Simultaneous P-P and P-S Waveform Inversion Algorithm using Pre-Stack Time Imaging Method

Hassan Khaniani*, John C. Bancroft and Eric von Lunen

November 30, 2012

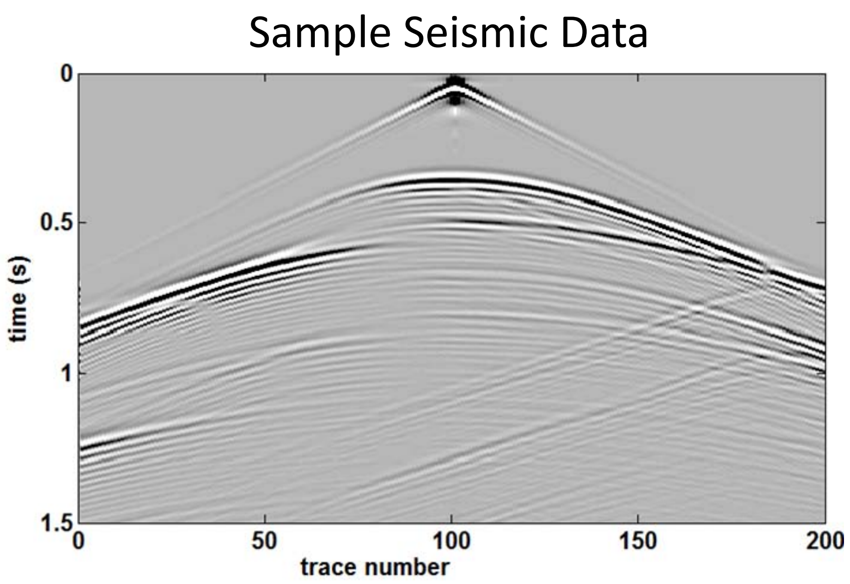
Annual CREWES Sponsors Meeting

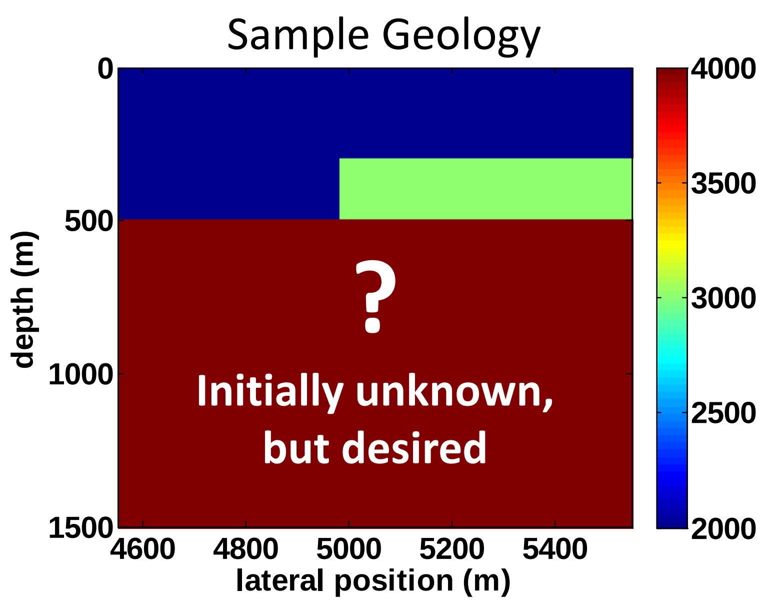
UNIVERSITY OF CALGARY

Outline

- Why Waveform Inversion?
- Review of Conventional Full Waveform Inversion
- Elastic Forward Modeling and Migration
- Waveform Inversion using PSTM
- Examples
- Conclusions

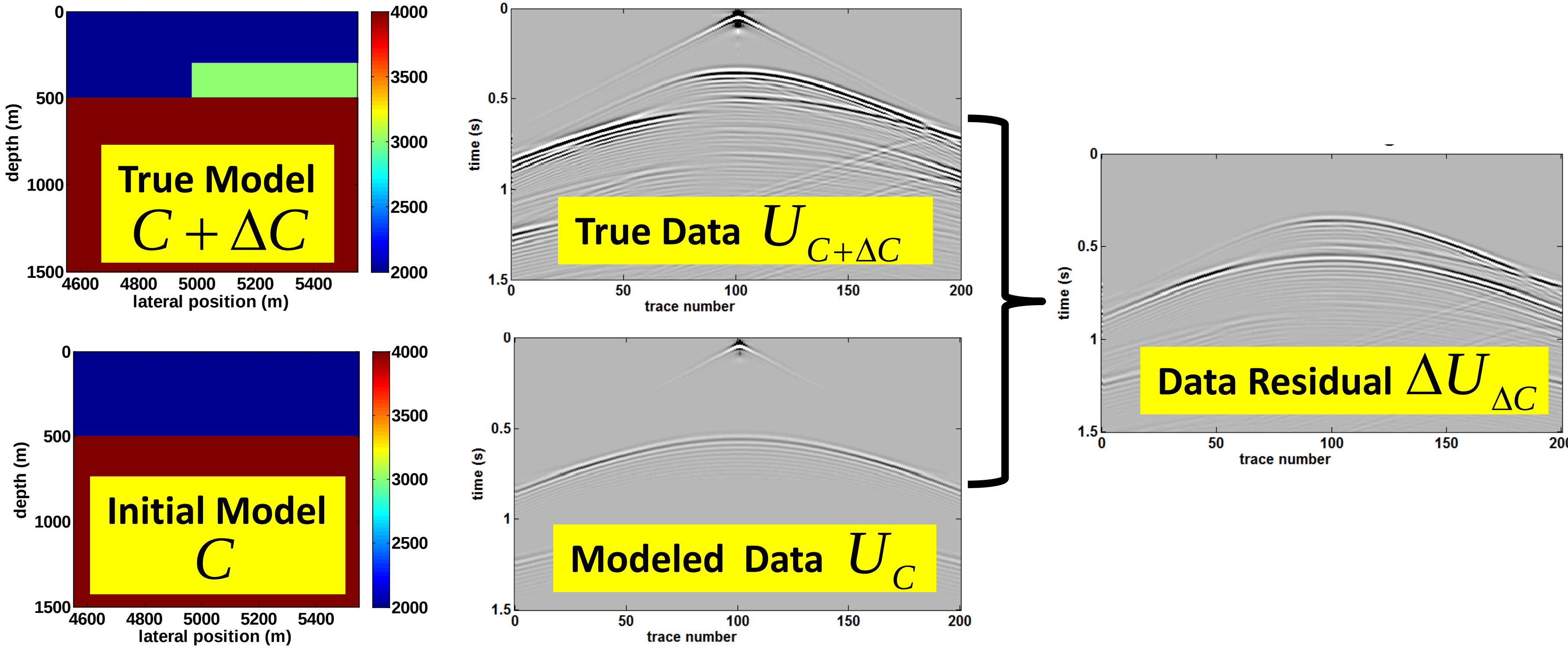
Waveform Inversion?





- **<u>Some Conventional Seismic Inversion</u>**
  - Travel time to invert for rock properties (eg. CMP velocity analysis)
  - Amplitude to invert for rock properties (eg. AVO)
- **<u>Waveform Inversion</u>**
  - Travel time and amplitude used simultaneously
  - High resolution model
  - Computational time is higher

Review of PSDM FWI
(Tarantola, 1984 & Beylkin and Burridge, 1990)



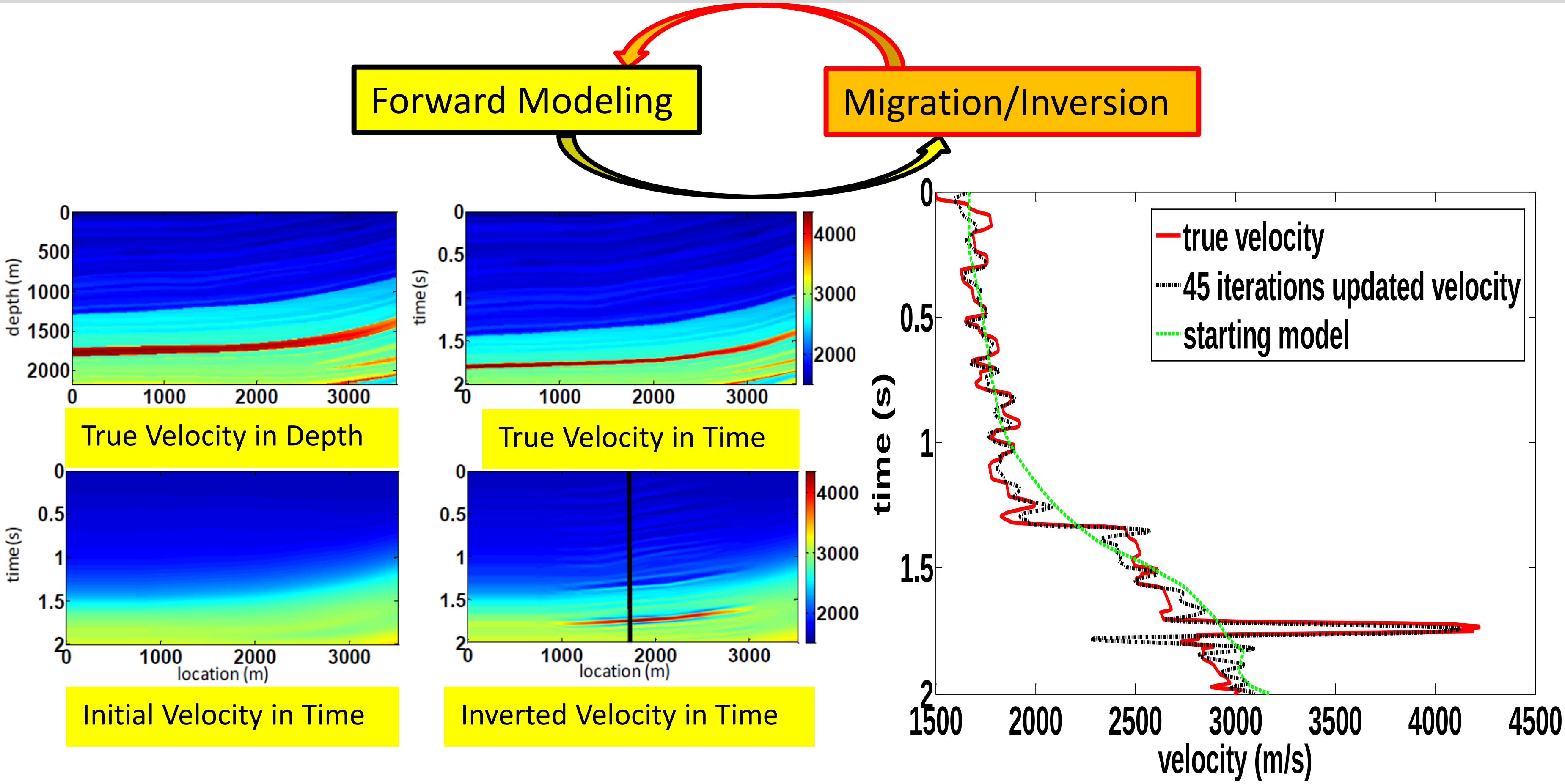
$$\Delta U_{\Delta C} = U_{C+\Delta C} - U_C = f(\Delta C)$$

$$\min \phi = \frac{1}{2}\sum_{x_s, x} \left\| \Delta U_{\Delta C} \right\|^2 \Rightarrow$$

Forward Modeling **Migration**

$$C_{k+1}(x,z) = C_k(x,z) - \boxed{\alpha_k}\boxed{\gamma_k(x,z)}$$

Acoustic FWI Algorithm result using PSTM



Wave Equation Finite Difference Solution:

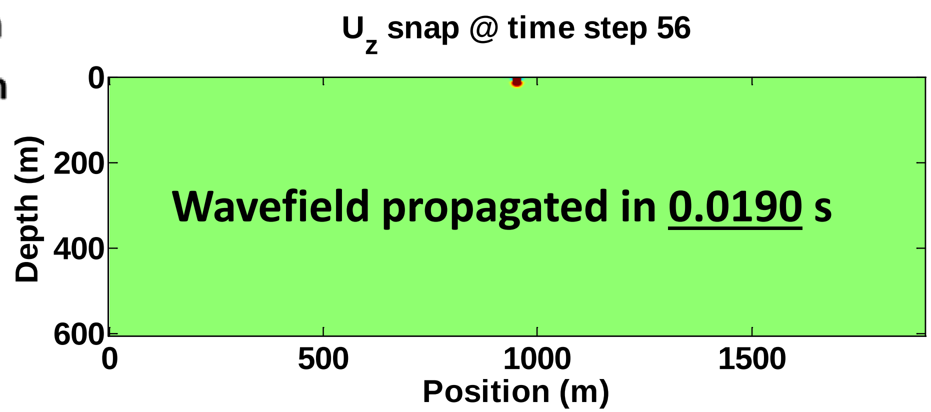
2D, continuous, elastic, homogeneous, isotropic medium

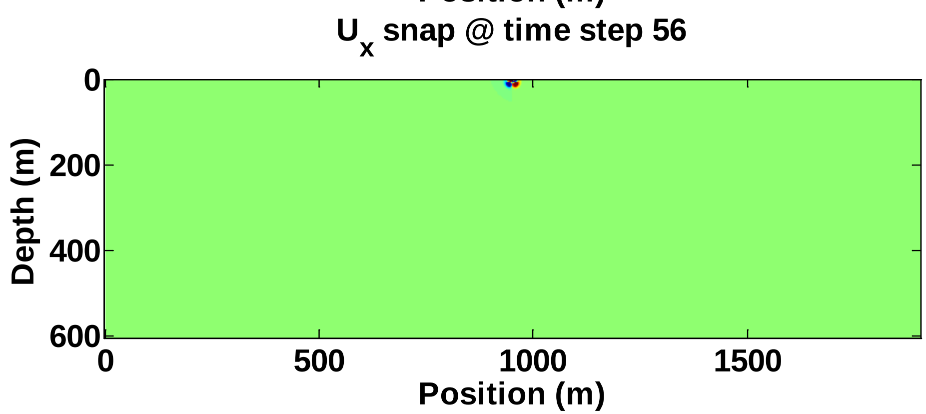
$$(\lambda + 2\mu)\frac{\partial^2 U_z}{\partial z^2} + (\lambda + \mu)\frac{\partial^2 U_x}{\partial x \partial z} + \mu \frac{\partial^2 U_z}{\partial x^2} = \rho \frac{\partial^2 U_z}{\partial t^2} \quad (1)$$

$$(\lambda + 2\mu)\frac{\partial^2 U_x}{\partial x^2} + (\lambda + \mu)\frac{\partial^2 U_z}{\partial x \partial z} + \mu \frac{\partial^2 U_x}{\partial z^2} = \rho \frac{\partial^2 U_x}{\partial t^2} \quad (2)$$

- **Where λ, μ are *Lamé constants***
- **U_z: displacement in z-direction**
- **U_x: displacement in x-direction**

Manning, Ph.D. Thesis (2007)





Wave Equation Finite Difference Solution:

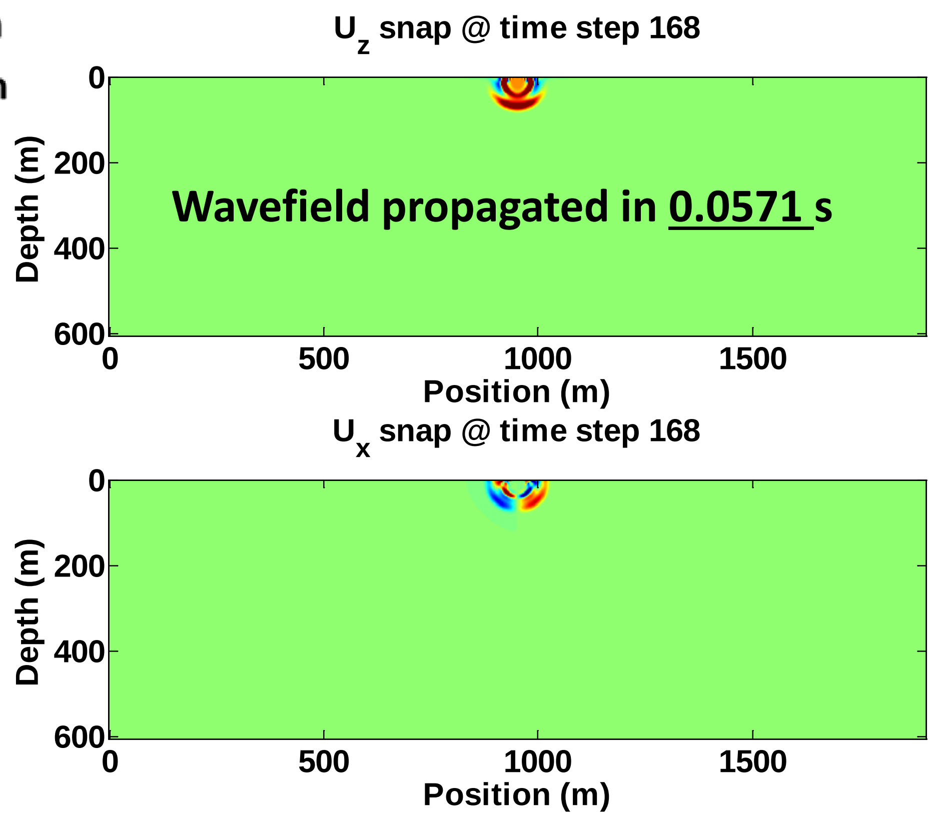
2D, continuous, elastic, homogeneous, isotropic medium

$$(\lambda + 2\mu)\frac{\partial^2 U_z}{\partial z^2} + (\lambda + \mu)\frac{\partial^2 U_x}{\partial x \partial z} + \mu\frac{\partial^2 U_z}{\partial x^2} = \rho\frac{\partial^2 U_z}{\partial t^2} \quad (1)$$

$$(\lambda + 2\mu)\frac{\partial^2 U_x}{\partial x^2} + (\lambda + \mu)\frac{\partial^2 U_z}{\partial x \partial z} + \mu\frac{\partial^2 U_x}{\partial z^2} = \rho\frac{\partial^2 U_x}{\partial t^2} \quad (2)$$

- **Where λ, μ are *Lamé constants***
- **U_z: displacement in z-direction**
- **U_x: displacement in x-direction**

Manning, Ph.D. Thesis (2007)



Wave Equation Finite Difference Solution:

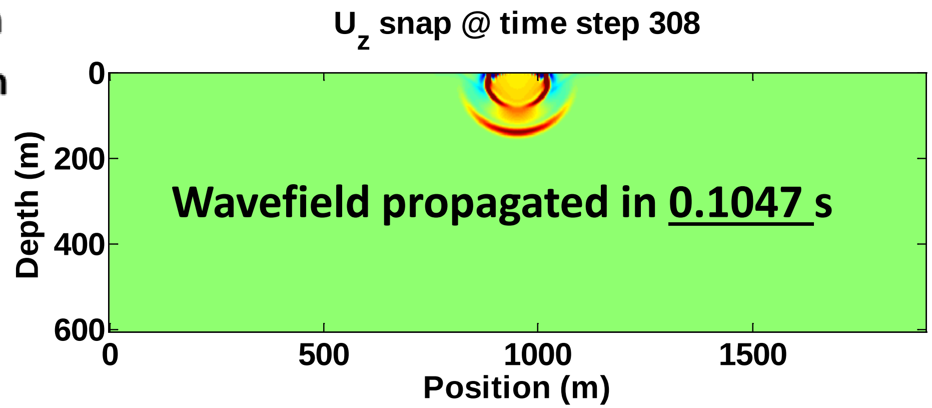
2D, continuous, elastic, homogeneous, isotropic medium

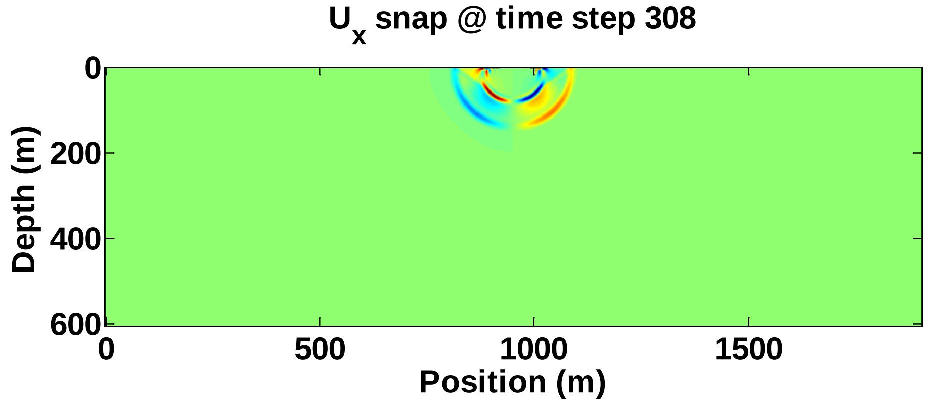
$$(\lambda + 2\mu)\frac{\partial^2 U_z}{\partial z^2} + (\lambda + \mu)\frac{\partial^2 U_x}{\partial x \partial z} + \mu\frac{\partial^2 U_z}{\partial x^2} = \rho\frac{\partial^2 U_z}{\partial t^2} \quad (1)$$

$$(\lambda + 2\mu)\frac{\partial^2 U_x}{\partial x^2} + (\lambda + \mu)\frac{\partial^2 U_z}{\partial x \partial z} + \mu\frac{\partial^2 U_x}{\partial z^2} = \rho\frac{\partial^2 U_x}{\partial t^2} \quad (2)$$

- **Where λ, μ are *Lamé constants***
- **U_z: displacement in z-direction**
- **U_x: displacement in x-direction**

Manning, Ph.D. Thesis (2007)





Wave Equation Finite Difference Solution:

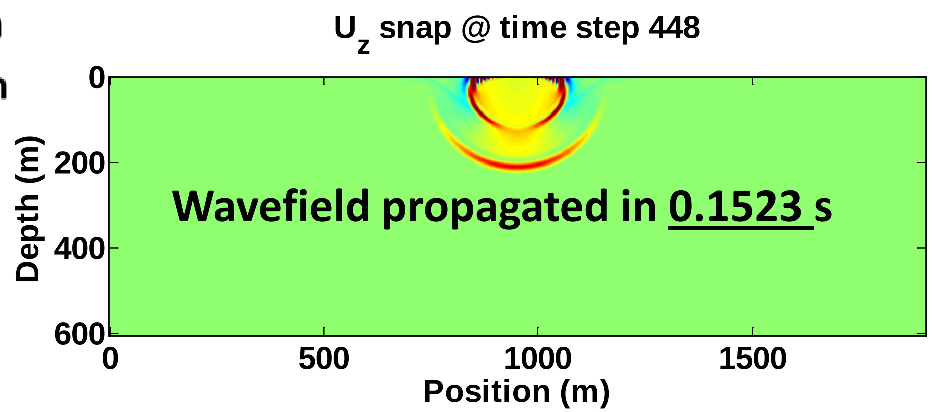
2D, continuous, elastic, homogeneous, isotropic medium

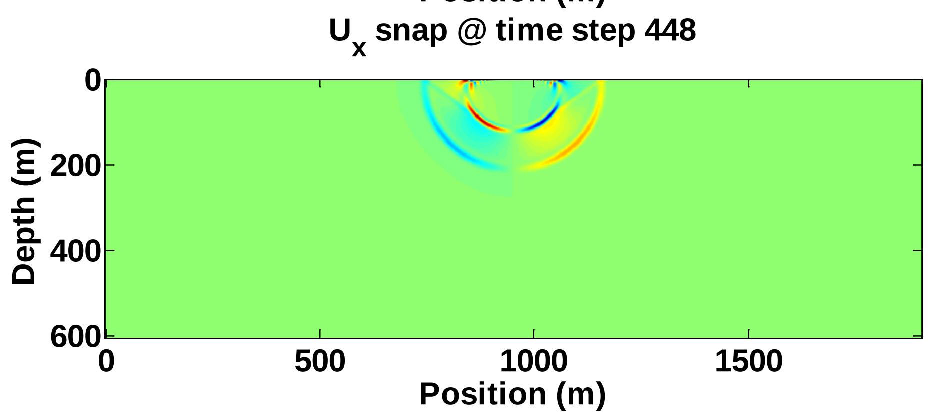
$$(\lambda + 2\mu)\frac{\partial^2 U_z}{\partial z^2} + (\lambda + \mu)\frac{\partial^2 U_x}{\partial x \partial z} + \mu\frac{\partial^2 U_z}{\partial x^2} = \rho\frac{\partial^2 U_z}{\partial t^2} \qquad (1)$$

$$(\lambda + 2\mu)\frac{\partial^2 U_x}{\partial x^2} + (\lambda + \mu)\frac{\partial^2 U_z}{\partial x \partial z} + \mu\frac{\partial^2 U_x}{\partial z^2} = \rho\frac{\partial^2 U_x}{\partial t^2} \qquad (2)$$

- **Where λ, μ are *Lamé constants***
- **U_z: displacement in z-direction**
- **U_x: displacement in x-direction**

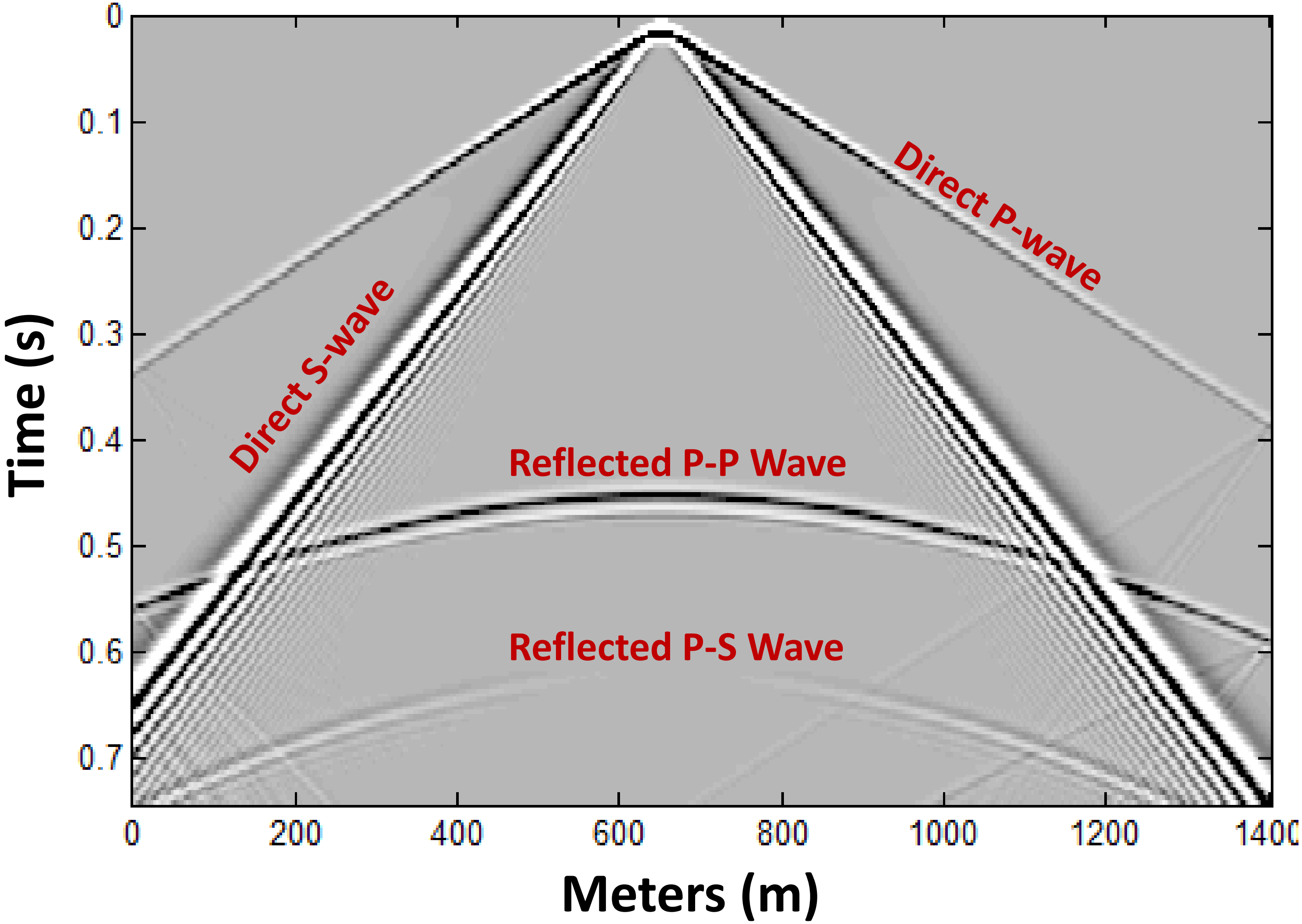
Manning, Ph.D. Thesis (2007)



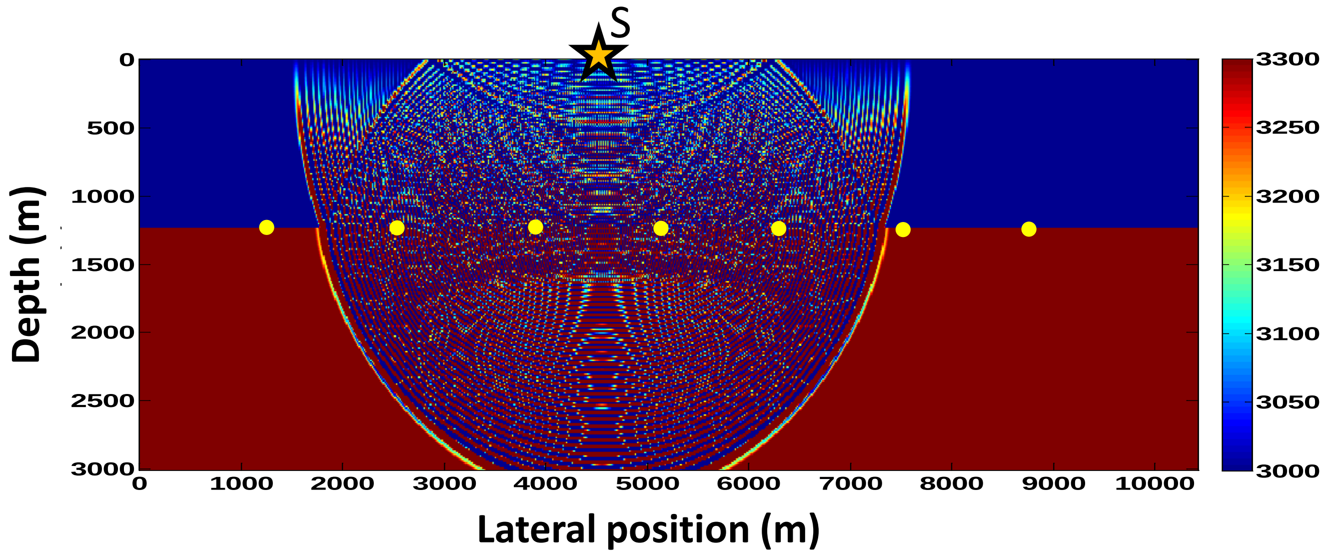


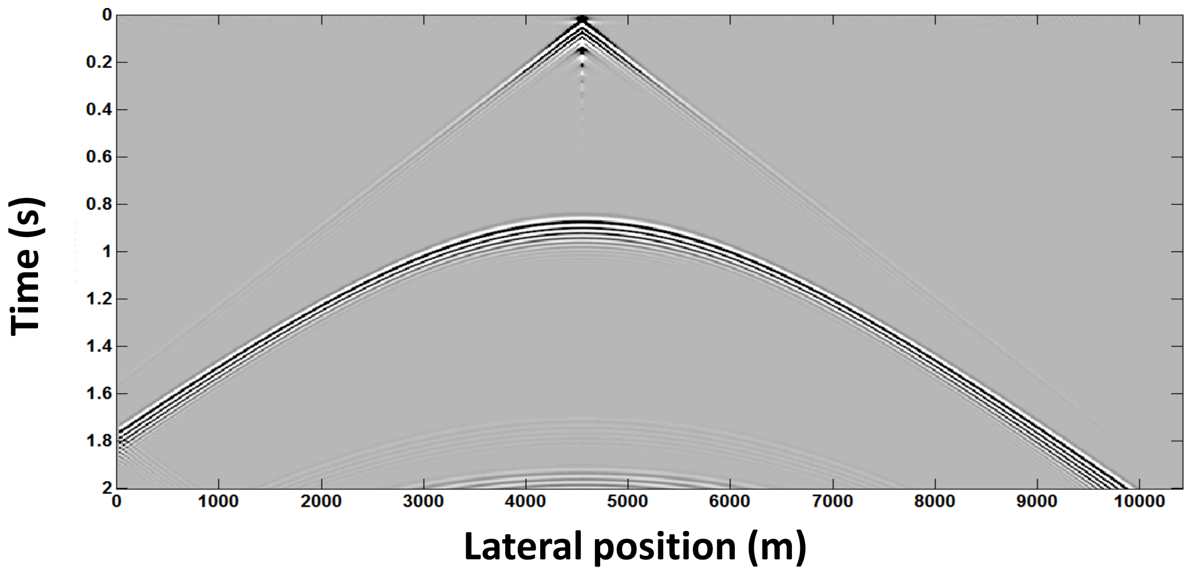
Wave Equation Finite Difference Solution:

2D, continuous, elastic, homogeneous, isotropic medium

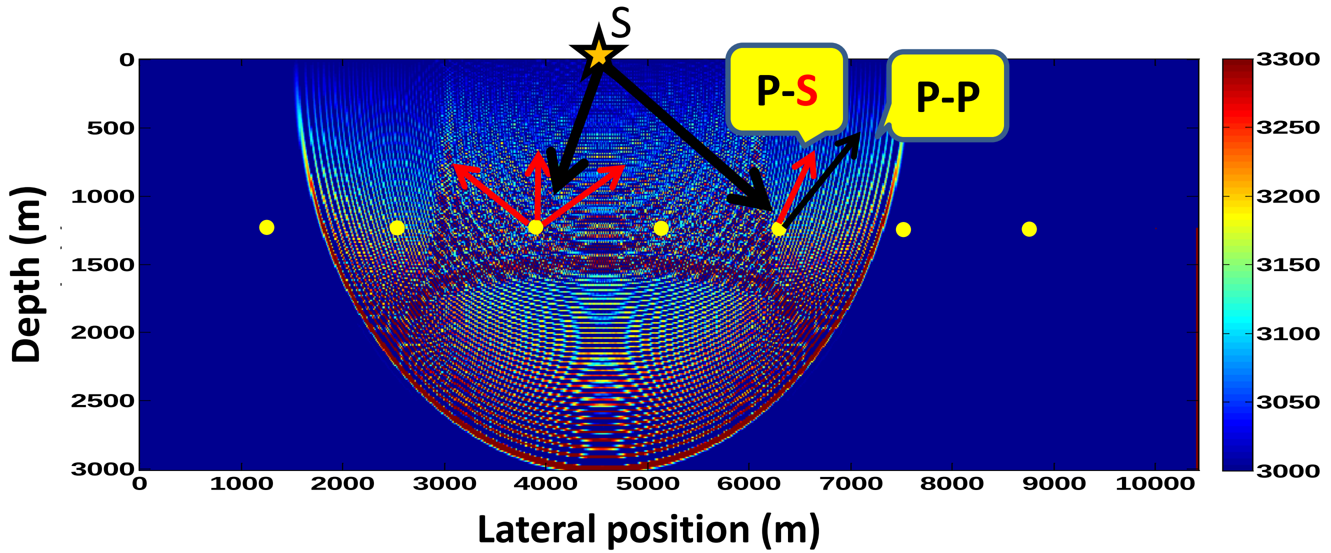


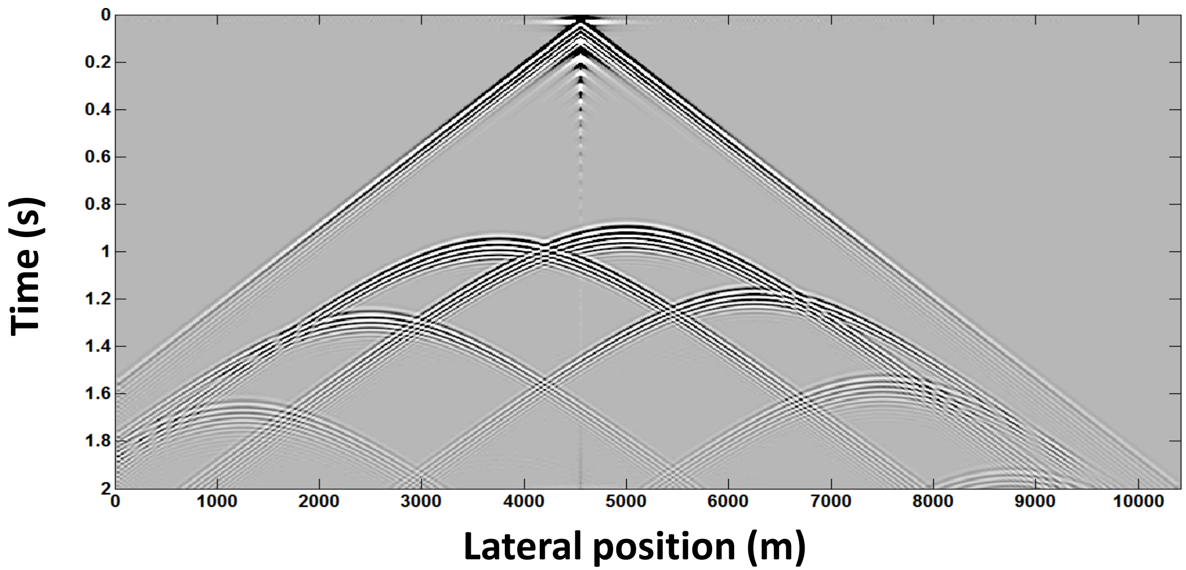
P-S Wave Equation Kirchhoff solution



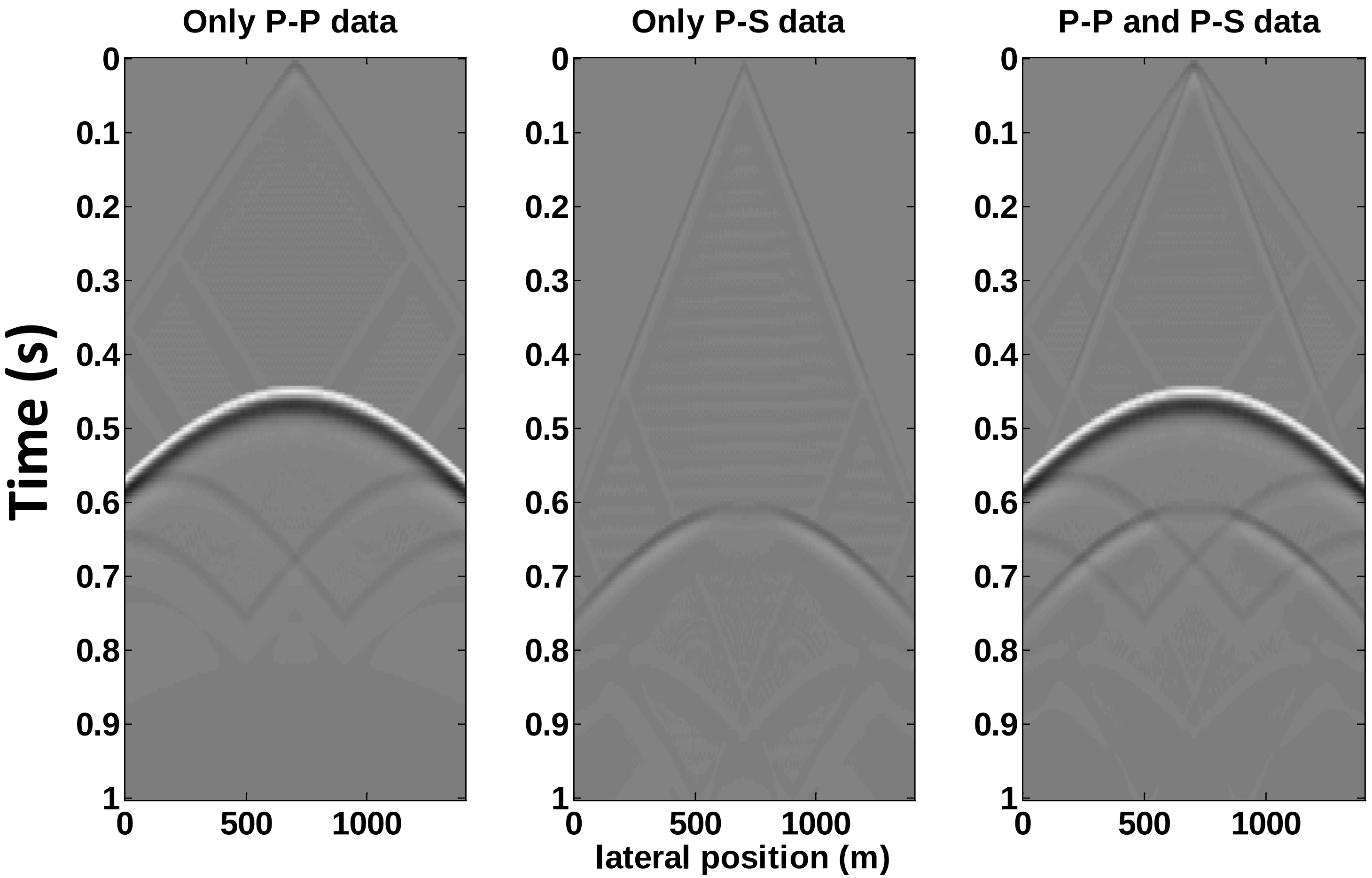


P-S Wave Equation Kirchhoff solution

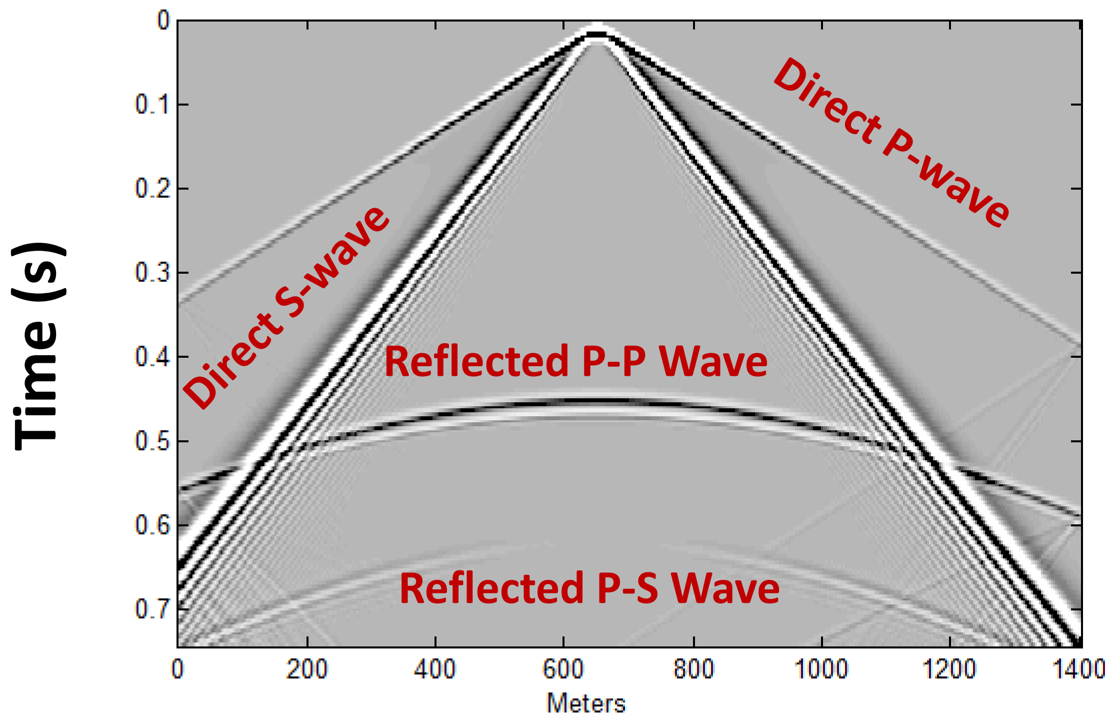




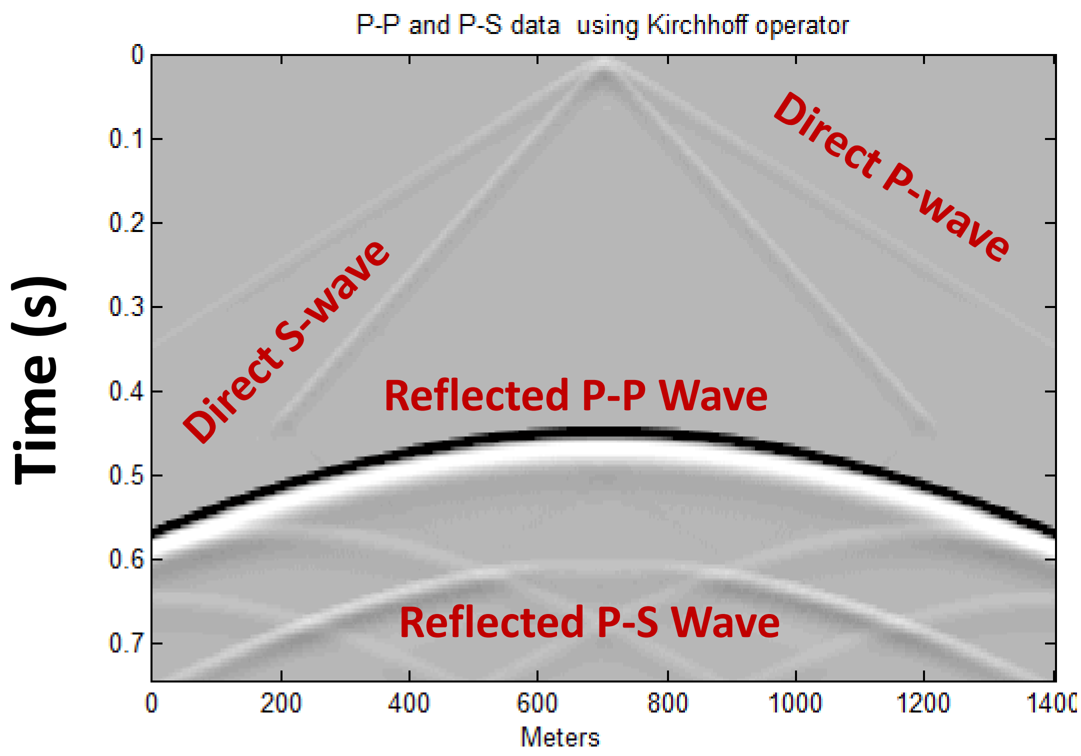
P-P & P-S Wave Equation Kirchhoff solution



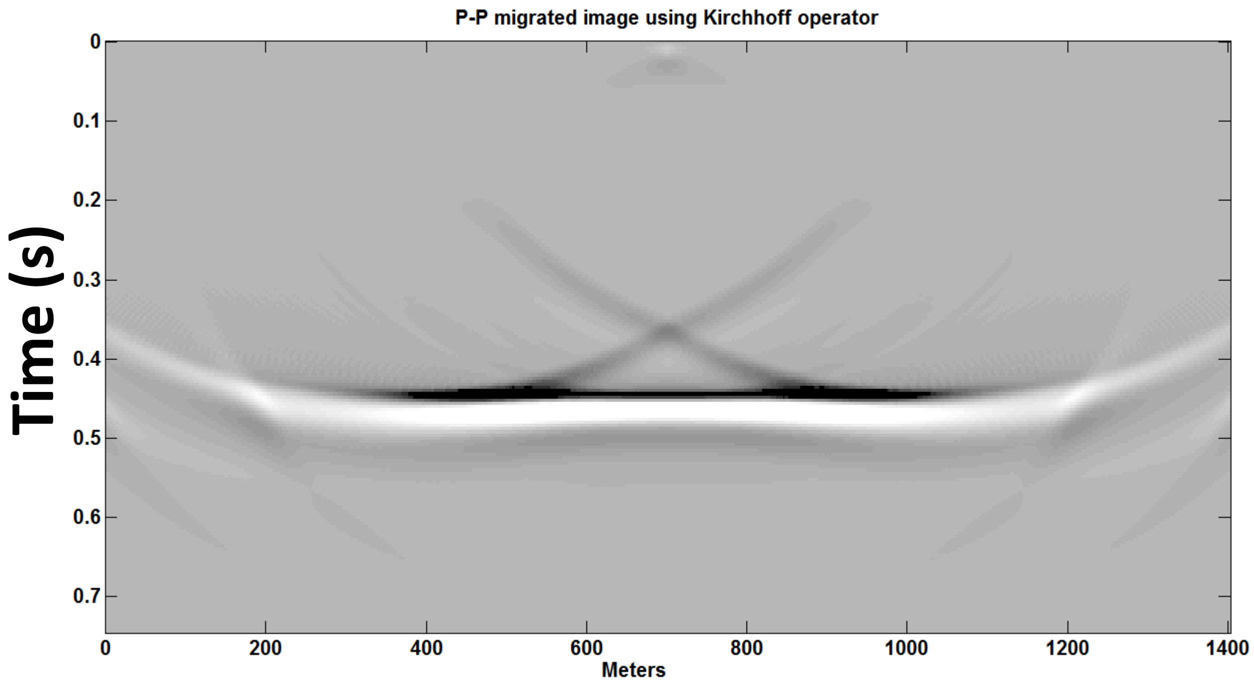
Wave Equation Finite Difference Solution:
2D, continuous, elastic, homogeneous, isotropic medium



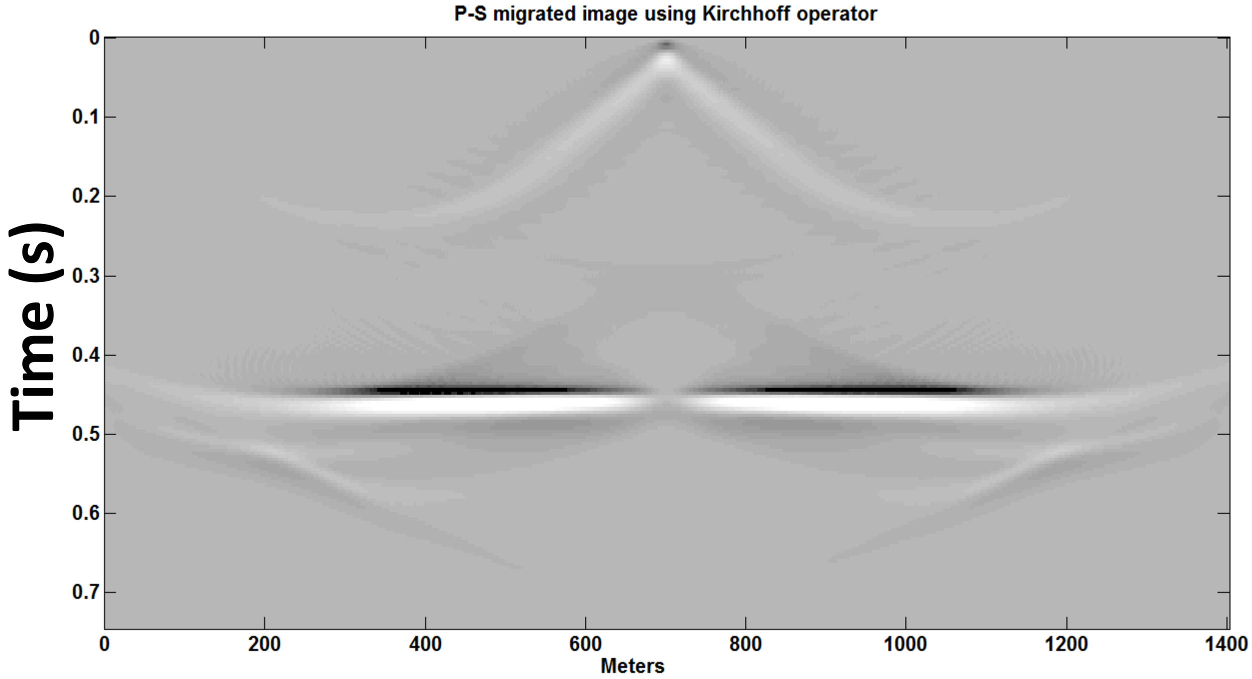
P-P & P-S Wave Equation Kirchhoff solution



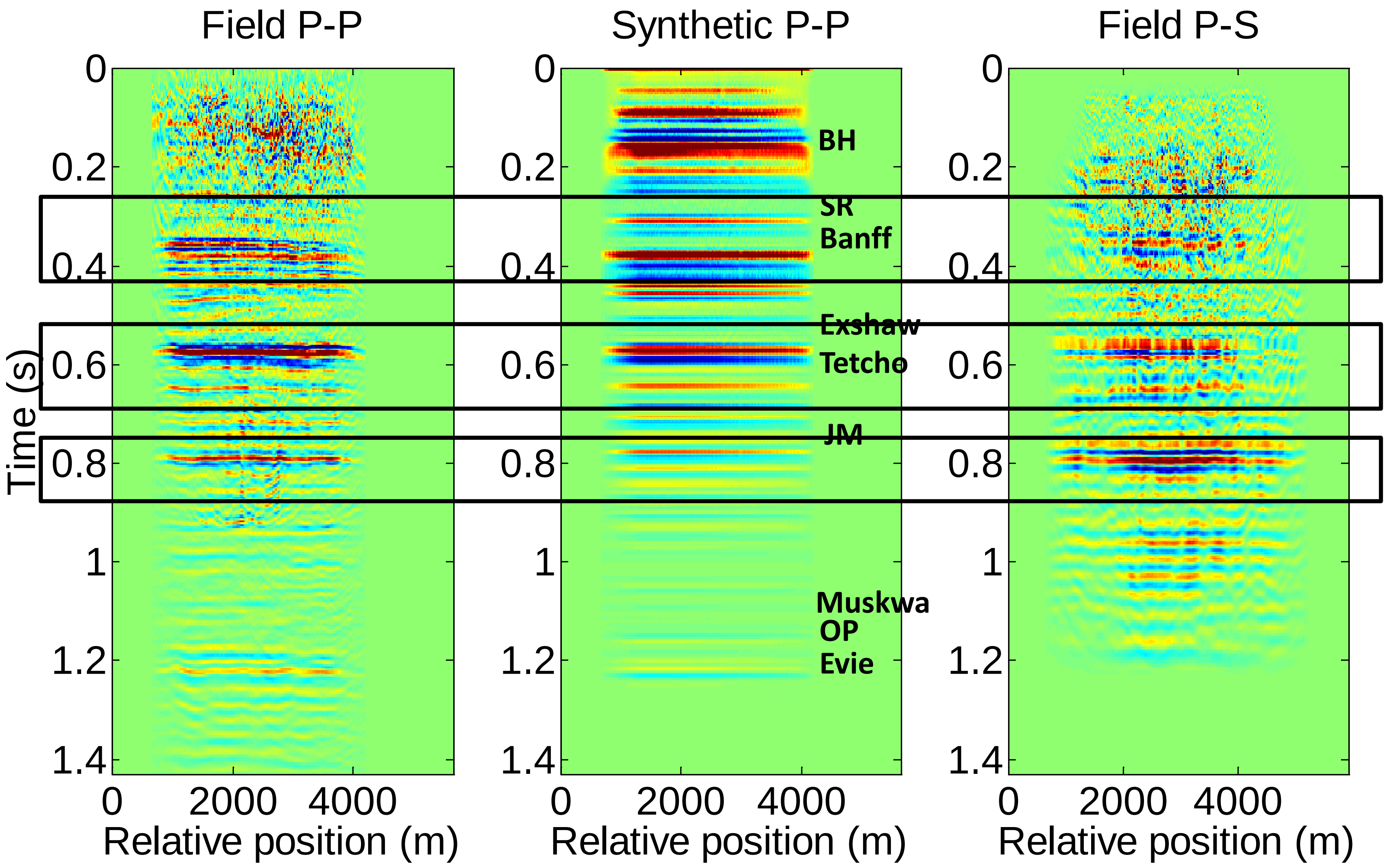
P-P Migration in Scatter Point time



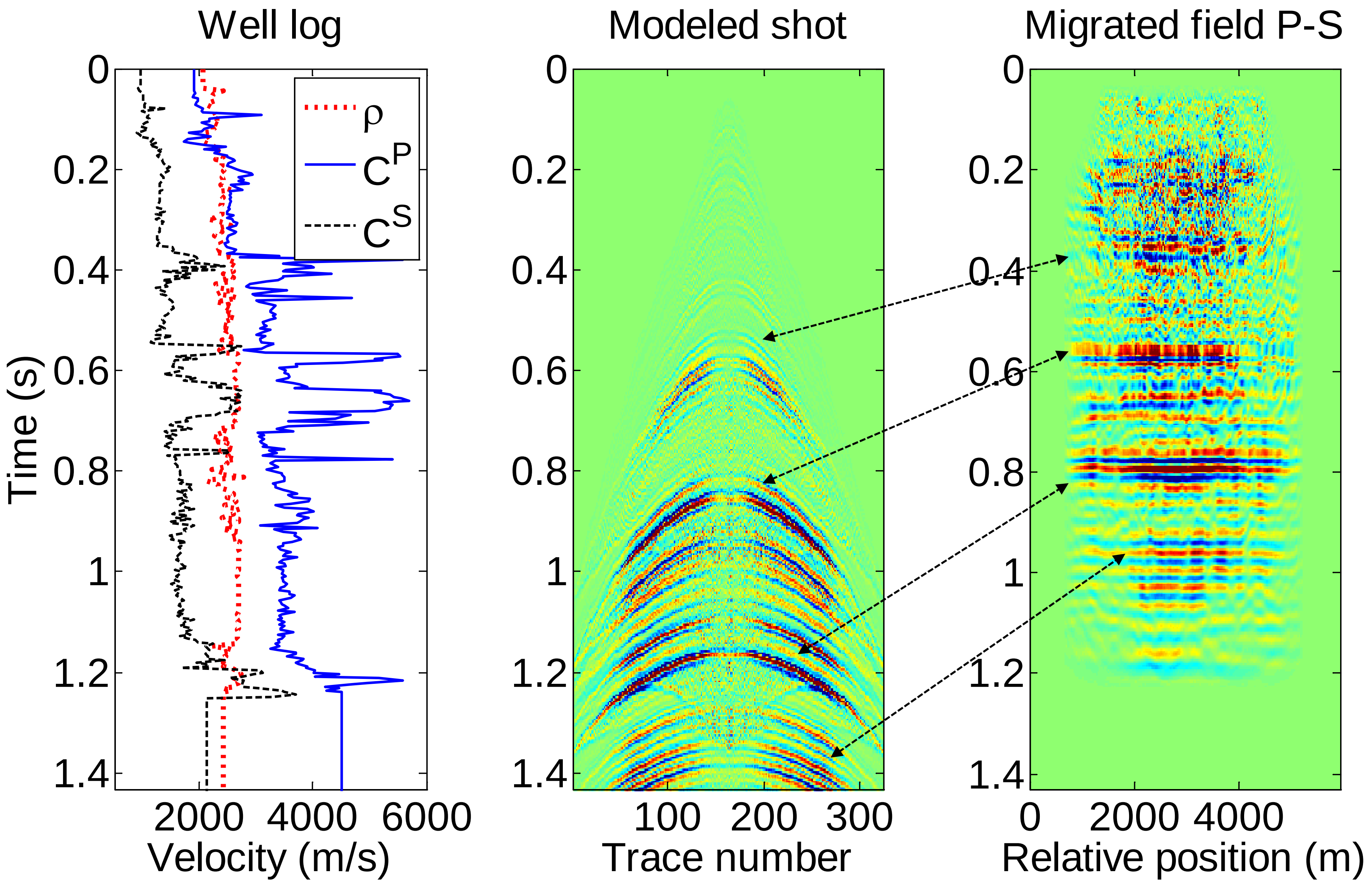
P-S Migration in Scatter Point time



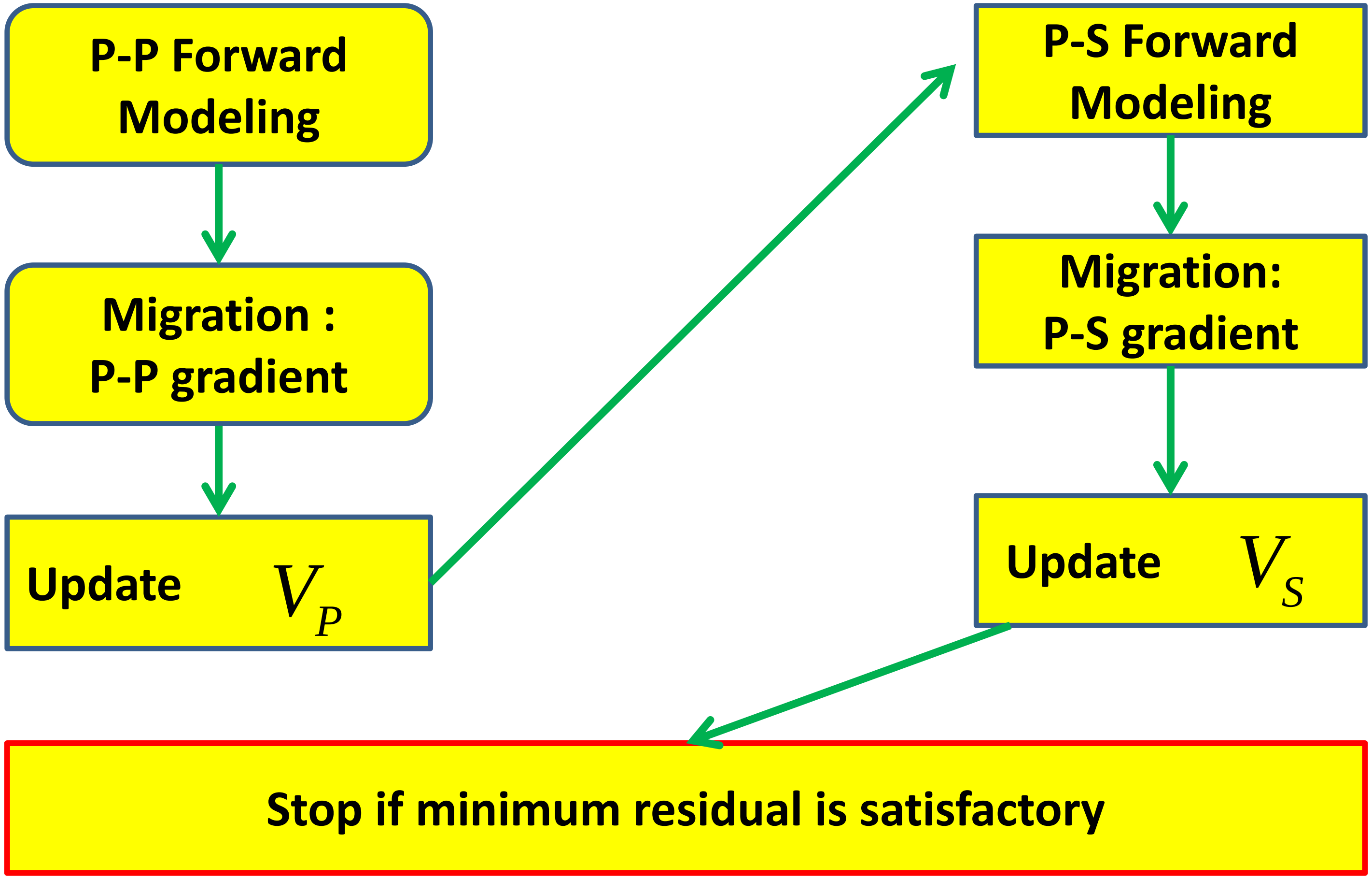
P-P and P-S Migration in real data



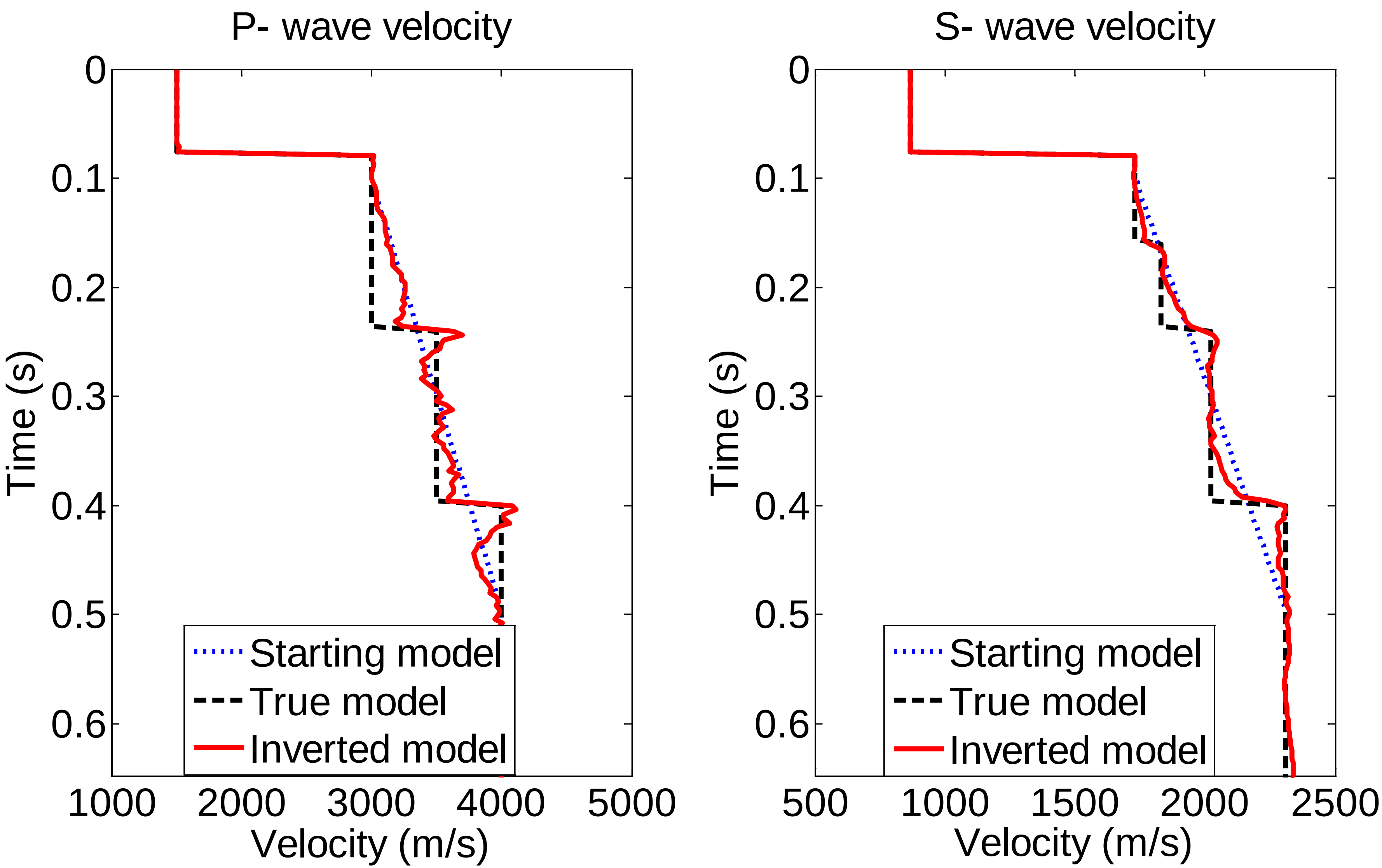
Forward Modeling vs Amplitude Realization



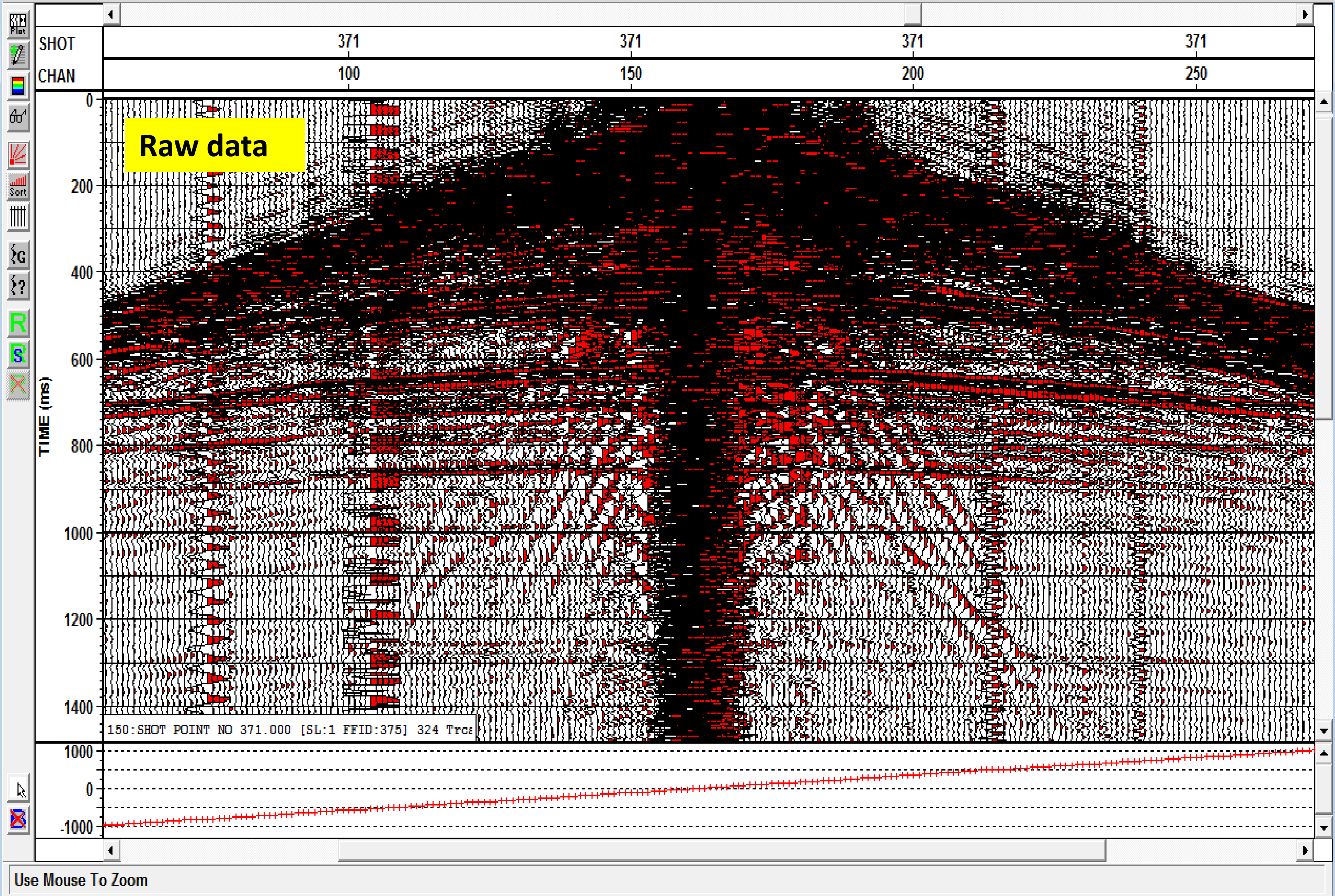
Algorithm of elastic PSTM FWI



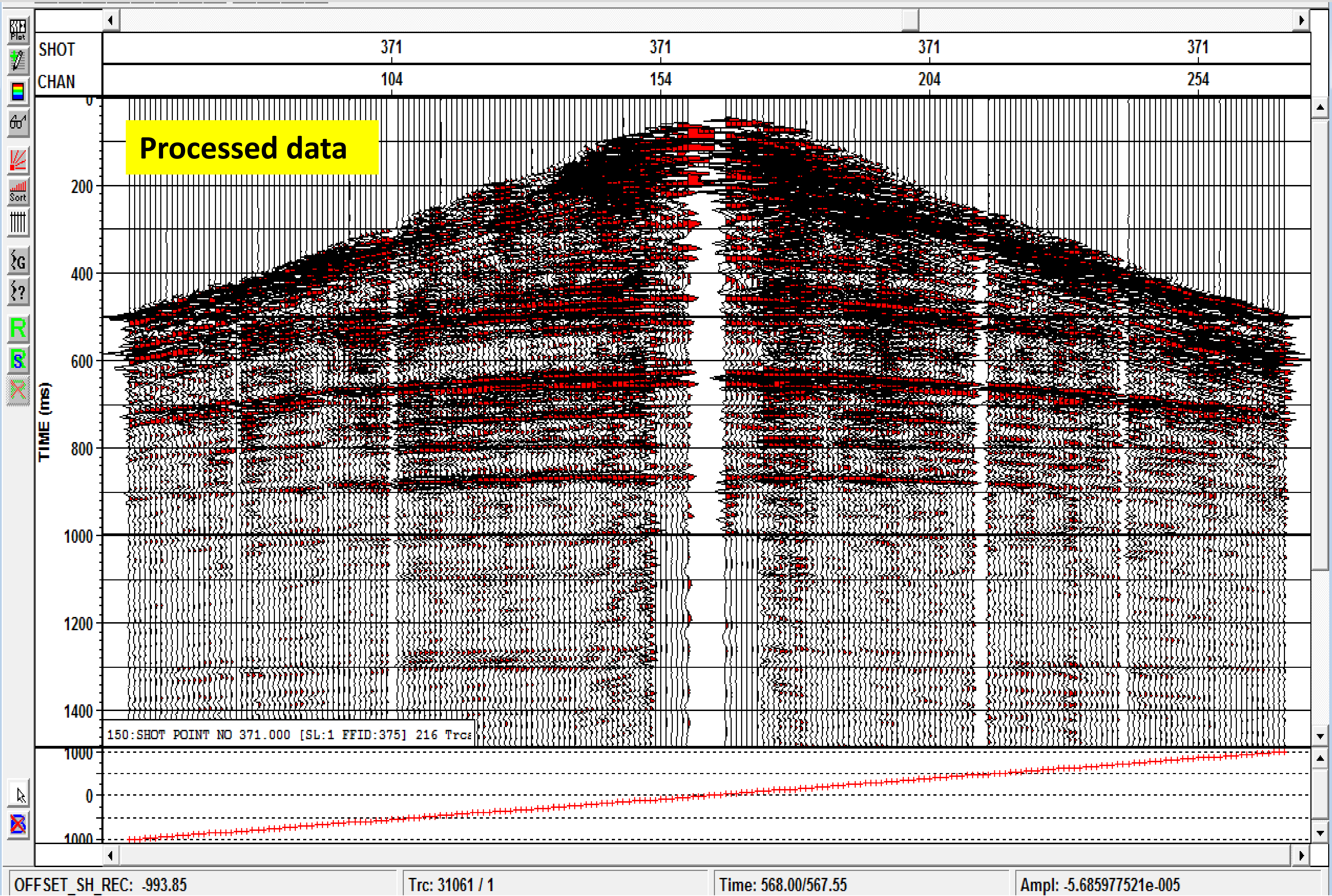
Inversion result synthetic data



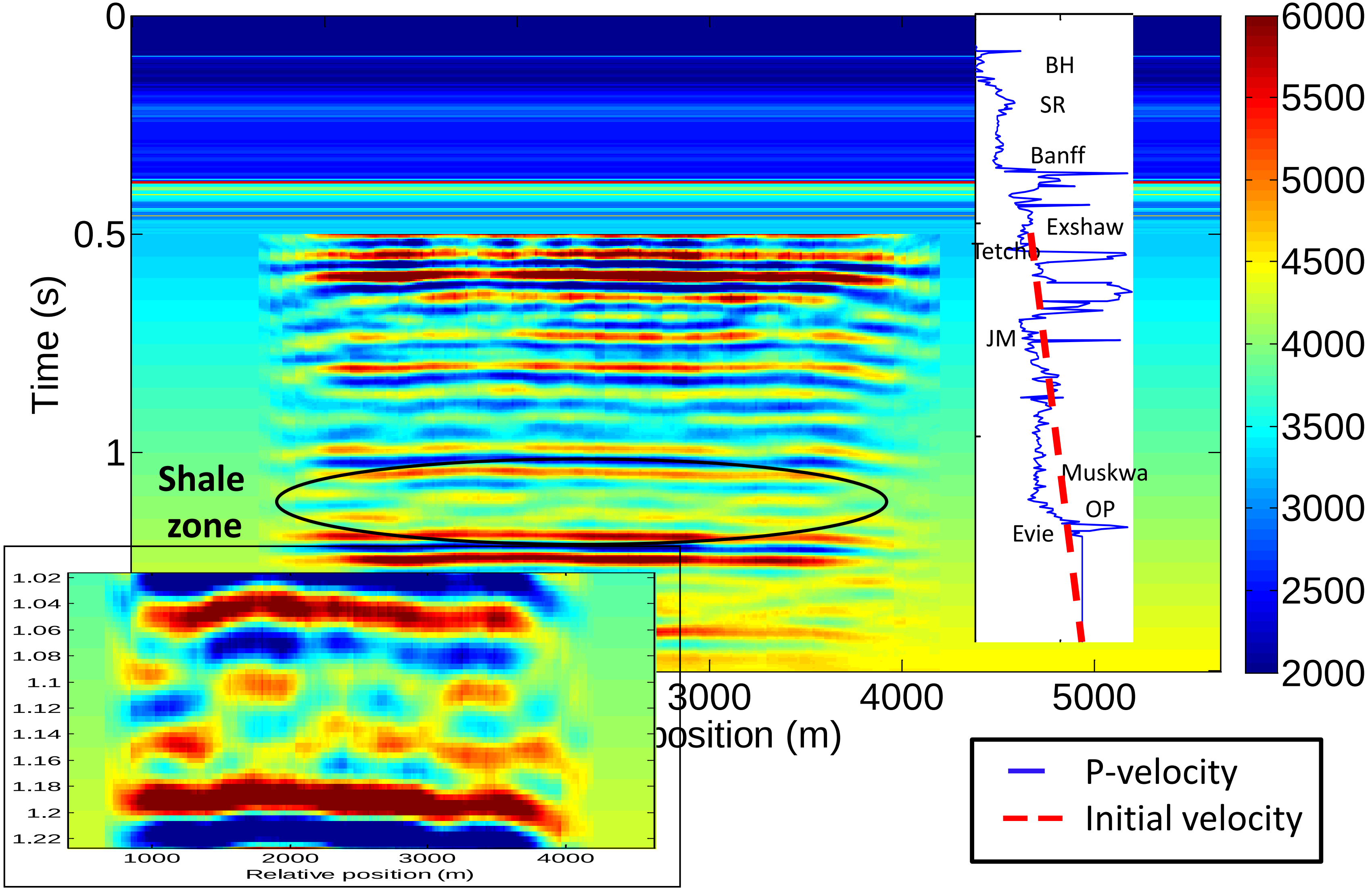
Real Data Example-NE BC



Real Data Example-NE BC



Preliminary P-P Velocity Inversion NE-BC



Remarks

- ✓ Another effective tool for reservoir characterization
- ✓ In conjunction with standard methods
- ✓ …or an alternative in future

Conclusions

- ✓ Algorithm designed for waveform inversion of P-P and P-S waves using PSTM
- ✓ Forward and adjoin Kirchhoff operator based on scatter point coordinate system
- ✓ No regsteration/ easy for interpretation
- ✓ Time migration/inversion is good approximation for mediums with smooth lateral variations
- ✓ Multiple free data
- ✓ Fast

Acknowledgments

- CREWES Faculty and Sponsors
- Nexen Inc.
- Neda Boroumand
- Peter Manning

THANK YOU !