Utilization of PSSP Waves

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CREWES

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NSERC CRSNG

PSSP Waves

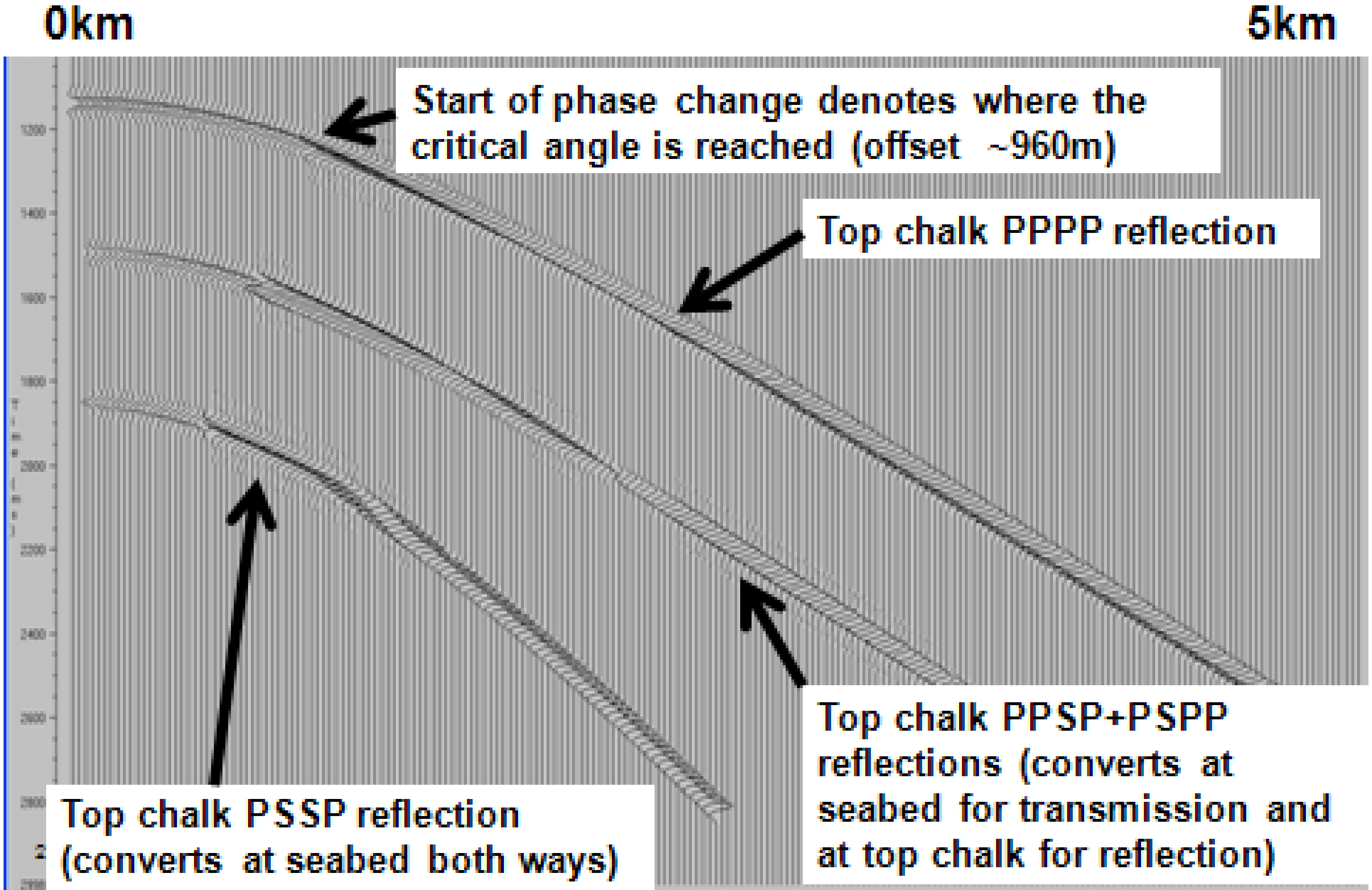
The PSSP arrivals on seismic sections can have strong amplitudes and large NMO .

Ian Jones (2014) showed the existence of PSSP on North Sea data. David Gray showed these on seismic data on reflections from the McMurray formation.

Can these arrivals be used to provide useful information in seismic inversions.

All top chalk events

Ian Jones, 2014, EAGE, Amsterdam



Modeling of PSSP Waves

P-SV finite-difference seismograms of P-SV modeling using method of Levander (1988 Geophysics)

Ray reflectivity modeling as described by Daley and Krebes (2015 CJEG).

P-SV Equations of Motion

Levander (1988)

- The equations of motion for displacement, u, in the x direction and displacement, w, in the z direction are:

$$\rho \frac{\partial u_t}{\partial t} = \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xz}}{\partial z}$$

$$\rho \frac{\partial w_t}{\partial t} = \frac{\partial \tau_{zx}}{\partial x} + \frac{\partial \tau_{zz}}{\partial z}$$

P-SV Equations of Motion
Levander (1988)

- Here ρ is the rock's density and the stress components $\underline{\tau}$ in the x and z directions are given in terms of the Lame' parameters (λ,μ) by:

$$\tau_{xx} = (\lambda + 2\mu)\frac{\partial u}{\partial x} + \lambda \frac{\partial w}{\partial z}$$

$$\tau_{zx} = \tau_{xz} = \mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)$$

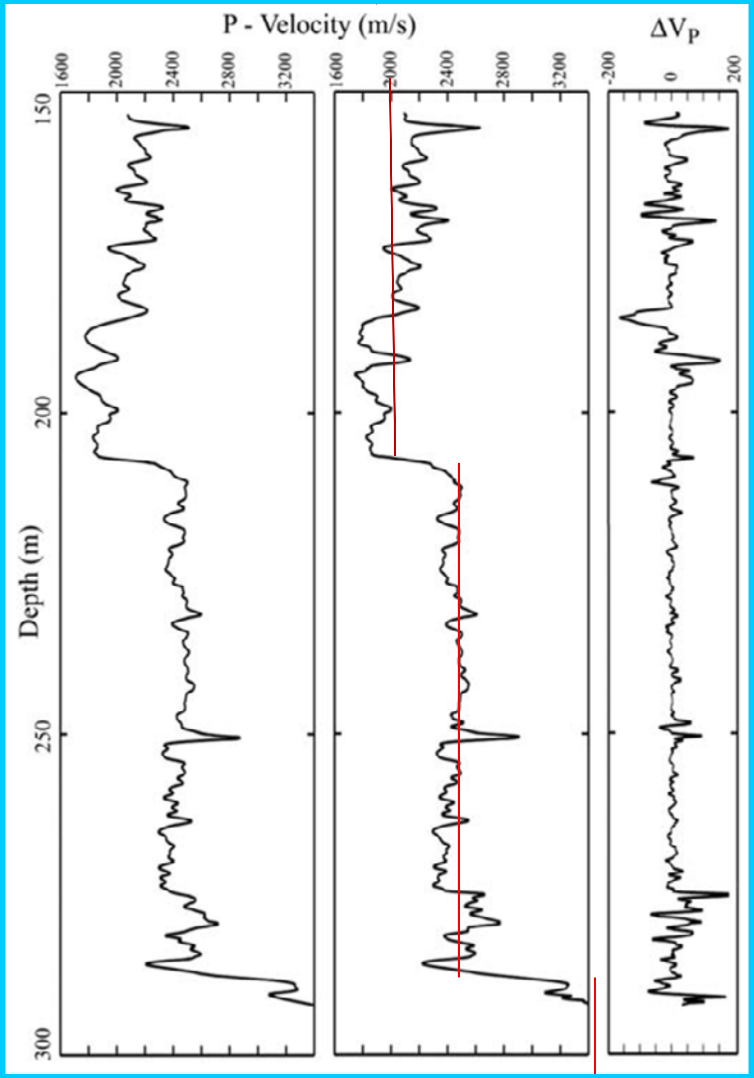
$$\tau_{zz} = (\lambda + 2\mu)\frac{\partial w}{\partial z} + \lambda \frac{\partial u}{\partial x}$$

Blocked P-wave Sonic Log

Layer 1 (above McMurray)
VP=2000 m/s

Layer 2 (McMurray) ,
Thickness = 70 m
VP=2400 m/s

Layer 3 (Devonian), VP=3500 m/s



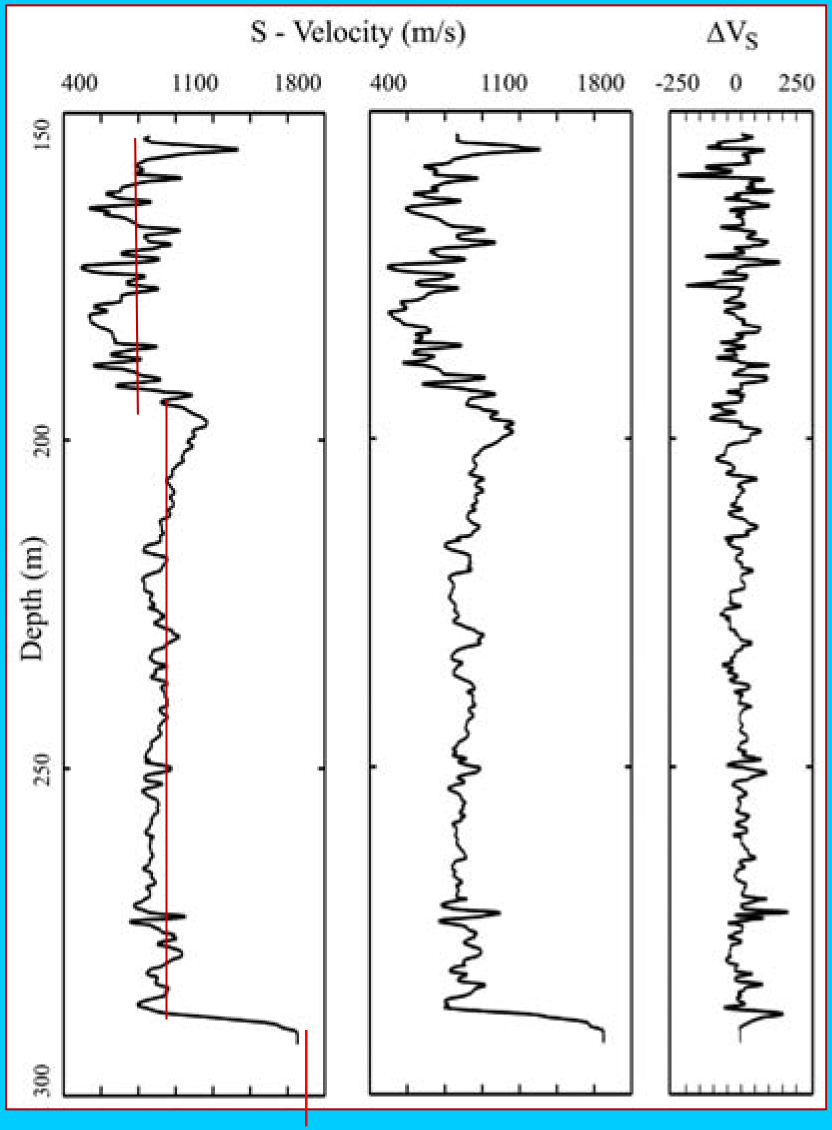
Blocked S-wave Sonic Log

Above McMurray VS=800 m/s

McMurray, VS=960 m/s

(thickness =70m)

Devonian, VS=1750 m/s



SAGD Model

Layer 1: 120m $\alpha = 2000 m/s$ $\beta = 800 m/s$ $\rho = 2.073 gm/cm^3$

120m

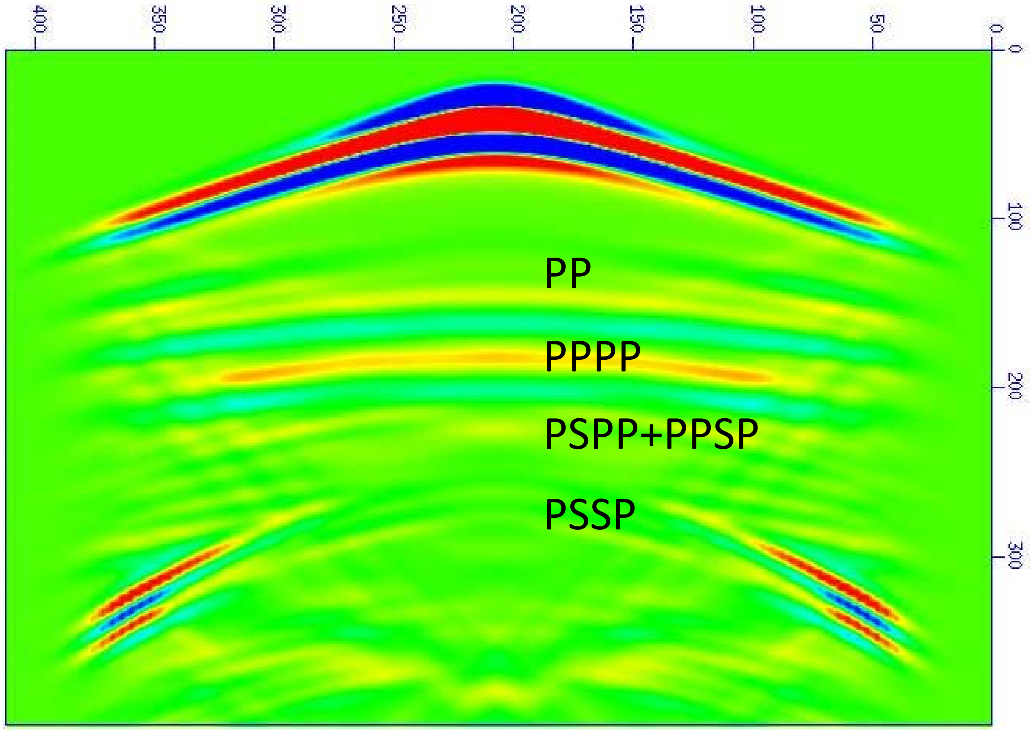
Layer 2: 70m $\alpha = 2400 m/s$ $\beta = 960 m/s$ $\rho = 2.170 gm/cm^3$

70m

Half Space: $\alpha = 3500 m/s$ $\beta = 1750 m/s$ $\rho = 2.384 gm/cm^3$

Finite-difference Synthetic Results – Initial Model
source at x=204m, z=10 m

receivers in every column, z=4m



traveltimes at x=0, surface source-receiver

PP:120 ms

PPPP: 178 ms

PSPP: 222 ms

PSSP: 269 ms

P-SV Ray-reflectivity method Daley and Krebes (2015)

$$u = \nabla \phi + \nabla \mathrm{X}\ (0, \psi, 0)$$

$$\nabla^2 \phi = \frac{1}{\alpha^2} \frac{\partial^2 \phi}{\partial t^2}$$

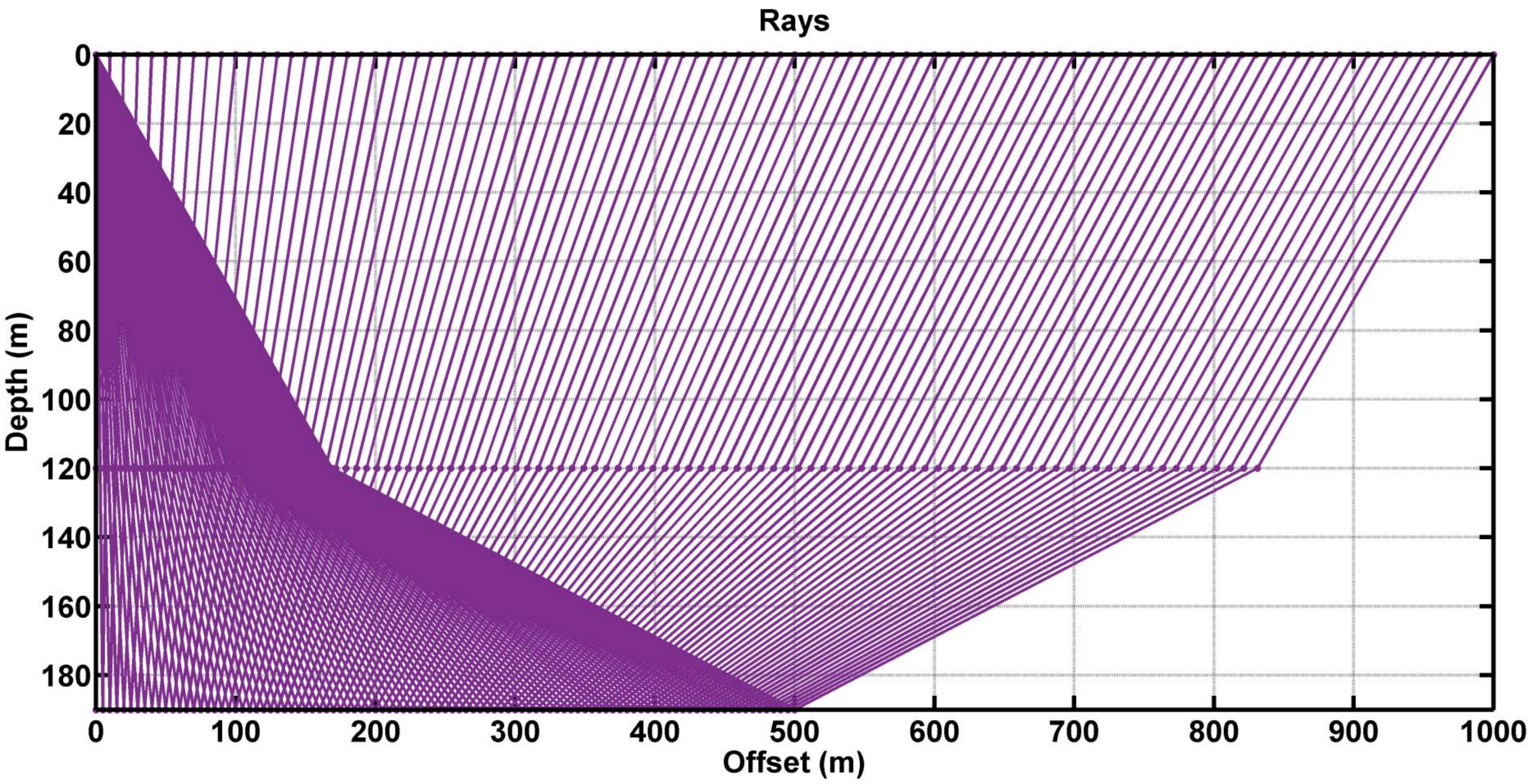
$$\nabla^2 \psi = \frac{1}{\beta^2} \frac{\partial^2 \psi}{\partial t^2}$$

Asymptotic Ray Theory

expansion – substitute into wave equation and solve for coefficients- produces eikonal equation governing traveltimes and equation for geometrical spreading effect on amplitudes.

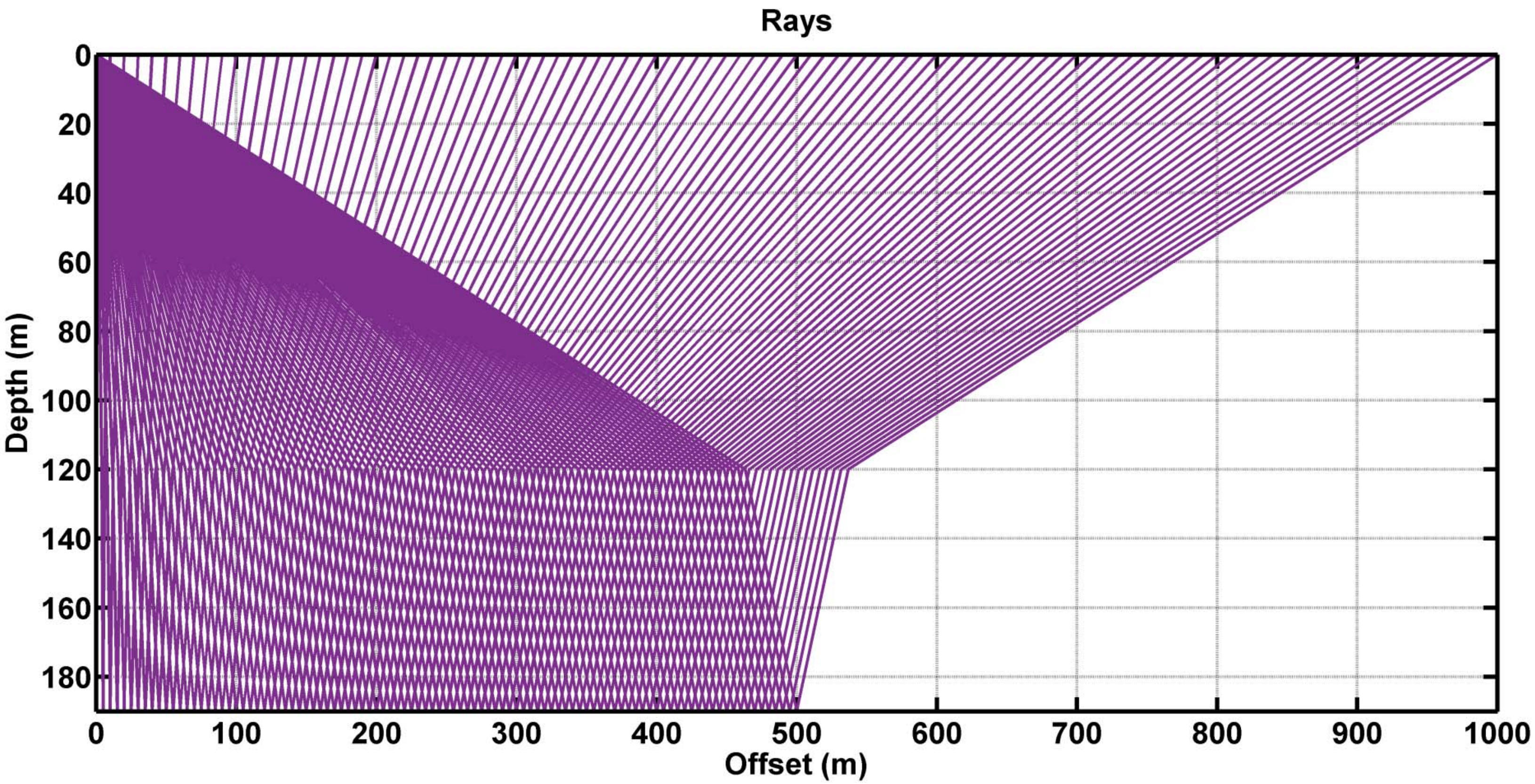
$$\phi(x,t) = \sum_{n=0}^{\infty} A_n(x) \frac{e^{i\omega(t-\tau)}}{(i\omega)^n}$$

PPPP rays



Rays
Depth (m)
Offset (m)
0
20
40
60
80
100
120
140
160
180
0
100
200
300
400
500
600
700
800
900
1000

PSSP rays


Rays
Depth (m)
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20
40
60
80
100
120
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100
200
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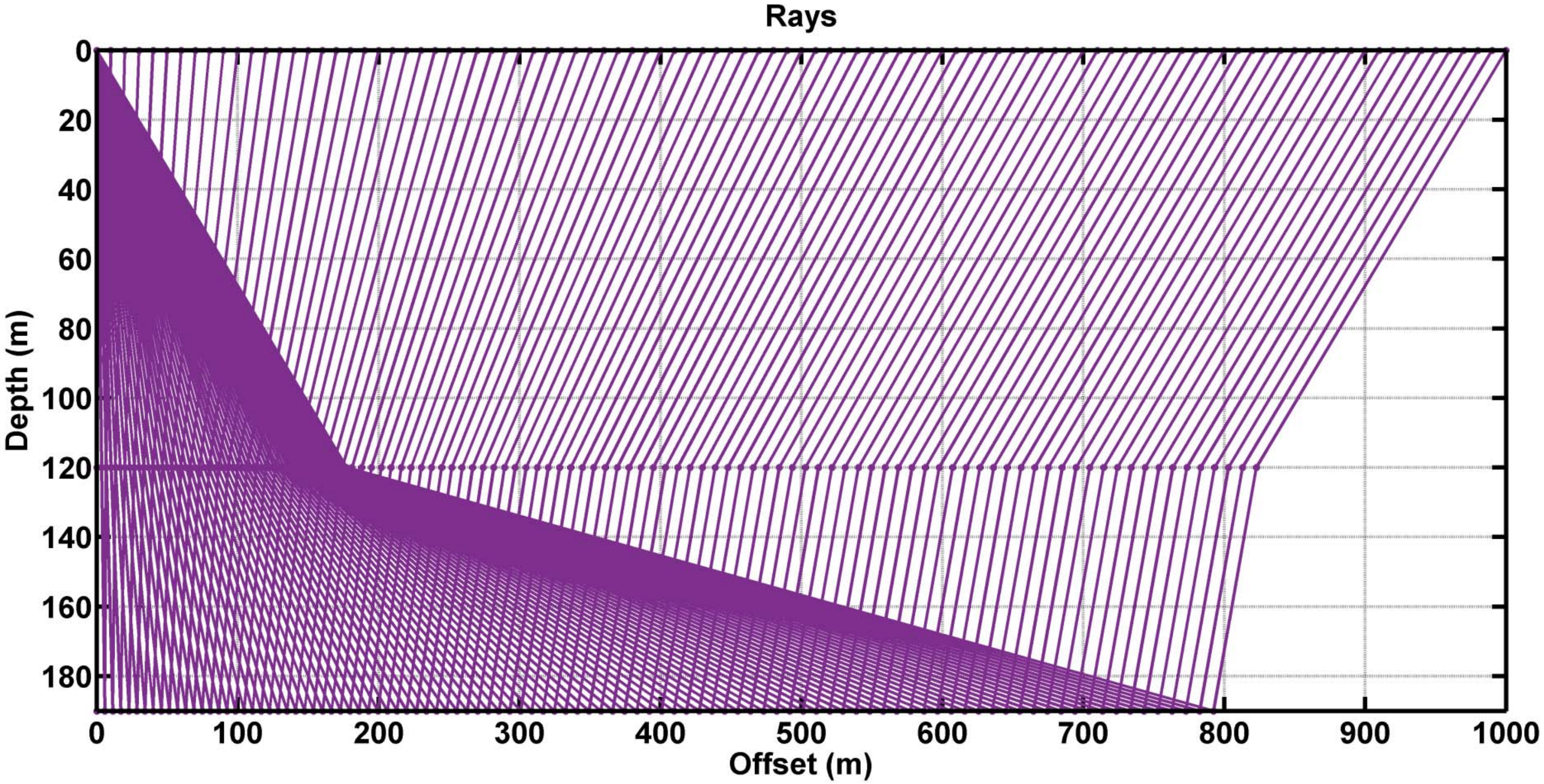
700
800
900
1000
Offset (m)

PPSP rays


Rays
Depth (m)
Offset (m)
0
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120
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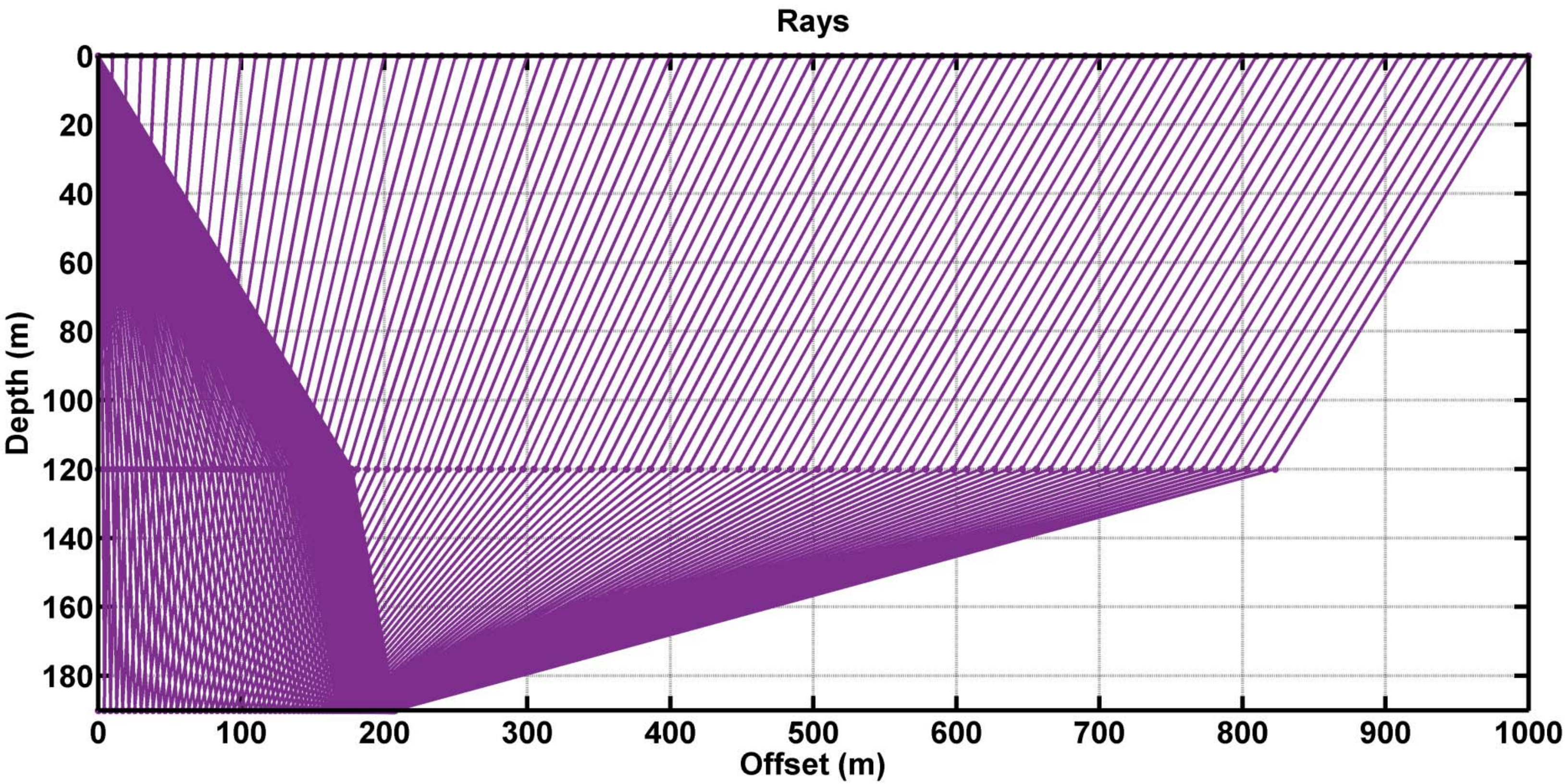
PSPP rays


Rays
Depth (m)
Offset (m)
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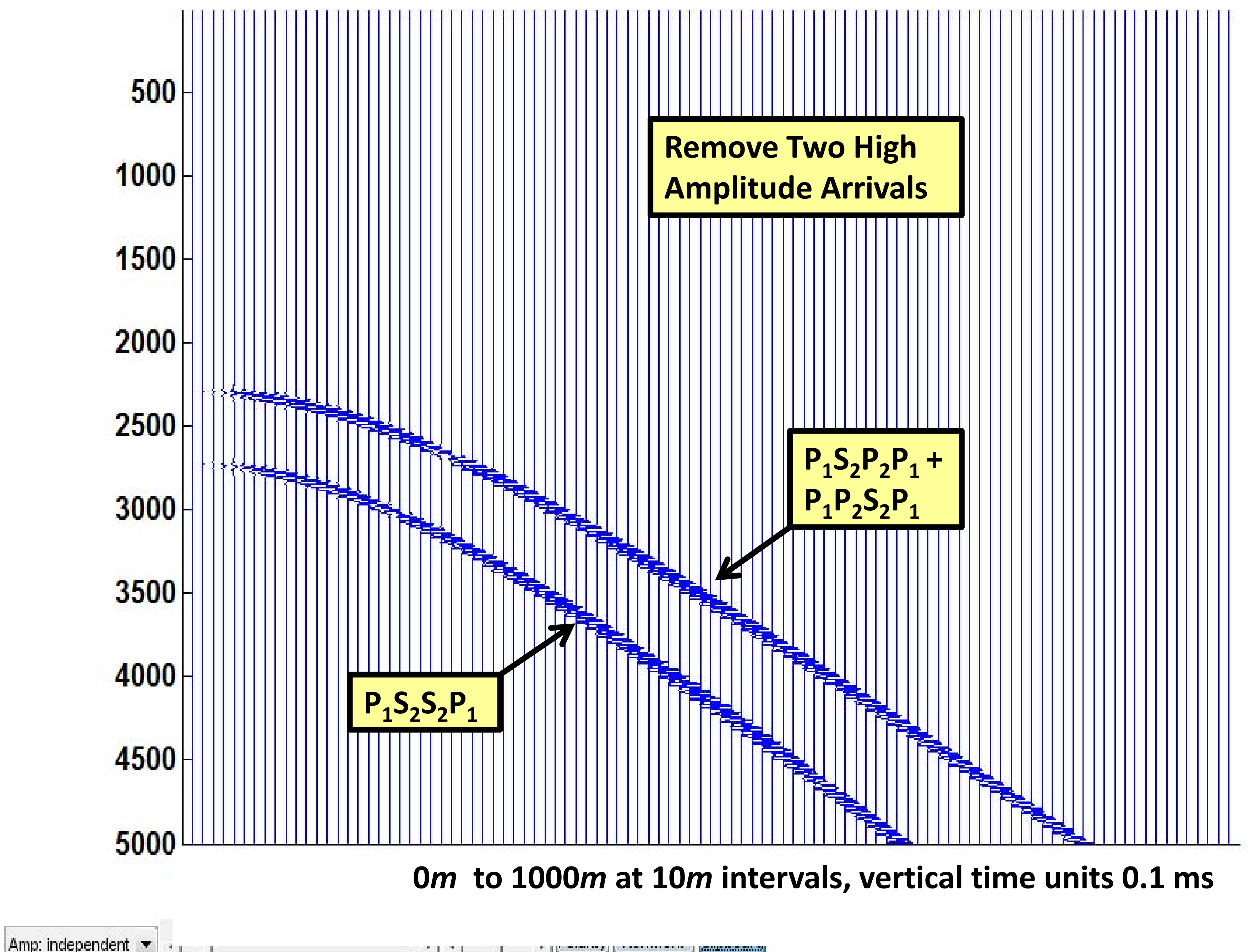
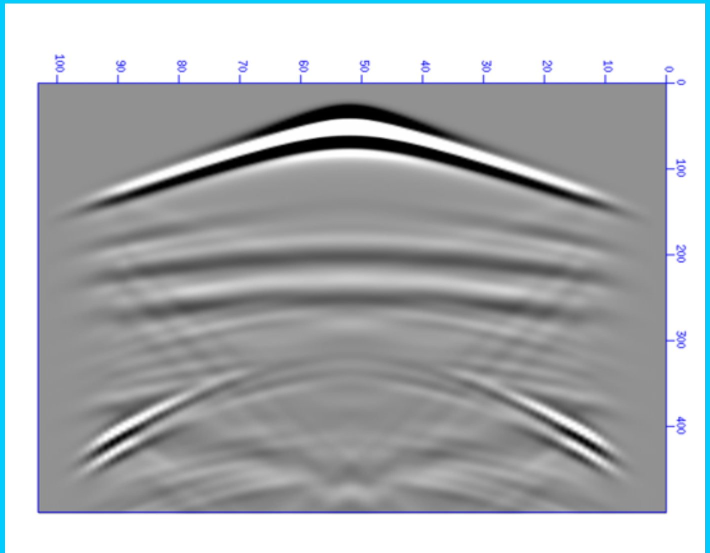
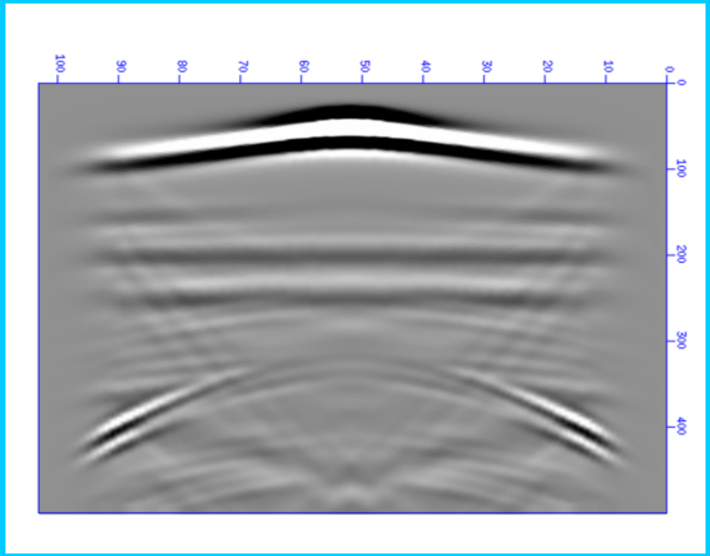


0*m* to 1000*m* at 10*m* intervals, vertical time units 0.1 ms





NMO corrections will align P-wave reflections and leave considerable NMO in converted waves. We can stack out the PSSP and PPSP+PSPP arrivals by using NMO from P-wave velocities, but is there a way to enhance information by using PSSP as signal?
Will full waveform inversion allow us to use PSSP information to enhance our inversion?

Model-based Inversion

- Recall the least squares solution for noiseless case

$$A\Delta x = b = y - f^0$$

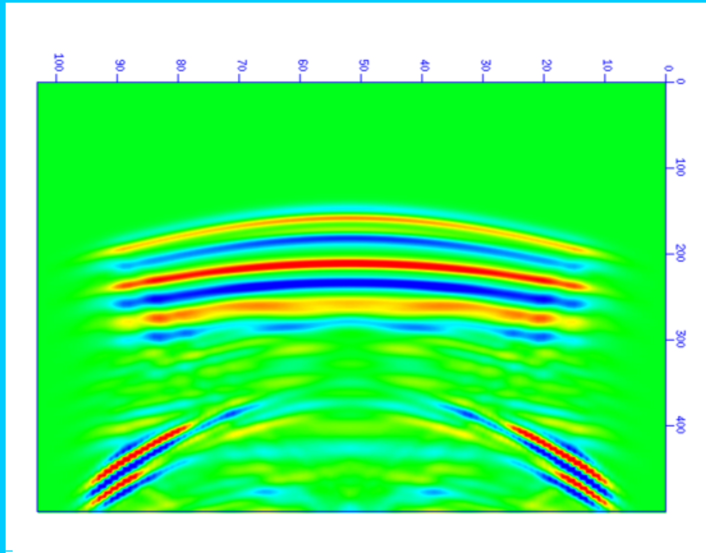
$$A^T A\Delta x = A^T b$$

- Compare to the noisy case where b is replaced by b+n.

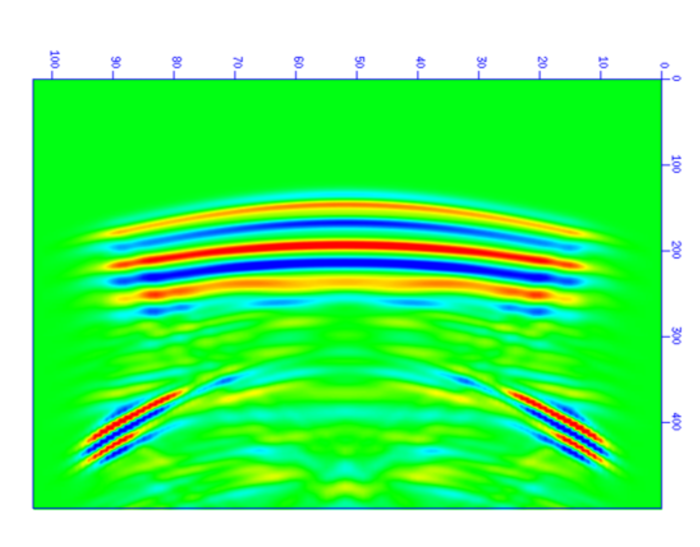
$e^T e$

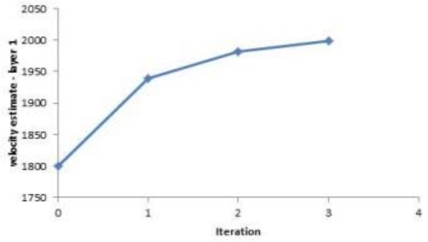
$$A^T A\Delta x = A^T b + A^T n$$

Initial model



Inversion = Actual





FWI, convergence achieved in 3 iterations for starting guess that is too low by 10%

FD wave equation modeling and ray tracing

- Ray tracing allows us to identify arrivals on FD wave equation seismograms.
- Amplitudes for ART are qualitatively similar to FD wave equation amplitudes.
- Ray tracing is cheaper but is a high frequency approximation.

Conclusions: Utilizing Converted Waves

- Get close: Use conventional processing to get close. Stack out PSSP, PPSP and PSPP arrivals. Get best P-wave velocity from this step.
- Get closer: Use FWI to estimate P and S-wave velocities to fit all signal – assuming that initial guess is "in the ballpark".

Acknowledgements

- Thanks to CREWES and NSERC.
- Thanks to David Gray for pointing out the significance of converted wave arrivals on seismic data from North Sea and Athabasca oil sands.

References

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