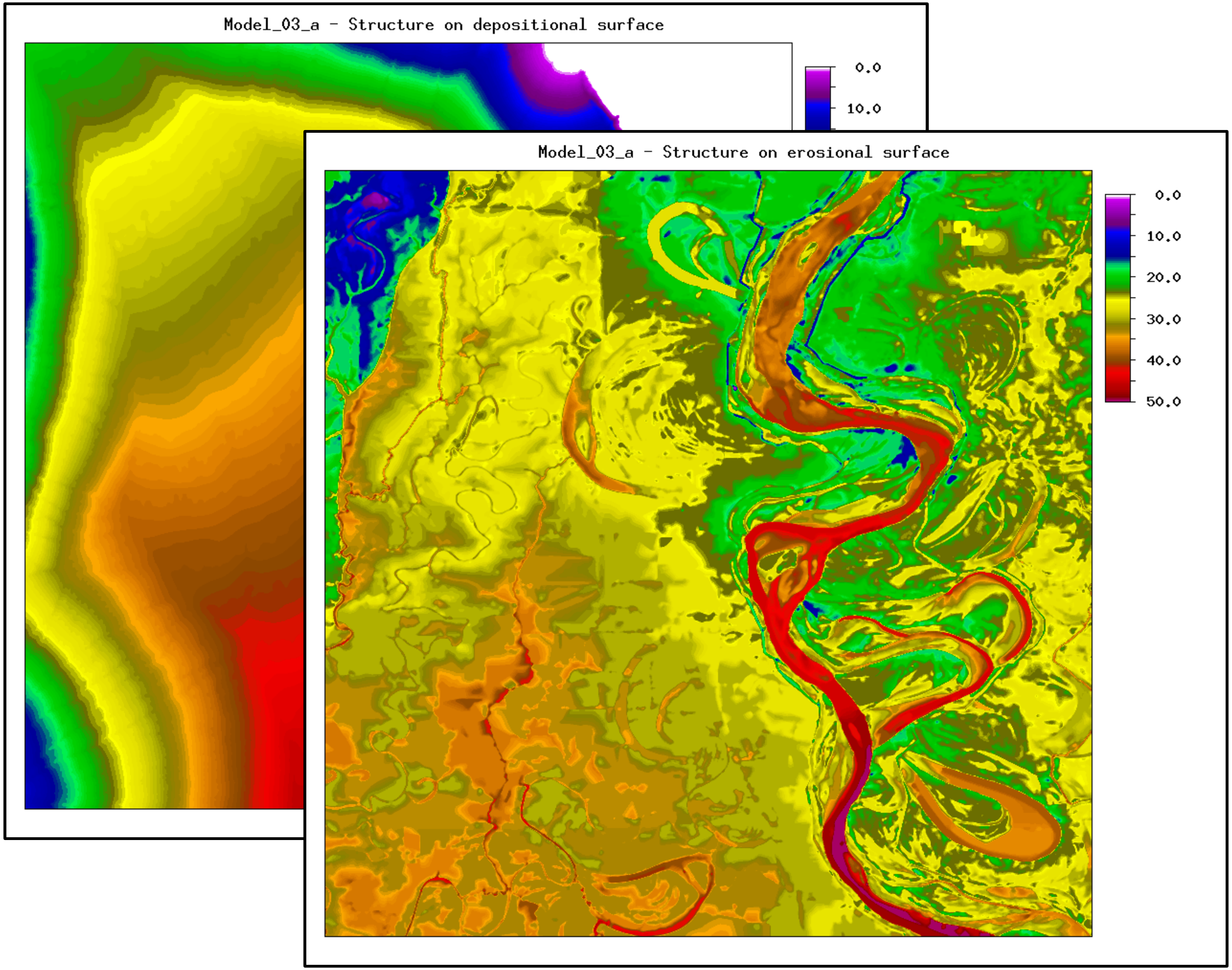
Near Surface

Propagation
Medium

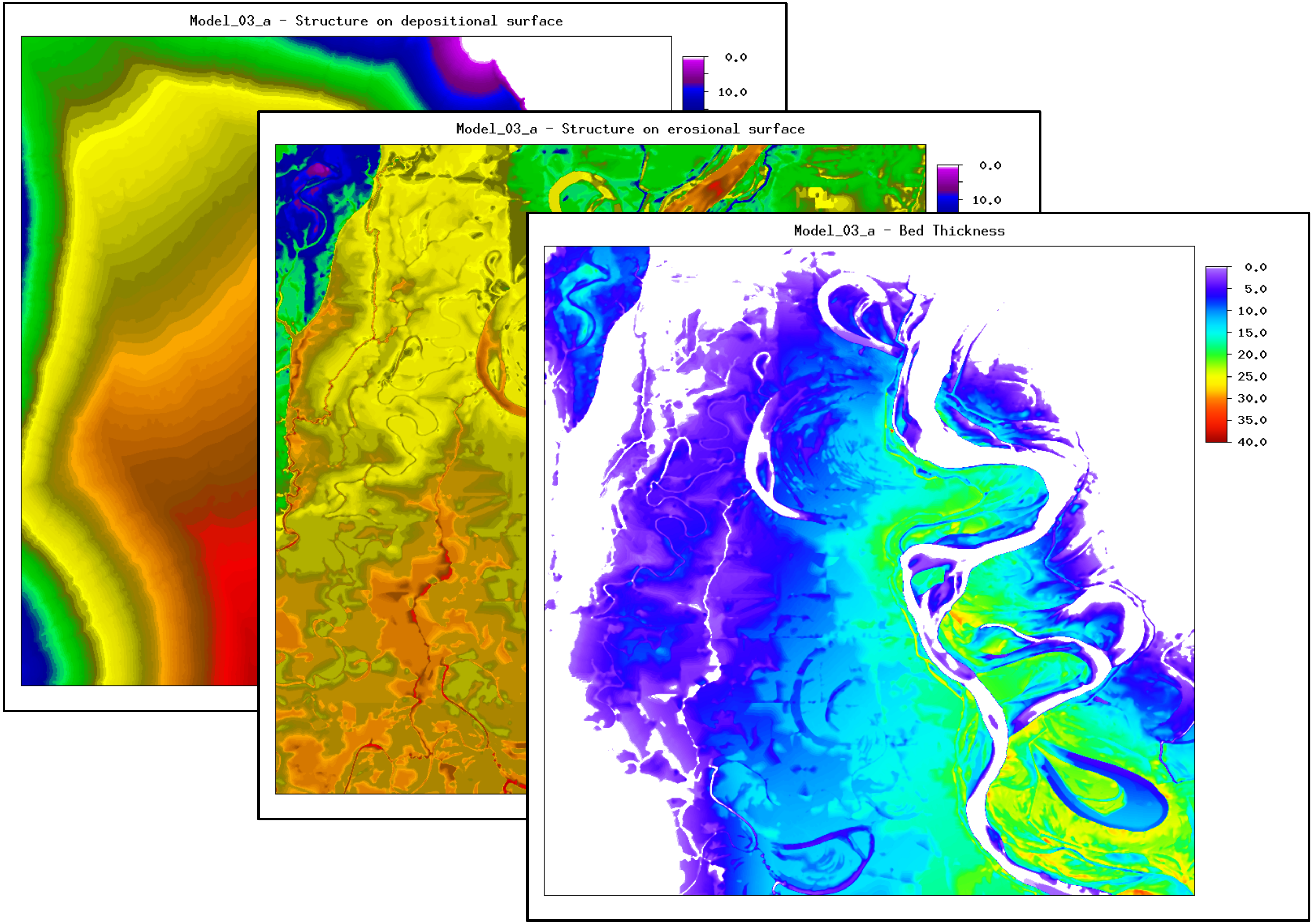
Target




Model_03_a - Structure on depositional surface
0.0
10.0
20.0
30.0
40.0
50.0



Allied Geophysics, Inc.



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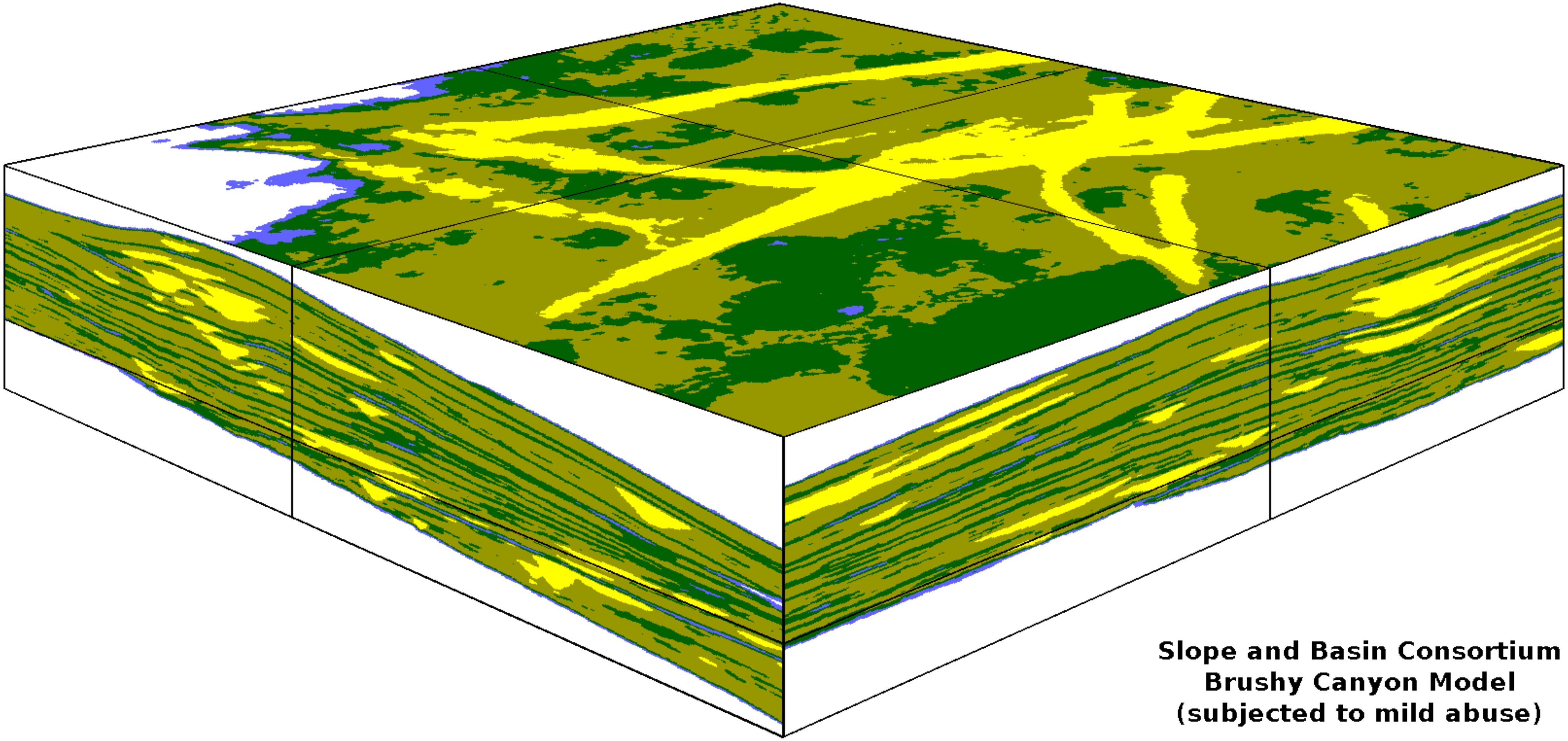


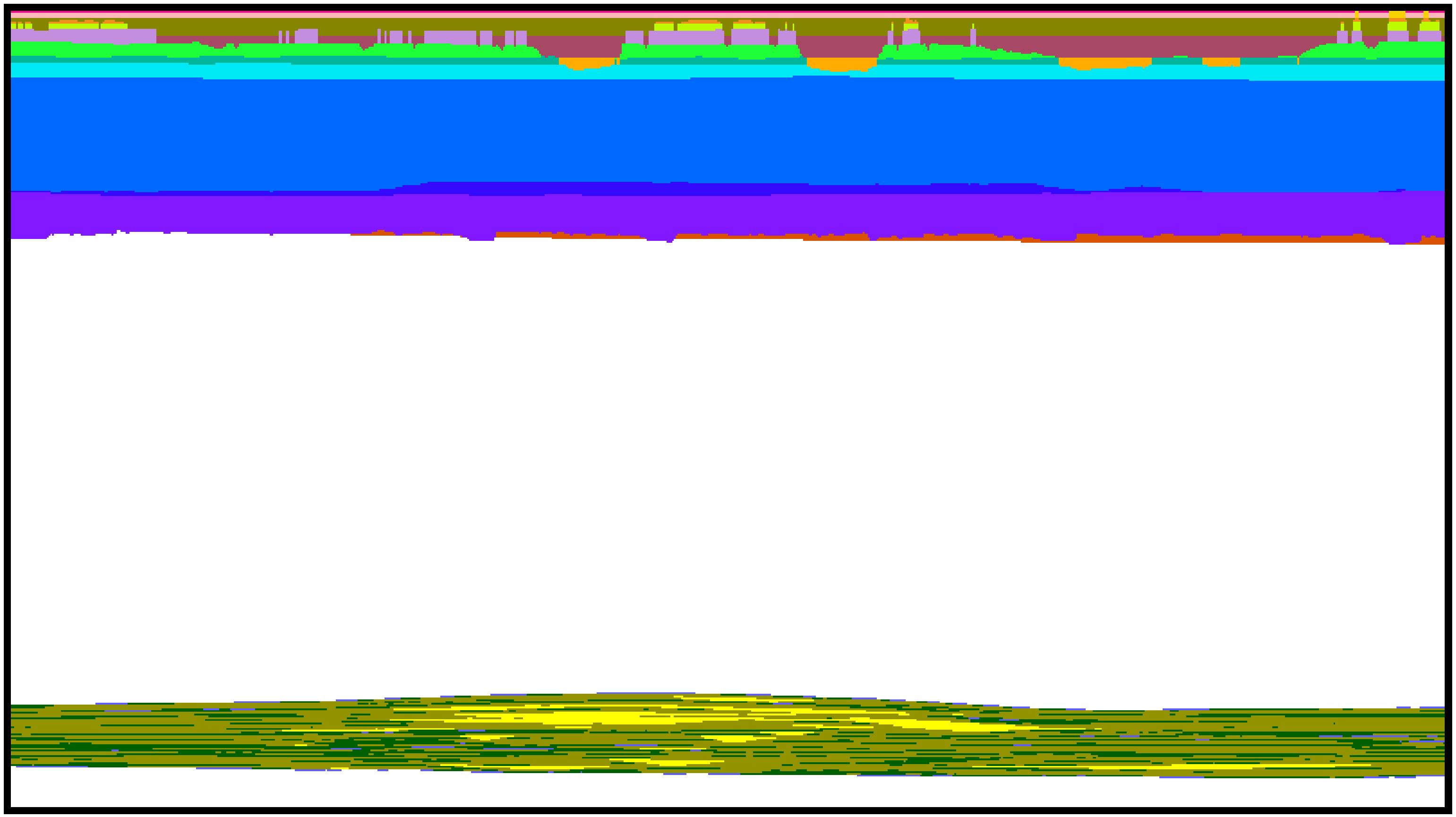
Slope and Basin Consortium
Brushy Canyon Model
(subjected to mild abuse)

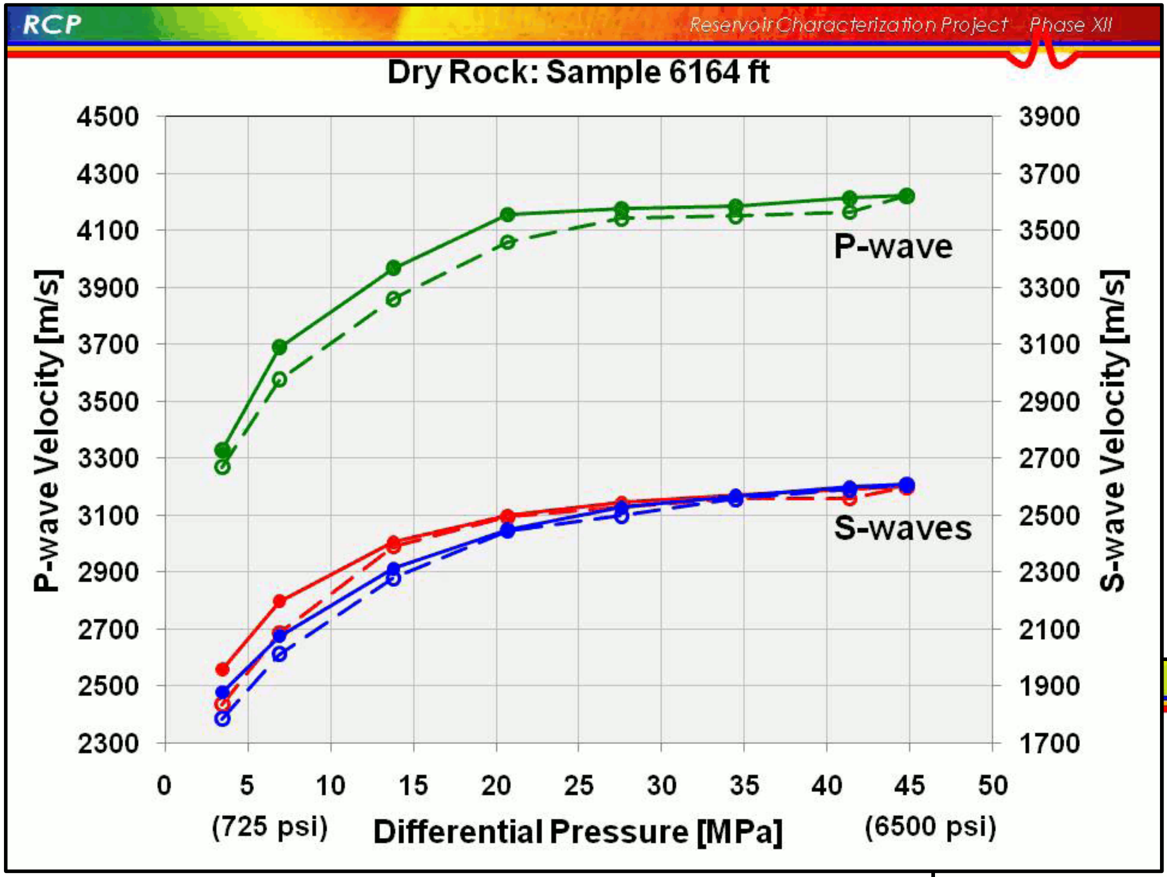
Geologic influences on seismic data quality

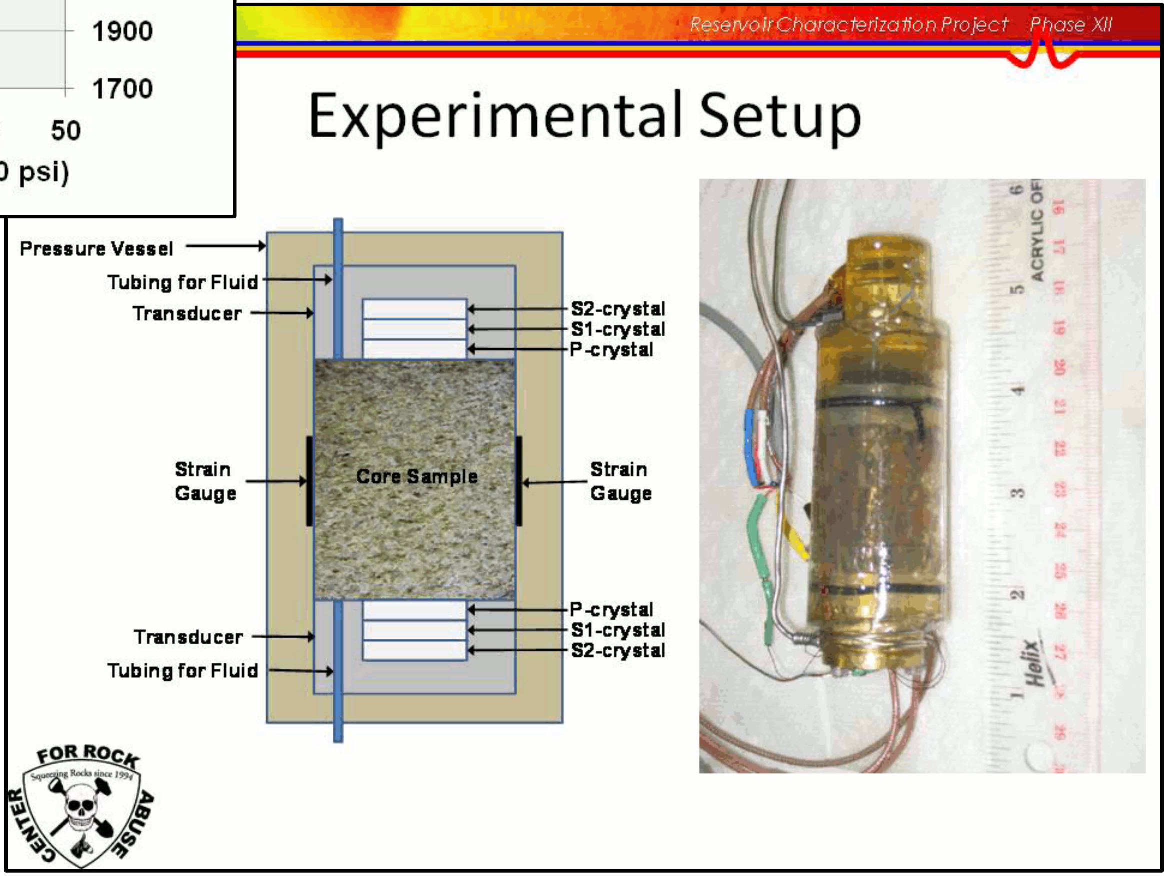
Near Surface

Propagation
Medium

Target

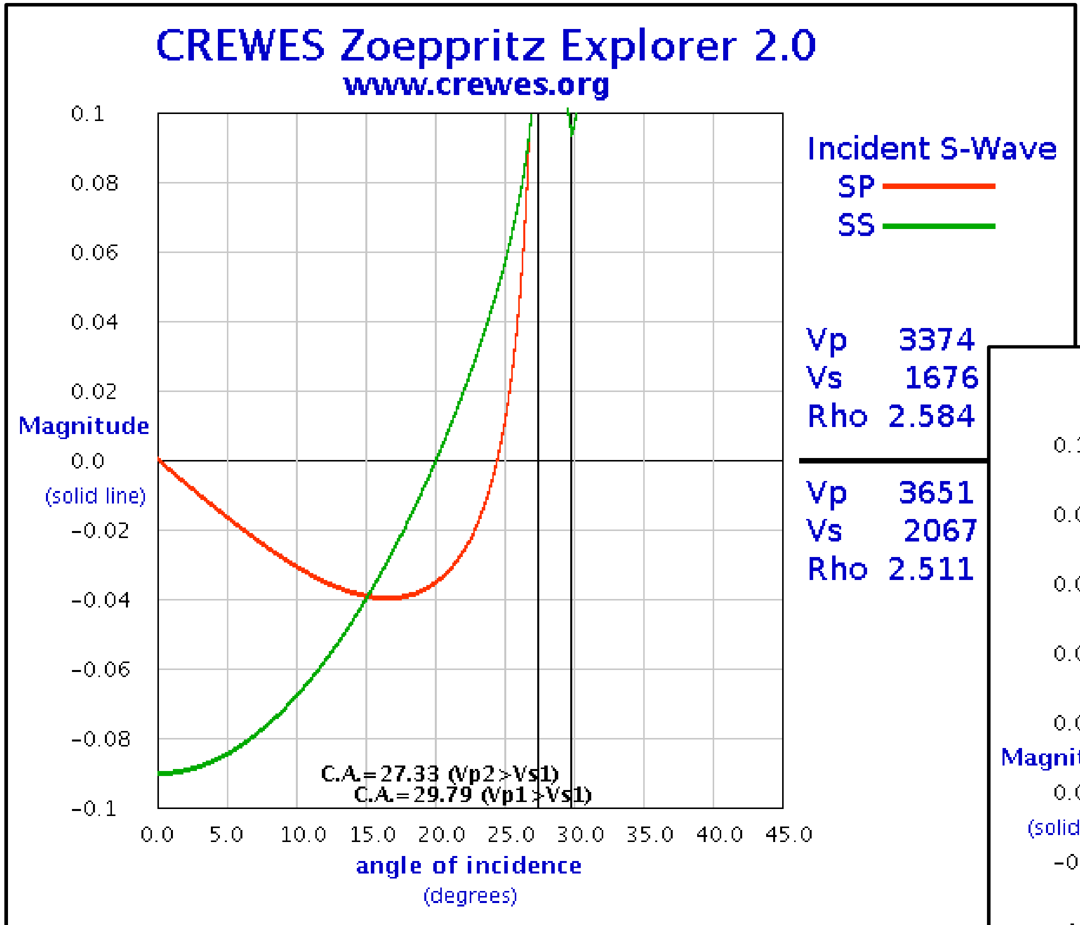




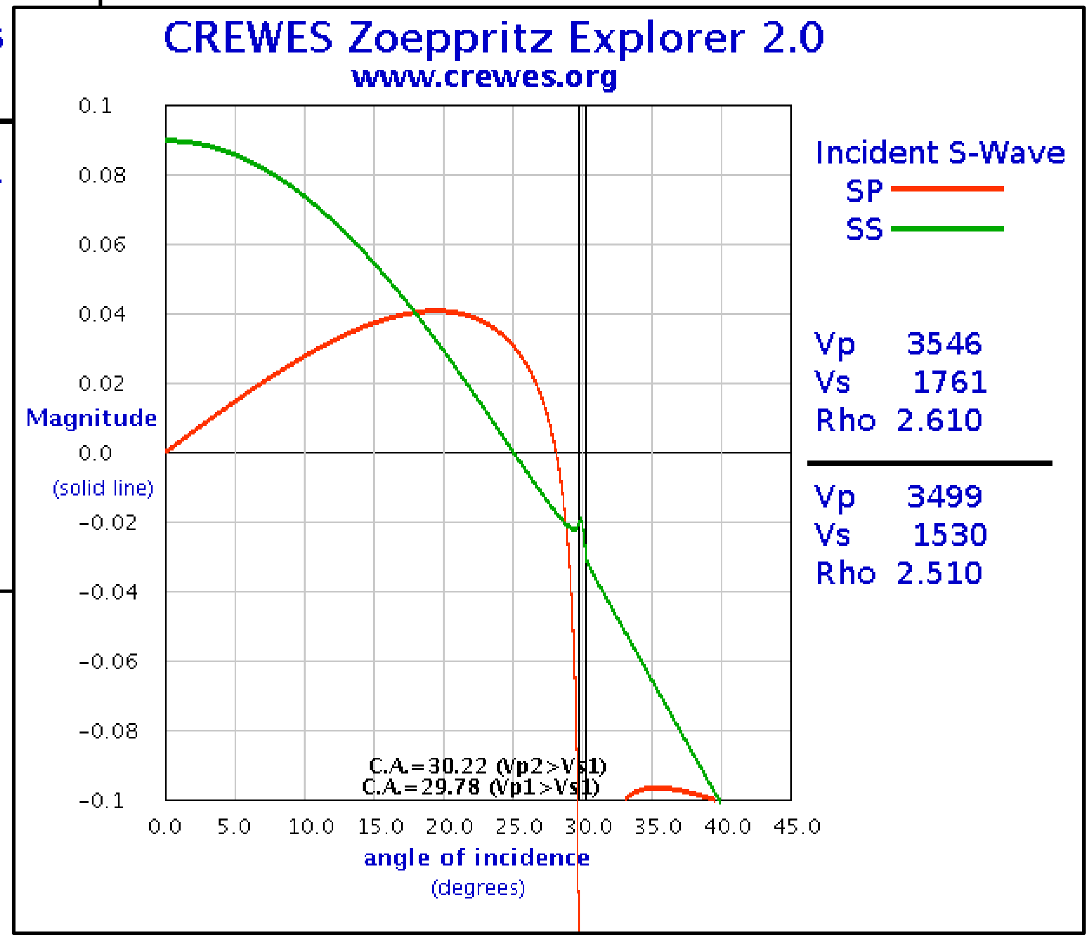


Borrowed from A. Wandler, 2009

Incident S-Wave AVO for A-Sand and Model



Postle A Sand



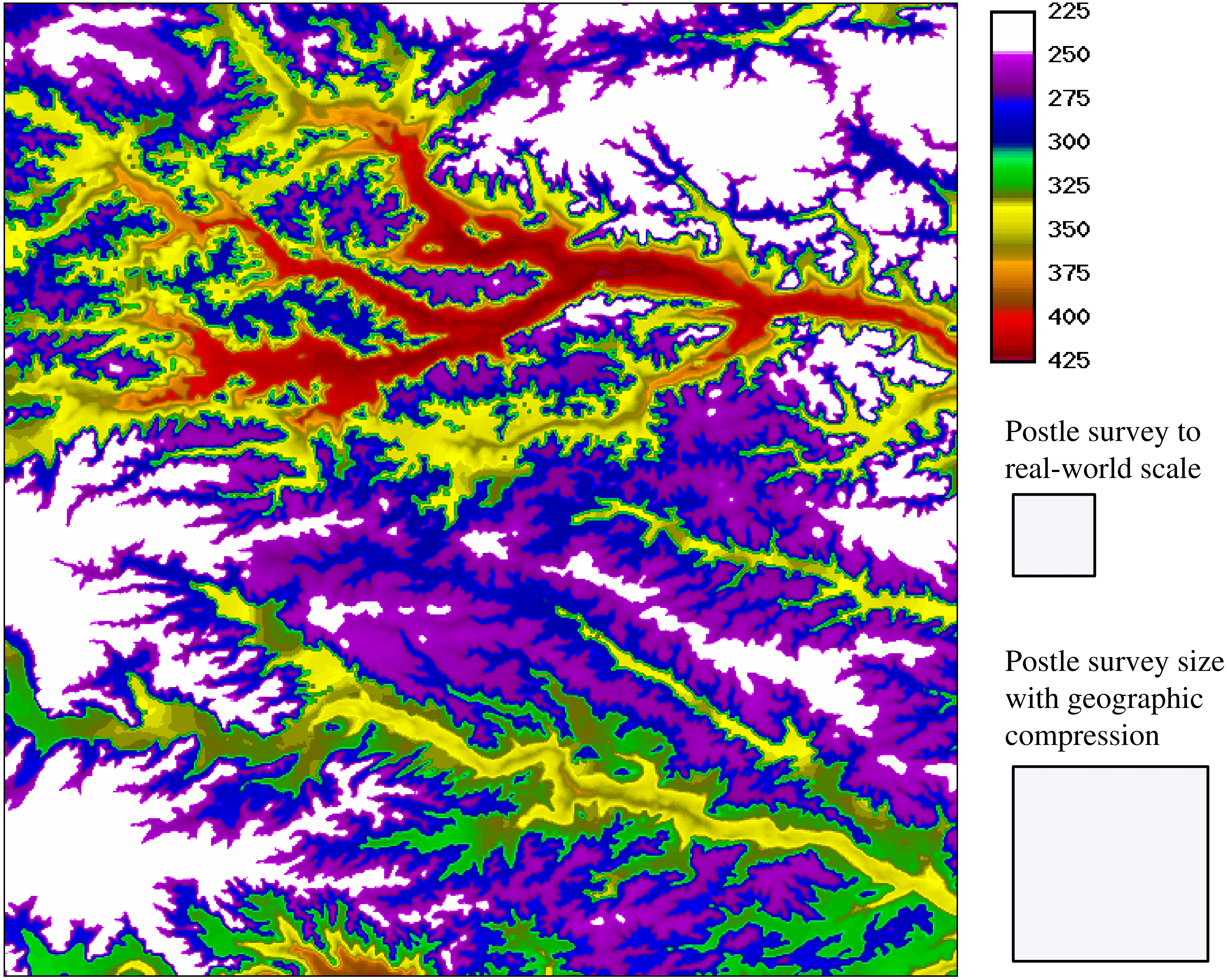
Model Channel Sand

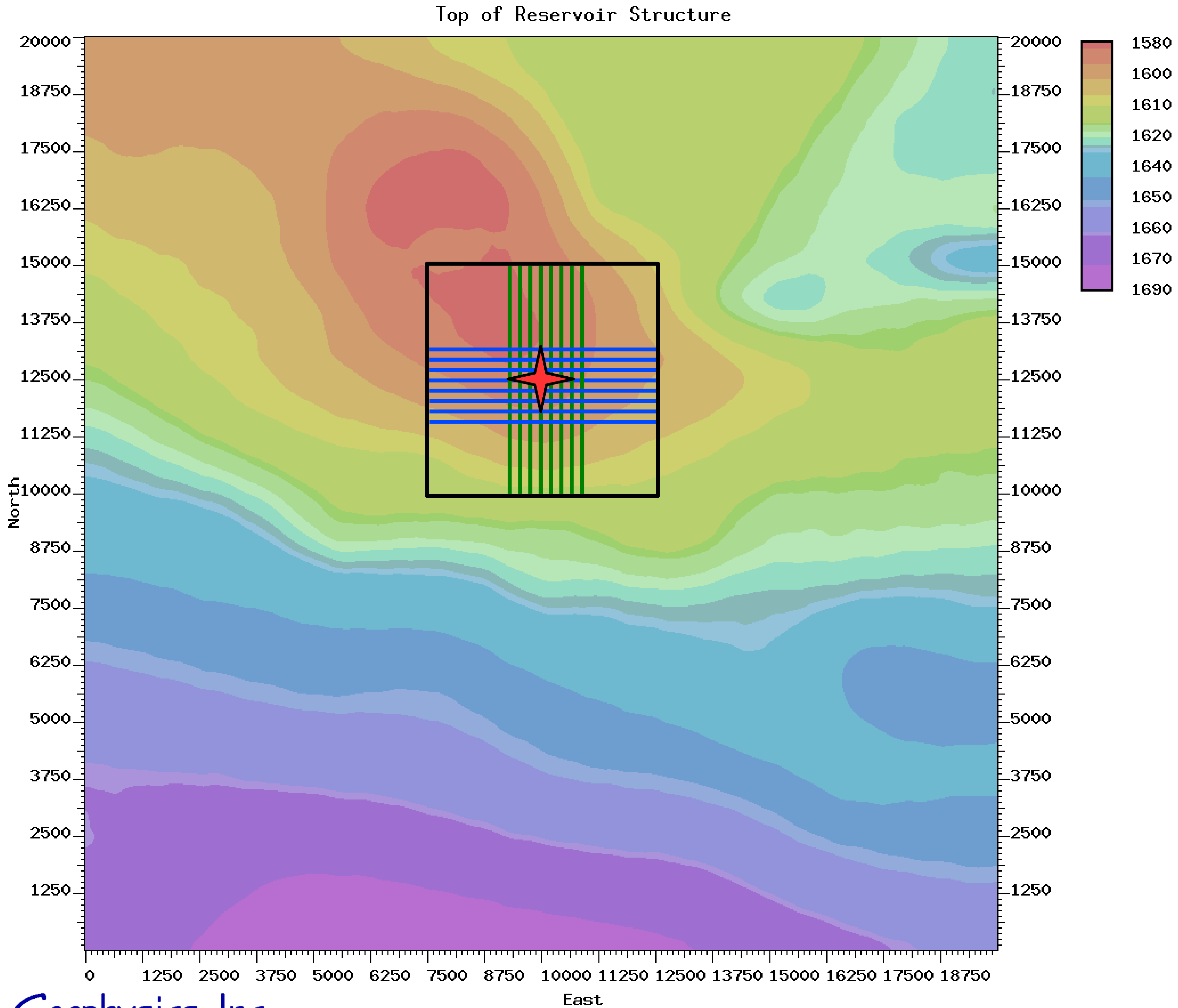
Notes on A-Sand:
Vp ~3900 m/s
Vs ~2350 m/s
Rho ~2.42 g/cc

Notes on Overburden:
Vp ~3322 m/s
Vs ~1524 m/s
Rho ~2.58 g/cc

Allied Geophysics, Inc.

One-way S-wave time through near surface





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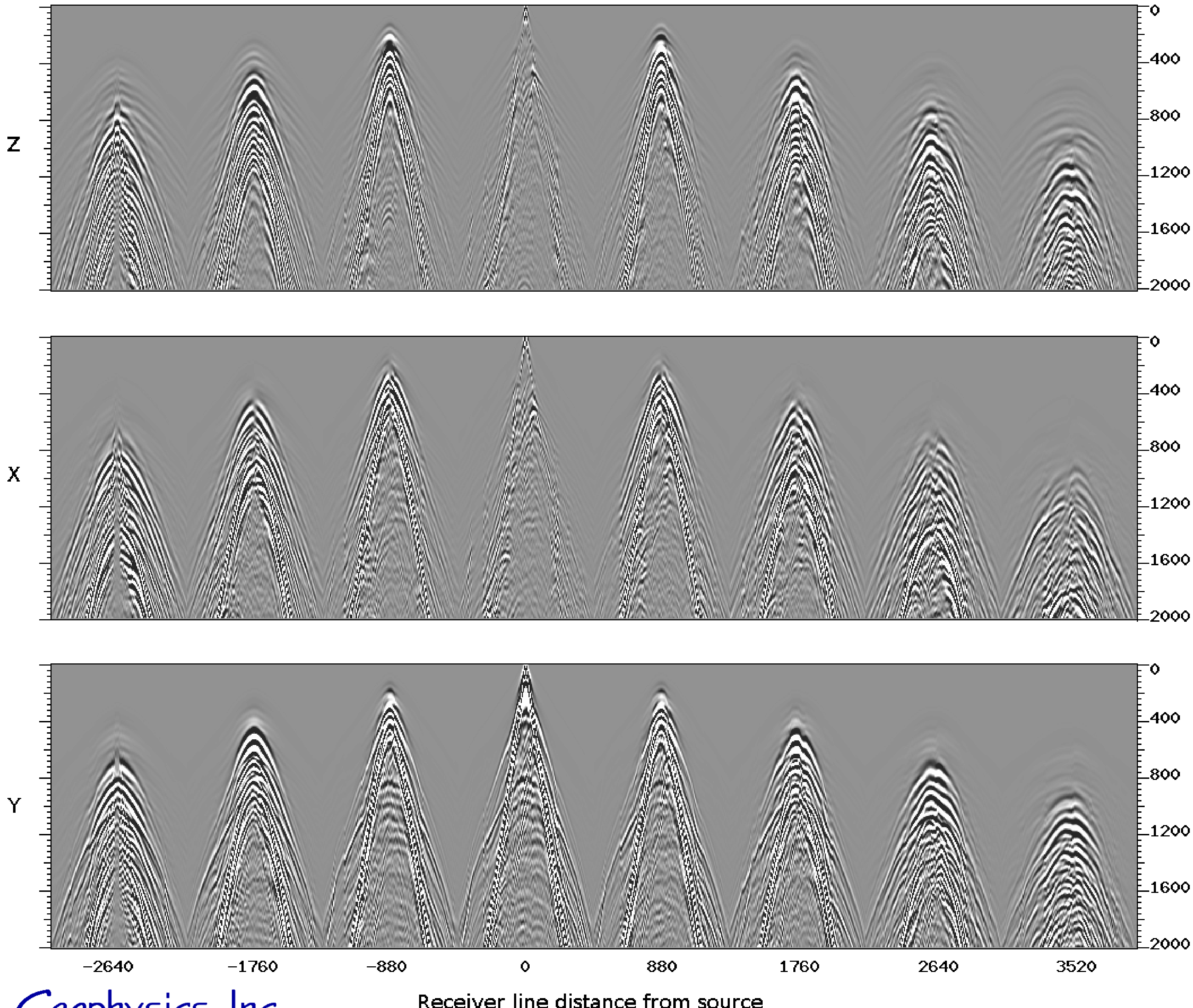
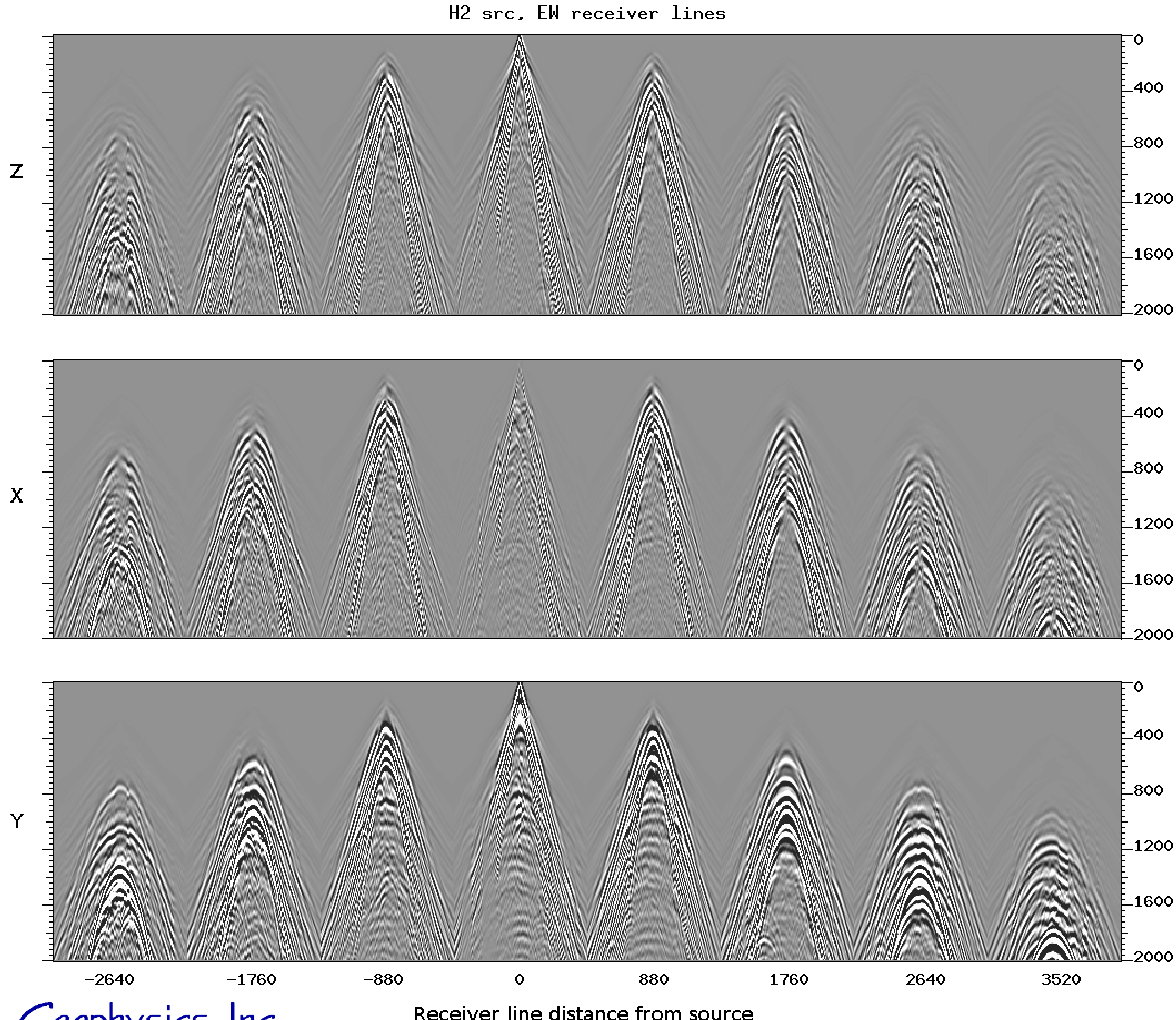
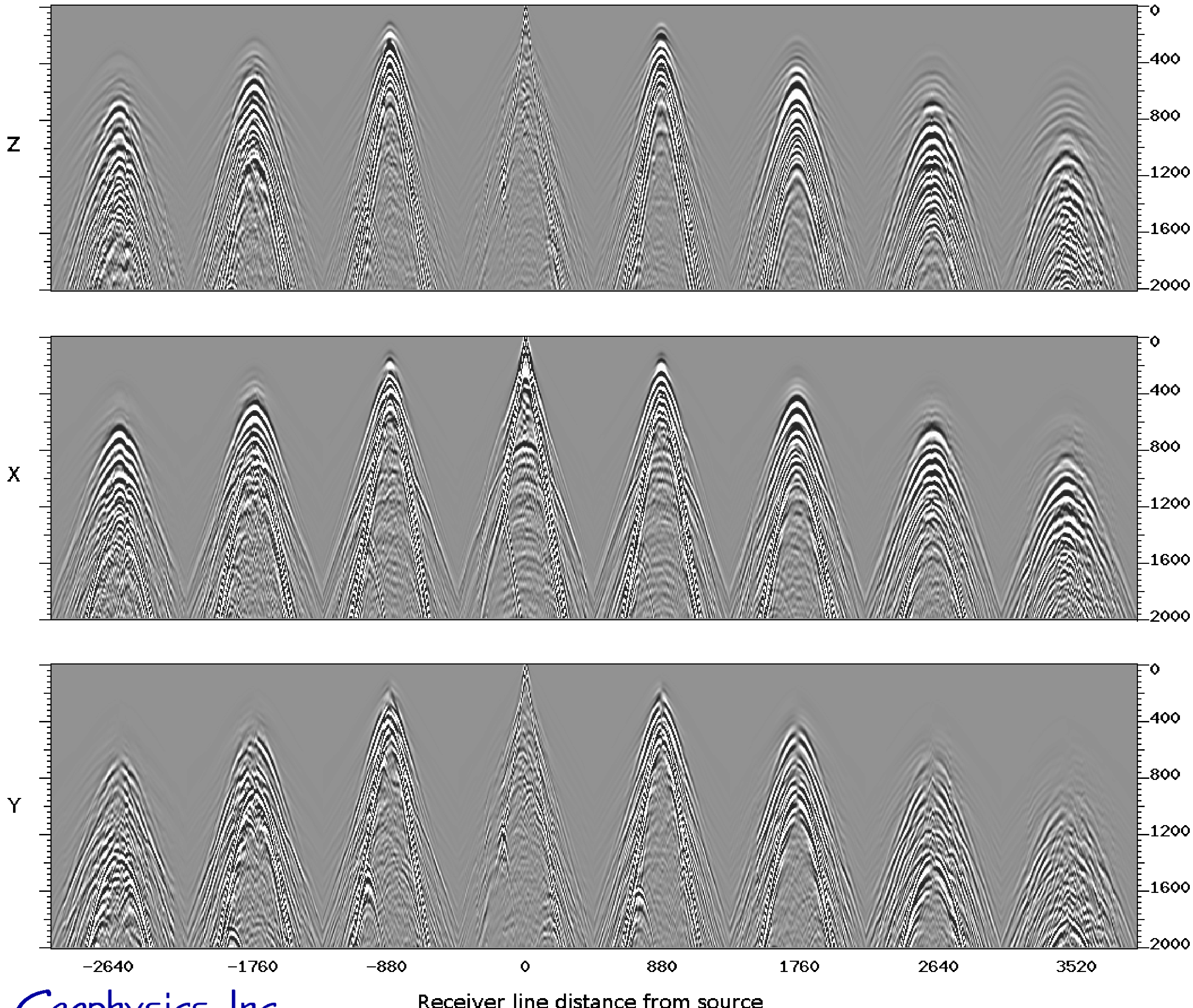
H2 src, NS receiver lines

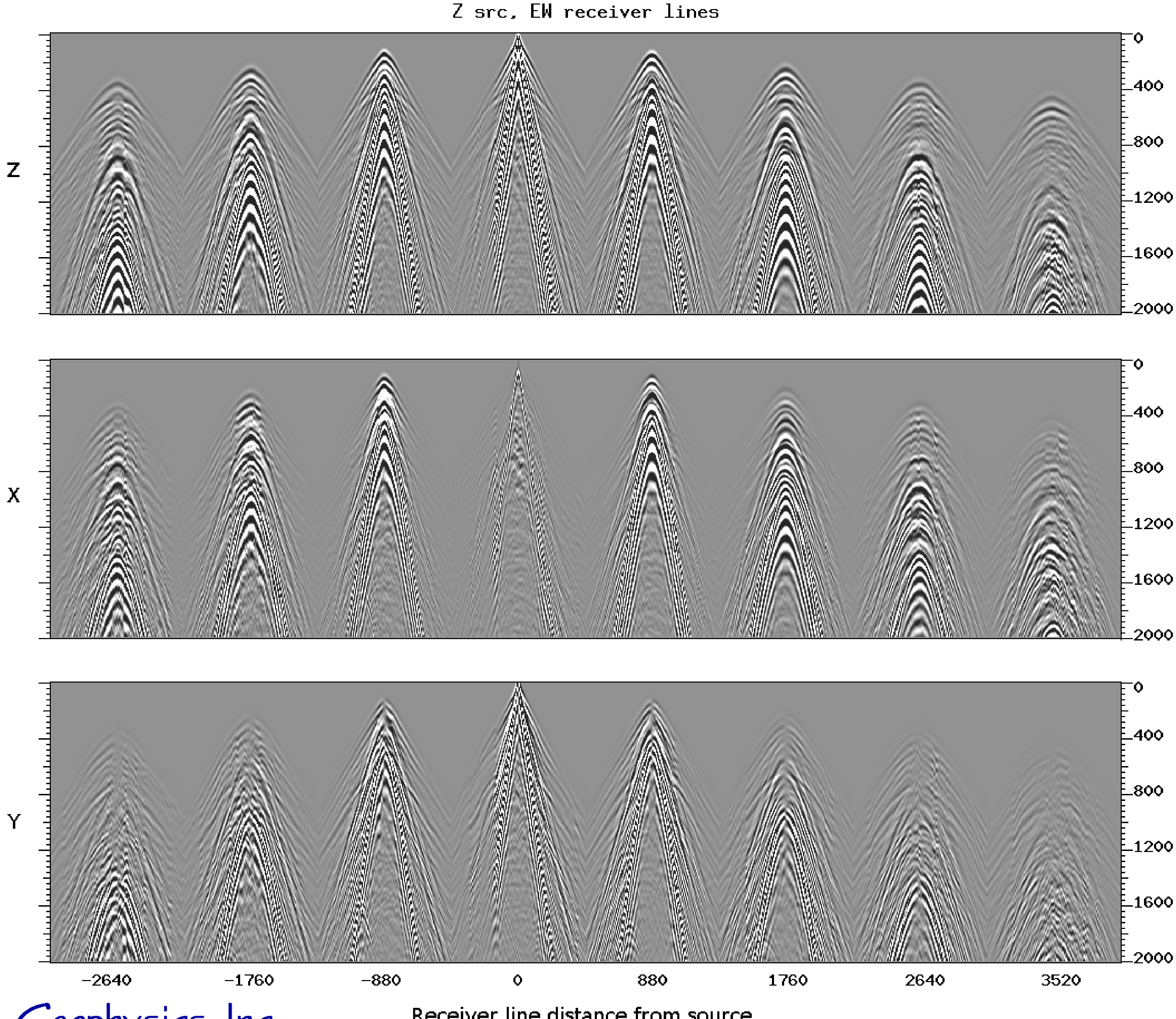



H2 src, EW receiver lines
Z
X
Y
0
400
800
1200
1600
2000
-2640
-1760
-880
0
880
1760
2640
3520
Receiver line distance from source

H1 src, EW receiver lines

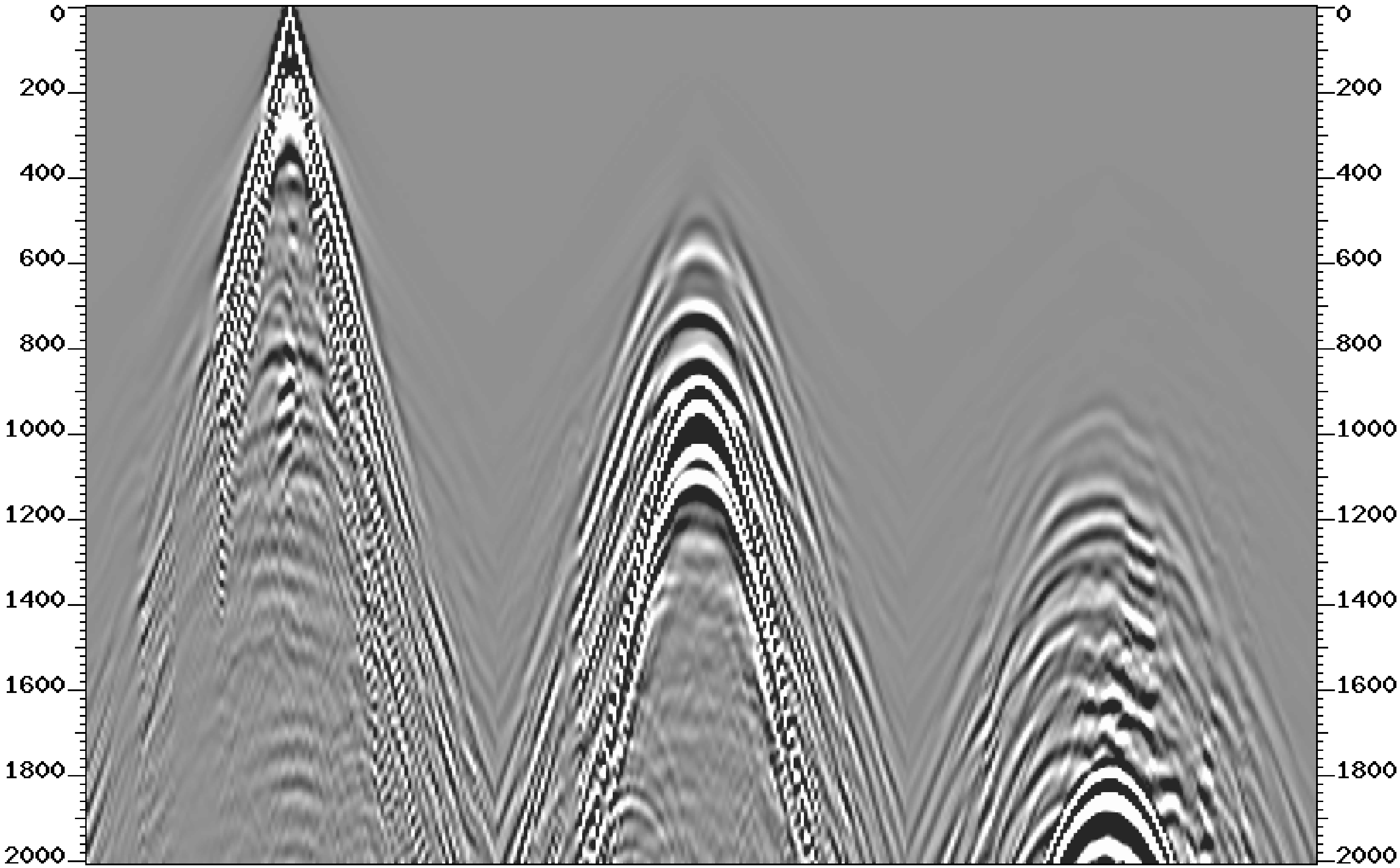


Allied Geophysics, Inc.

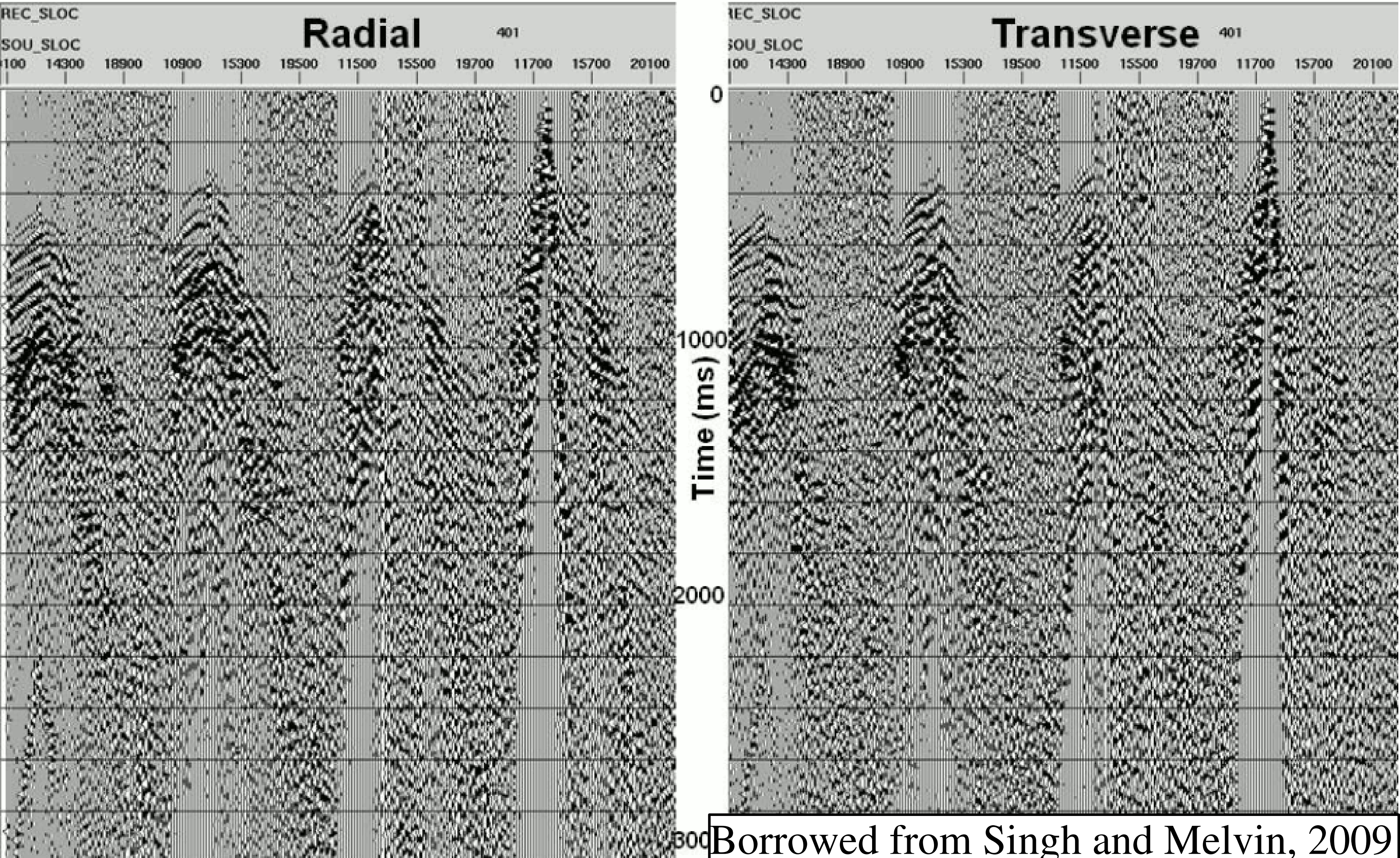


Allied Geophysics, Inc.

H2 src, H2 rcvr, EW receiver lines



Radial and Transverse Gather



Borrowed from Singh and Melvin, 2009

Conclusion 1

Readily available digital information enables rapid construction of useful models.

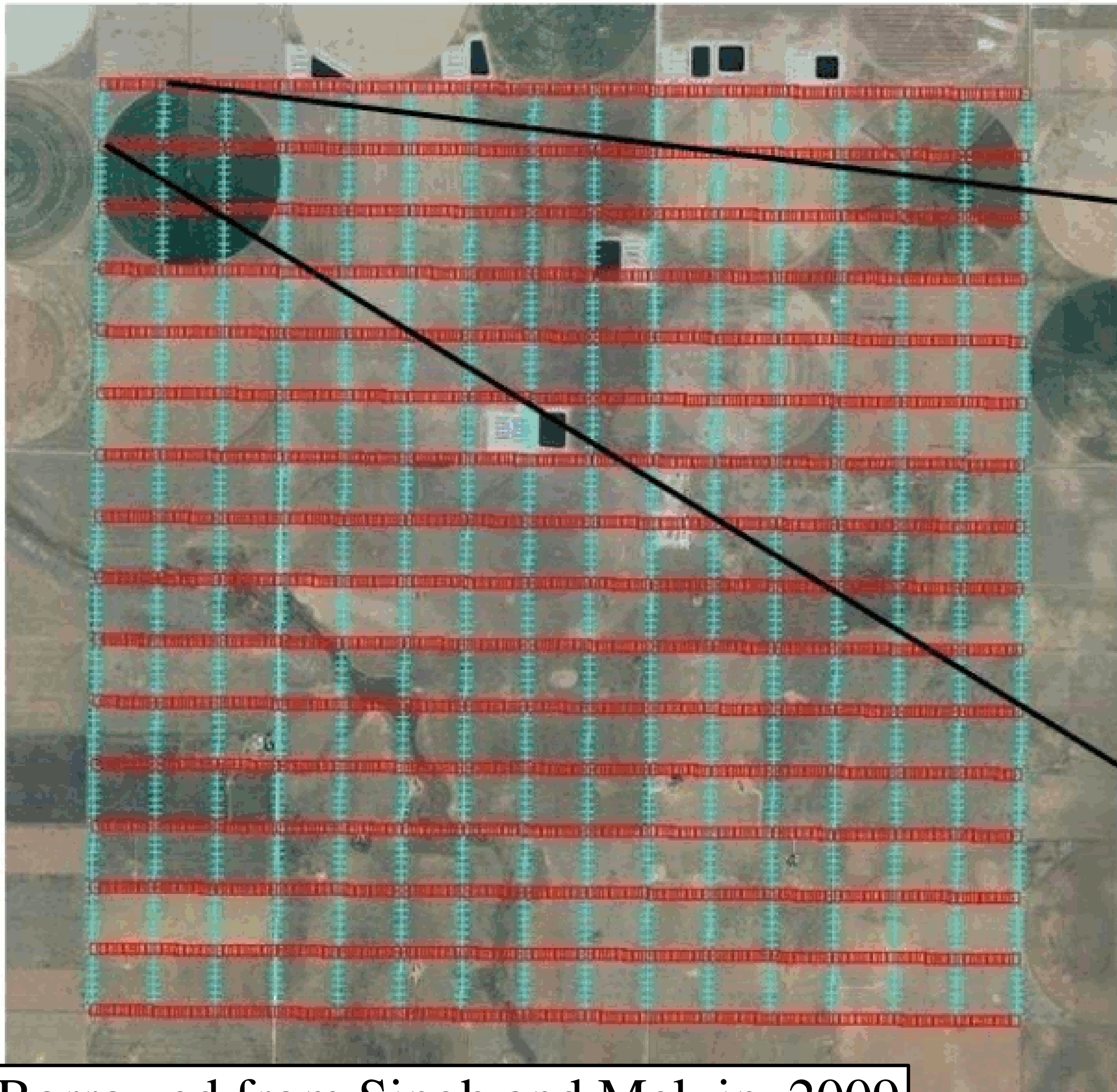
Next Issue

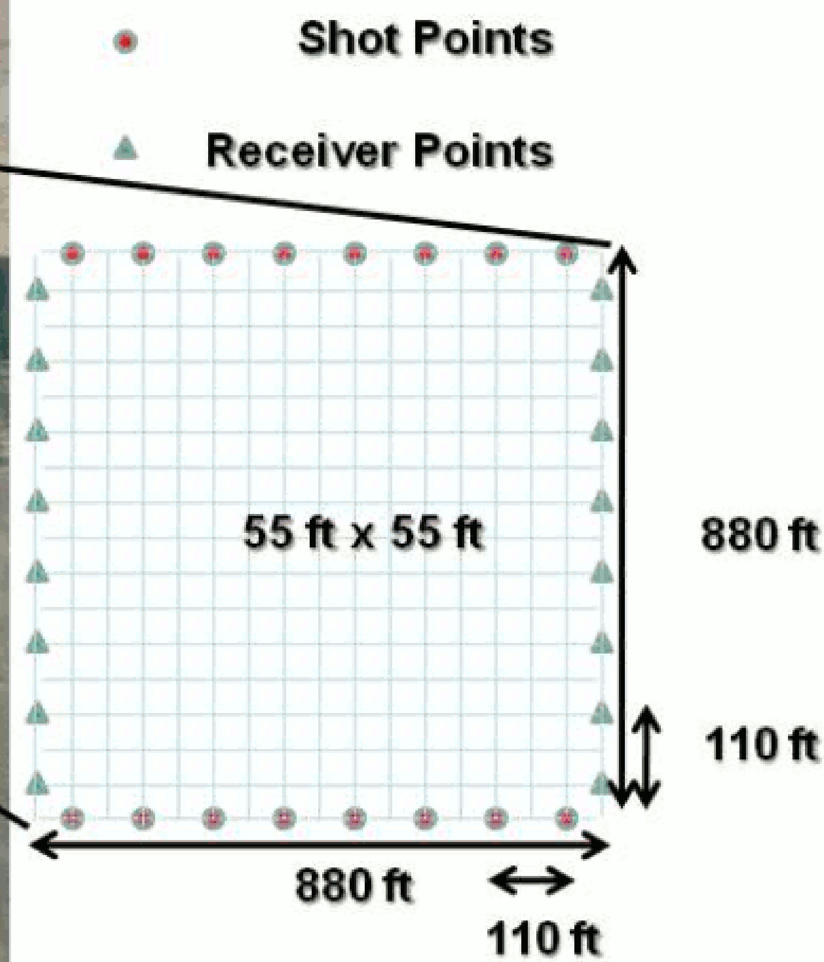
Is the calculation practical?

Desired Model

Dimensions:	**20 x 20 x 2.5 km**
Upper Freqency:	**40 Hz**
Velocity Range:	**500 – 5030 m/s**
Grid Spacing:	**4-1/6 m**
X,Y Offsets:	**+/- 4 km**
Record Length:	**4 seconds**
Symmetry:	**Heterogeneous HTI**
Target run time:	**100 host-hrs/shot**

Acquisition Parameters





No. of shot lines : 16
No. of receiver lines : 16
Minimum offset : 76.86 ft
Maximum offset : 18590.74 ft

Borrowed from Singh and Melvin, 2009

The Test Code

Algorithm: 1987 (J.T. Etgen, SEP Report 56-3)

Implemented: 2003 ('Modern' version of Etgen SEPLIB code)

Ownership: BP

RCP Access: 2004 (Restricted to Allied Geo hardware)

Run Time Estimate

For 5760 shots in an RCP-sized survey

105 days on modern 512 host cluster

(220 host-hours per shot)

Speeding the Calculation

Employ Regone's Method:
Only calculate what you need to conduct your tests

RCP-sized == small

Reduce submodel widths from 8 to 6 km	**~ 2x**
Consider reducing frequency content	**~16x**
VSP data with 40 Hz vs. surface data with 20 Hz	
Frequency reduction 40 -> 34 Hz	**~2x**
Use model-specific code	**??**

Conclusion 2

Calculating an RCP-sized 9-C survey in an anisotropic 3D elastic model is practical.

With compromise.

An industrial-sized calculation, but smaller than many being routinely undertaken today.

References

Davis, T., 2010, The state of EOR with CO_2 and associated seismic monitoring: The Leading Edge, **29**, 31-33.

Etgen, J.T., 1987, Finite-difference elastic anisotropic wave propagation: Stanford Exploration Project Report **56**, 23-58.

Borrowed Material

Singh, P., and C. Melvin, 2009, Postle field processing and modeling: Presented at the Reservoir Characterization Project Spring Sponsors Meeting, p. 121, 127.

Singh, P., and C. Melvin, 2009, Postle field MC seismic processing and modeling: Presented at the Reservoir Characterization Project Spring Sponsors Meeting, Breakout session, p. 4.

Wandler, A., 2009, Effects of stress from confining pressure and pore pressure on elastic-wave velocities: Presented at the Reservoir Characterization Project Fall Sponsors Meeting, p. 54-55.

Windels, R., 2009, S-wave direct mode processing highlights: Presented at the Reservoir Characterization Project Fall Sponsors Meeting, p. 75, 84.

Windels, R., and M. O'Brien, 2010, The shear difference: Insightful perspectives and a proposal, part 1: Presented at the Reservoir Characterization Project Spring Sponsors Meeting, p. 11, 13.

Acknowledgments

RCP
RESERVOIR CHARACTERIZATION PROJECT
COLORADO SCHOOL OF MINES

bp

USGS
science for a changing world

fairfieldnodal

Slope & Basin Consortium

CREWES

DDS Data Dictionary System
A Flexible Format, Multidimensional Seismic Processing System

FreeUSP.org

Proposal

To engage RCP sponsors in a collaborative calculation of synthetic shear data.

Timing

Summer 2010

Allied Geo prepares models and executables for distribution to sponsor computing centers.

Fall 2010 through 2011

Sponsors perform calculation in 'white space' and retrun data to RCP.

2011 and beyond

Data are used to advance understanding of S-wave data quality issues.

Models to Calculate

Heterogeneous HTI without near-surface complexity (elastic)

Introduce near-surface complexity (elastic)

Introduce time-lapse component (elastic)

Introduce attenuation (anelastic)

Next steps

Get help! Your help.

Find ways to do the calculation

- **Code contributions from anywhere**
- **White space in consortium member systems**

Evaluate cost/value trade offs

- **Make sure valuable features aren't needlessly omitted**
- **Find more ways to reduce run time**

Continue testing model parameters

- **Relative amplitudes between near surface and target**
- **Ability to separate noise from signal**