Geophysical Inversion – Provehito in Altum! (Probe the Depths)

Larry Lines

Department of Geology and Geophysics

University of Calgary

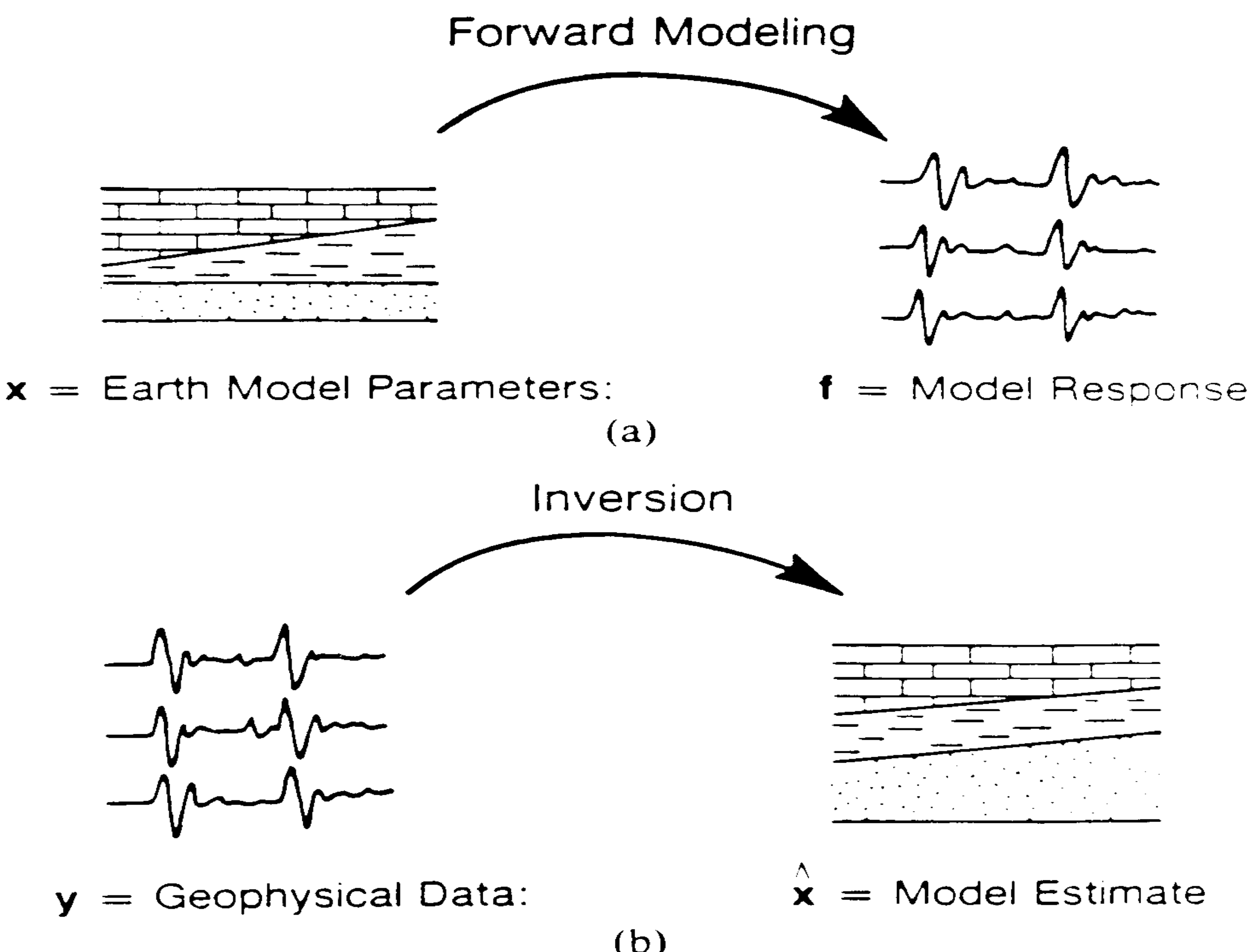
Photo by courtesy of Deborah Spratt

Inversion Topics in This Talk

- Imaging Rock Boundaries
- Imaging Using Rays (Kirchhoff Migration)
- Imaging FD Wave Equation Calculations (Reverse-Time Migration)
- Estimating Anisotropic Velocity Models and Images
- AVO – Inversion for Rock Properties
- Conclusions

Inversion: From Waves to Rocks

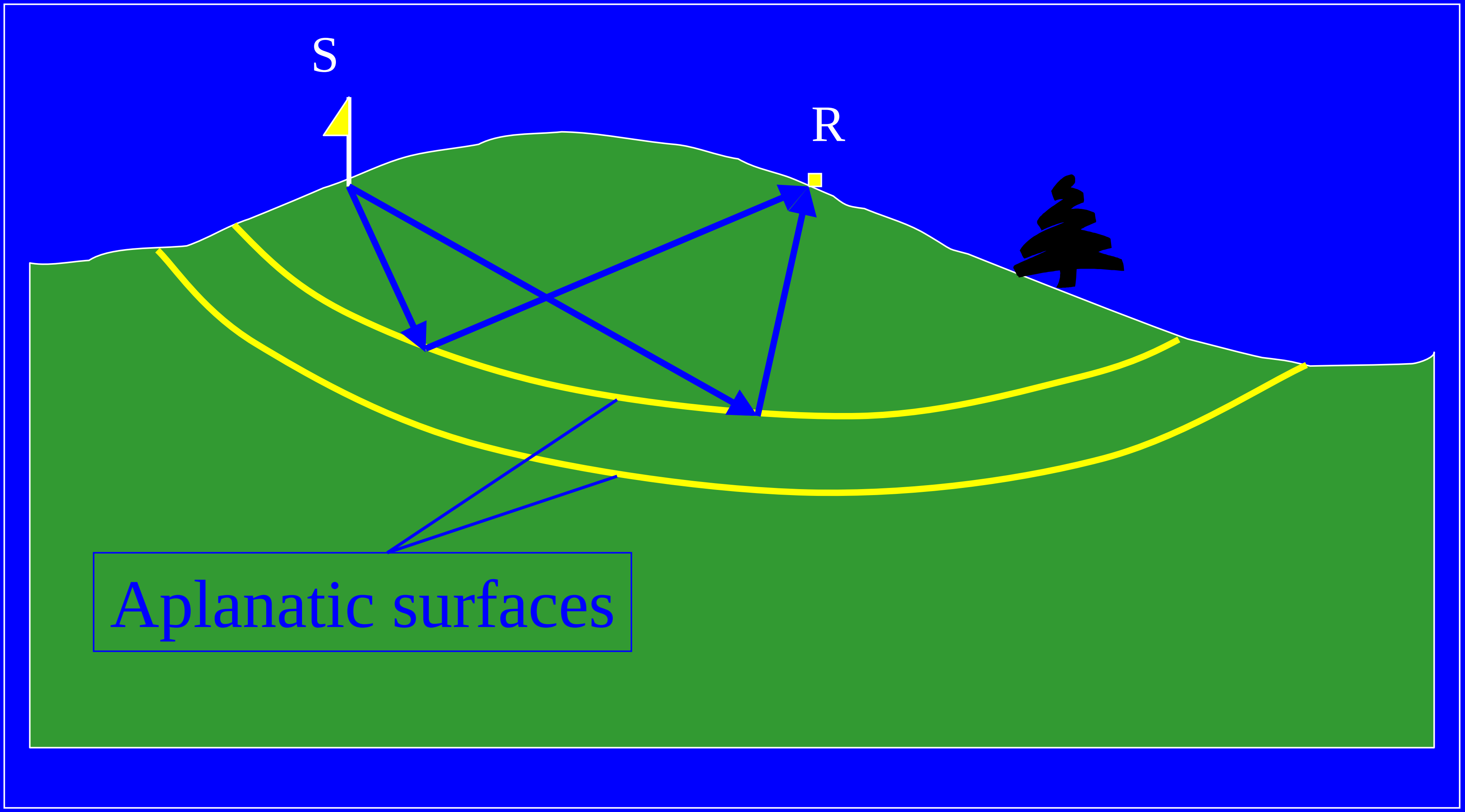
Inversion is the process of finding an earth model whose response matches available data.



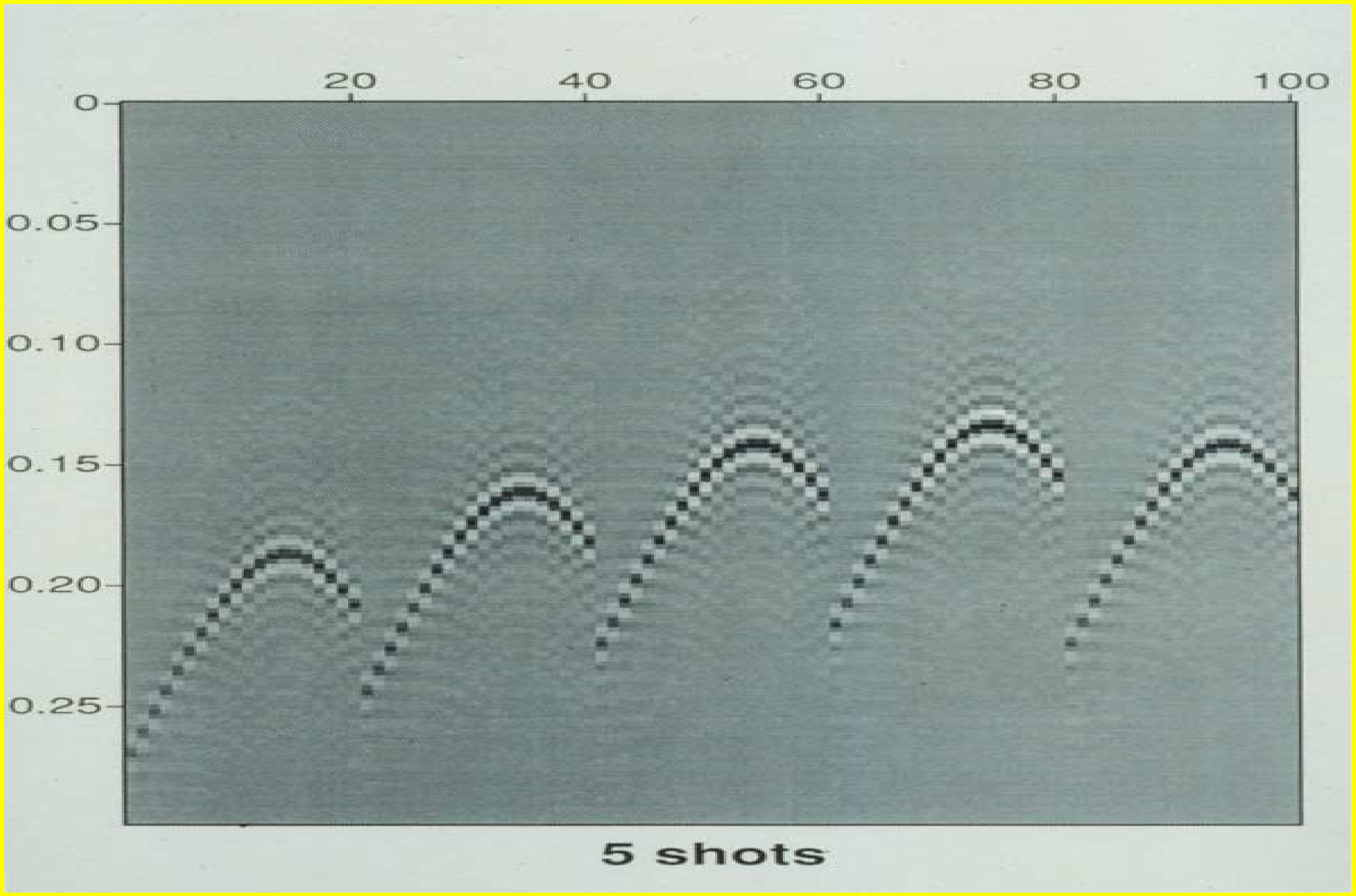
Benefits of Migration

- focuses events
- steepens dipping events, moves energy updip
- broadens synforms, collapses antiforms
- reduces size of Fresnel zone
- suppresses random noise
- overall effect is section that may be interpreted with significantly more confidence than stacked section

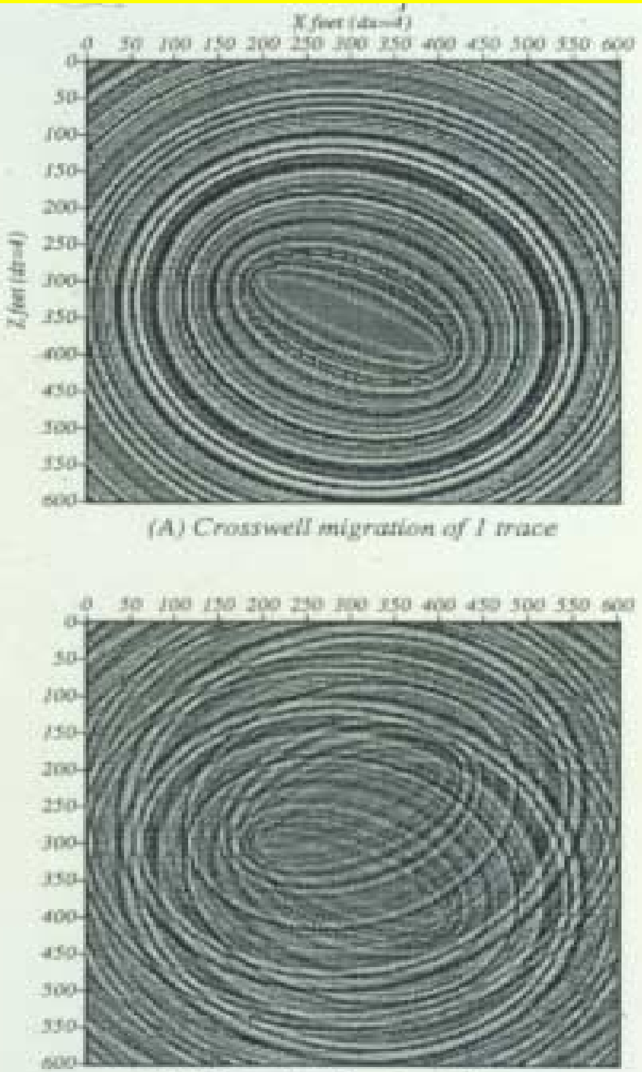
Prestack depth migration



Shot Gathers – Point Diffractor



Impulse Response – 2 traces

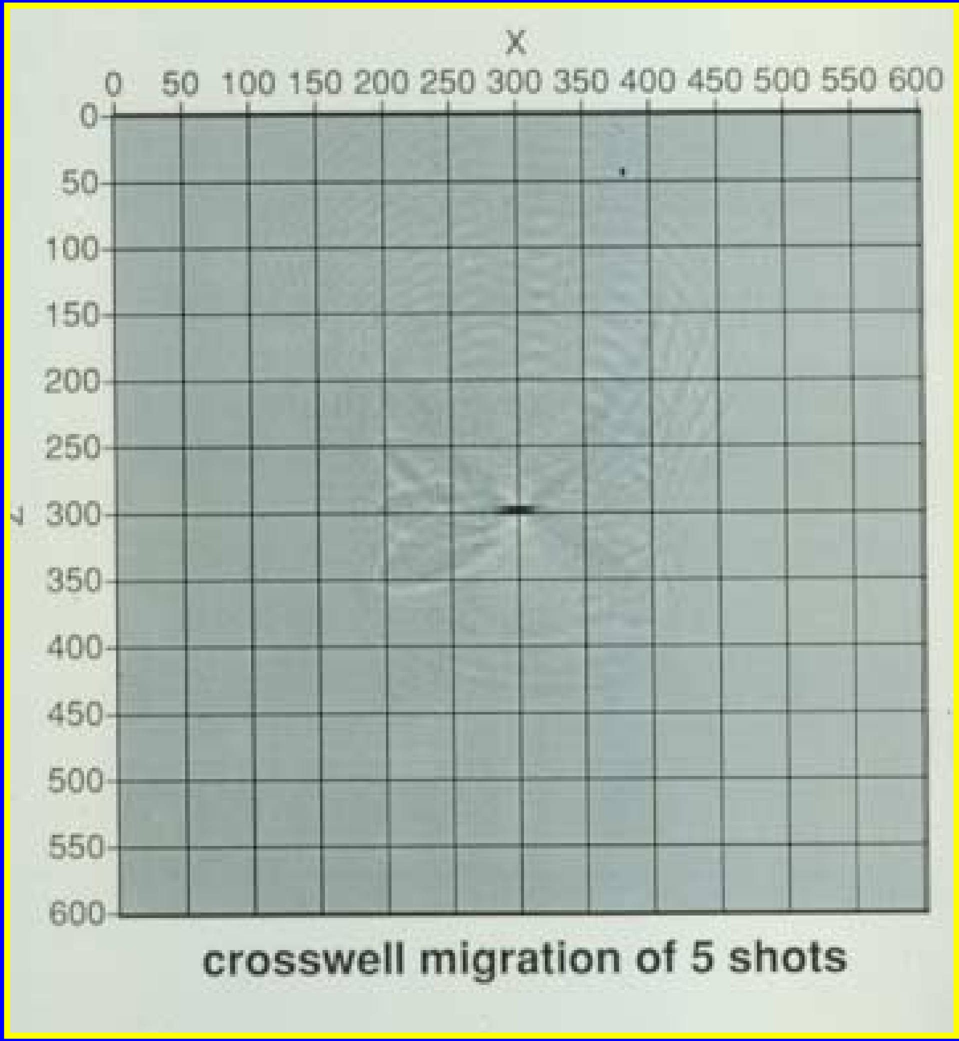


(A) Crosswell migration of 1 trace

(B) Crosswell migration of 2 traces

Figure 2. Impluse response(s) of crosswell migration
Source well is at x=200 and receiver well at x=400.

Image – Impulse Response Sums



Kirchhoff Depth Migration

- traveltimes to define diffraction obtained through:
  - raytracing - rays modelled to propagate through velocity model, bend according to Snell's Law, interpolate to grid
  - direct solution of eikonal equation onto a regular grid

$$\left(\frac{\partial \tau}{\partial x}\right)^2 + \left(\frac{\partial \tau}{\partial z}\right)^2 = \frac{1}{c^2}$$

Tectono-stratigraphic interpretation Line B

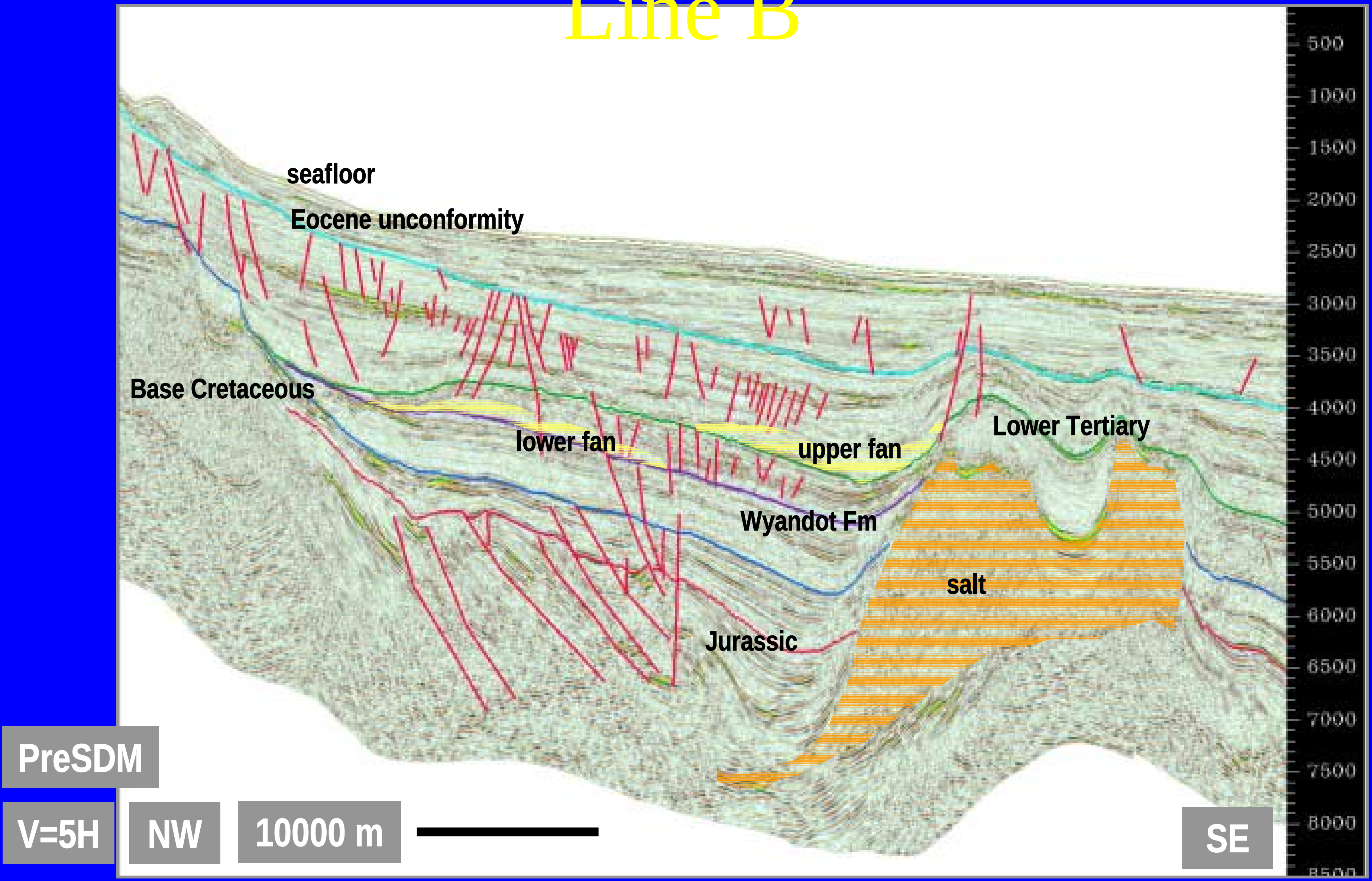
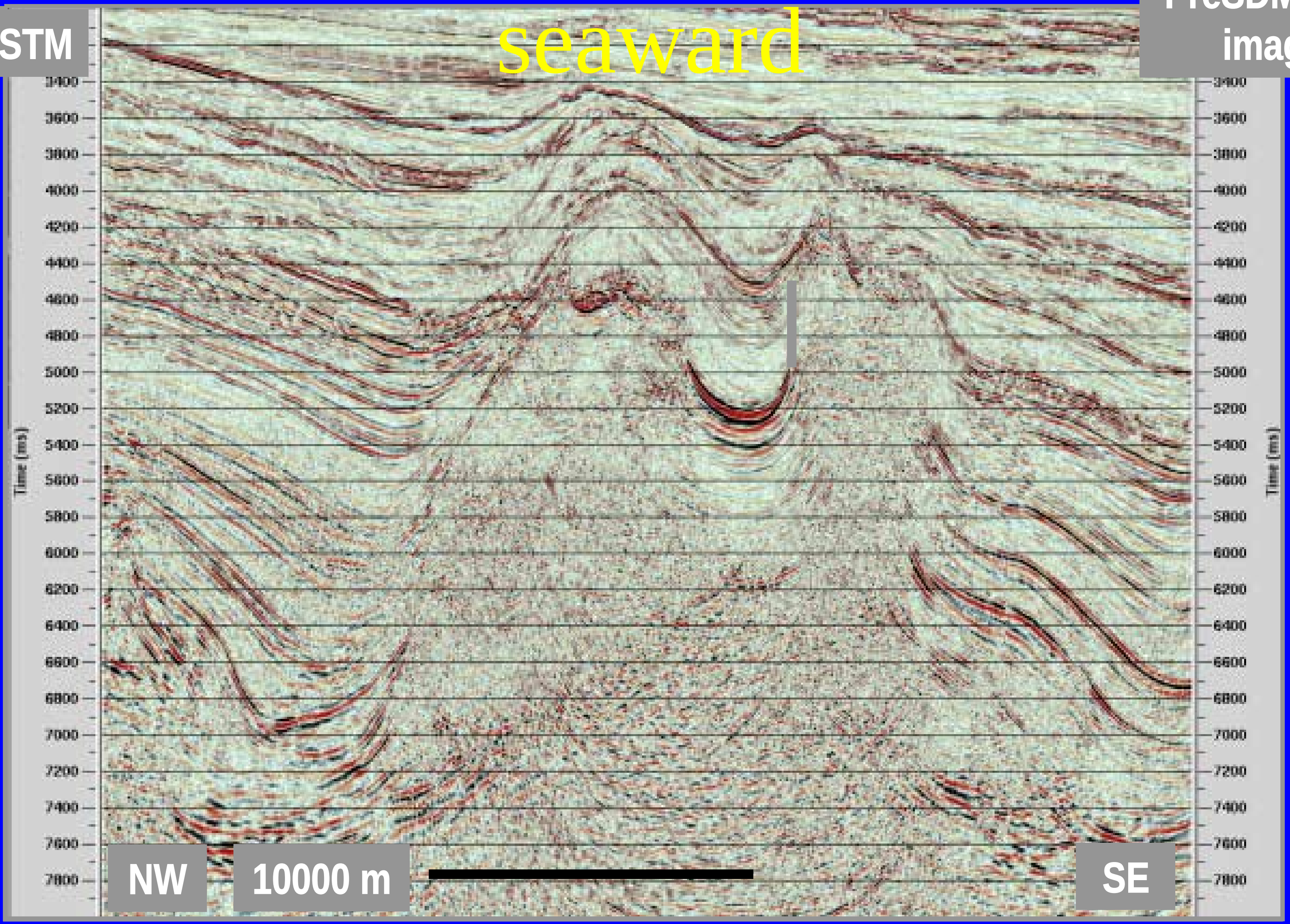


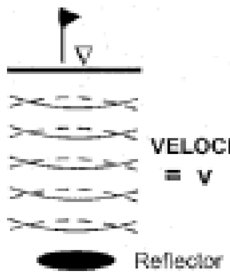
Image Comparison - Line B - seaward



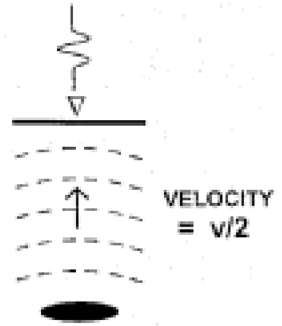
FD Calculations for Reverse-time Depth Migration

- Divide the subsurface into velocity cells.
- Time-reverse seismic trace values to supply time-varying surface boundary conditions.
- Choose cell size, h, fine enough to avoid grid dispersion.
- Choose time sampling and cell size to avoid instability.
- Backward propagate wavefield using FD wave equation calculations.

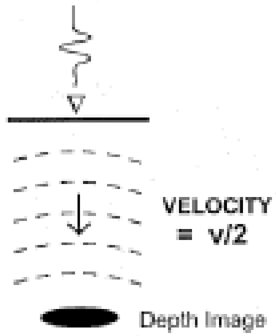
Seismic Experiment



Exploding Reflector Model



Reverse-Time Migration



Finite-differencing of the wave equation

$$\nabla^2 u = \frac{1}{v^2}\frac{\partial^2 u}{\partial t^2}$$

FD Evaluation of Derivatives

- Second derivatives are evaluated by finite-differences.

$$\frac{\partial^2 u}{\partial x^2} = \frac{1}{h^2}\left[u(x_0 + h) + u(x_0 - h) - 2u(x_0)\right]$$

Stability Condition

- Choose

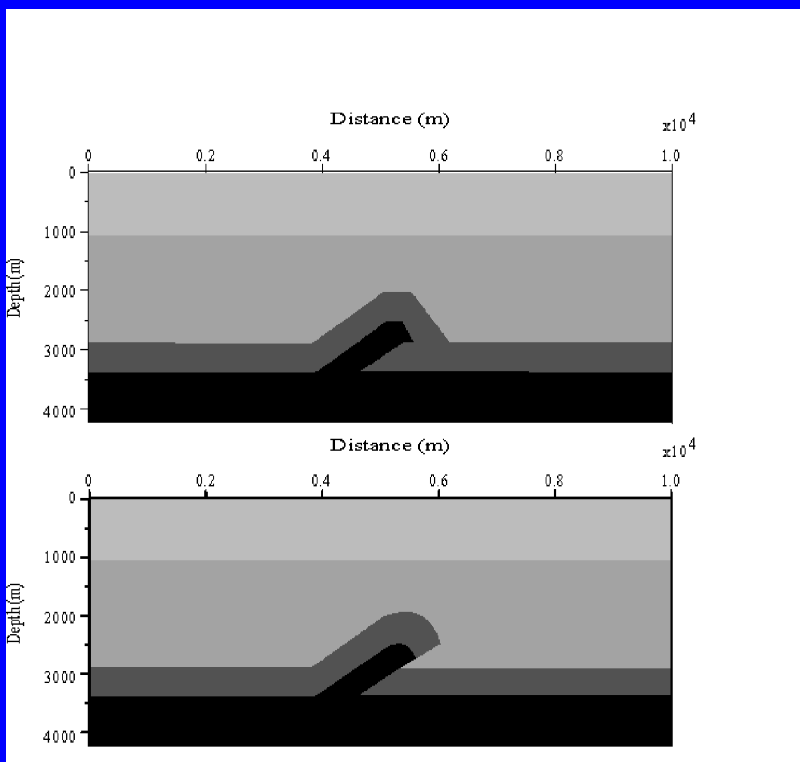
$$\frac{v \Delta t}{h} \leq \sqrt{\frac{a_1}{a_2}}$$

- Where a_1= sum of absolute values of FD weights of second derivative in time
- And where a_2=sum of absolute values of FD weights of second derivatives in space

Characteristics of Reverse-time Migration

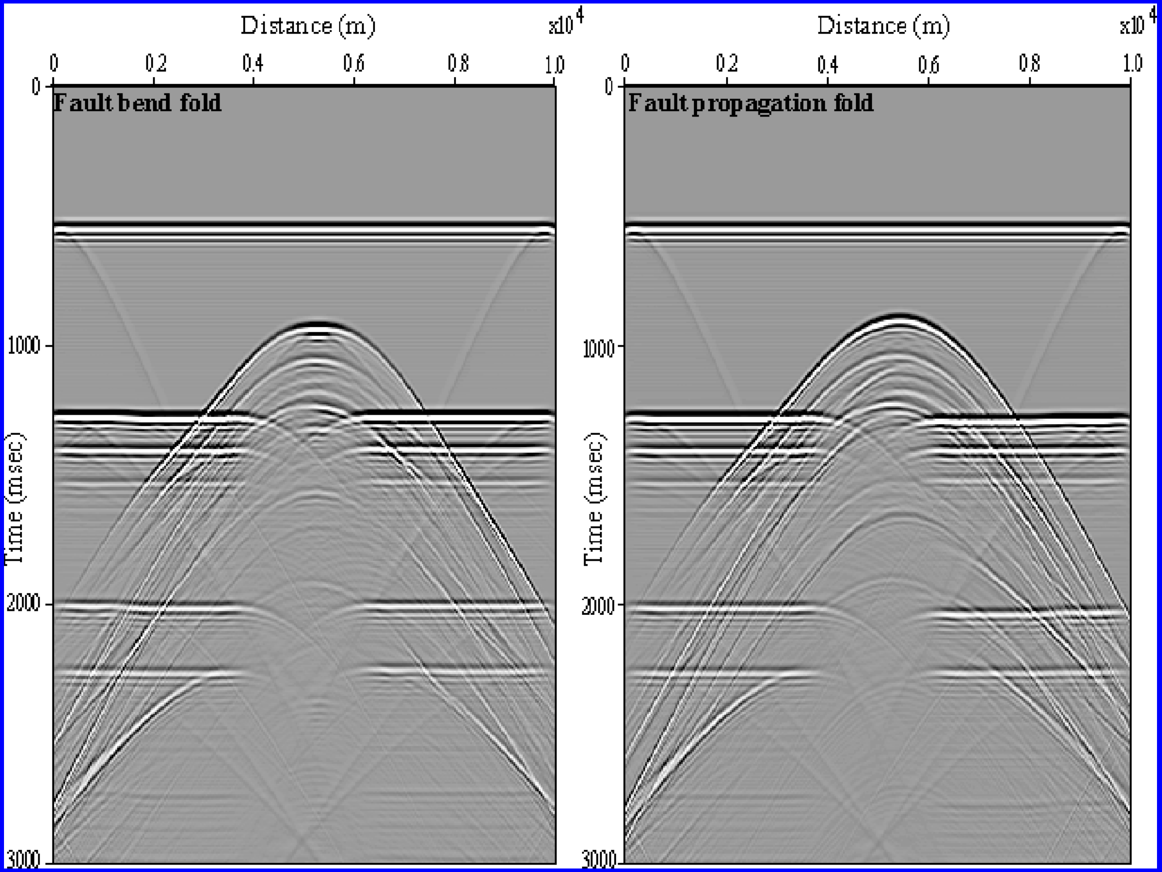
- General
- Accurate
- Relatively easy to code
- Computational Cost O(Nx*Ny*Nz*Nt)
- Expensive

Thrust Fault Models

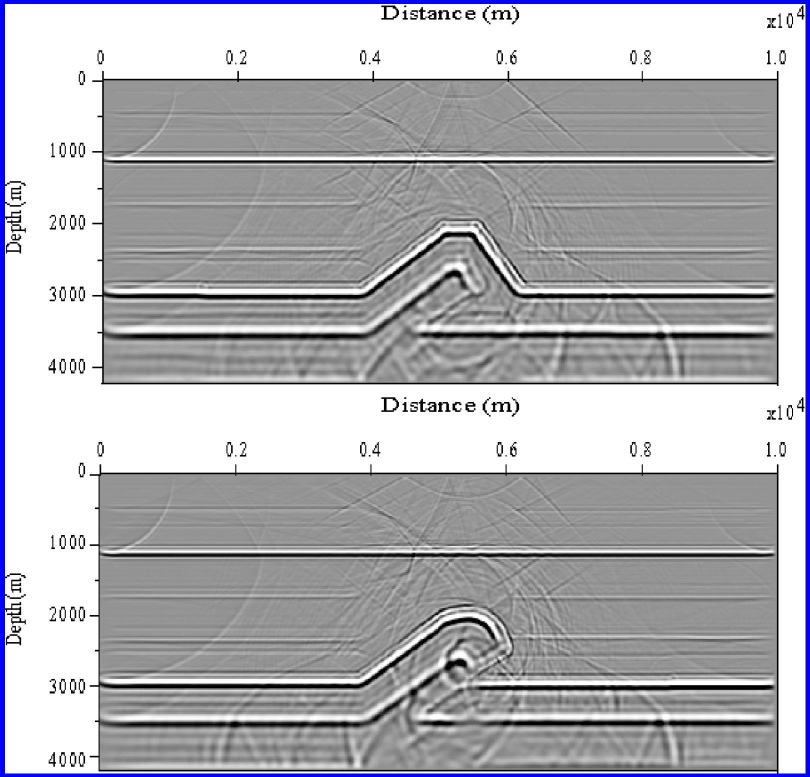


- Fault Bend Fold
- Fault Propagation Fold

Unmigrated seismic data



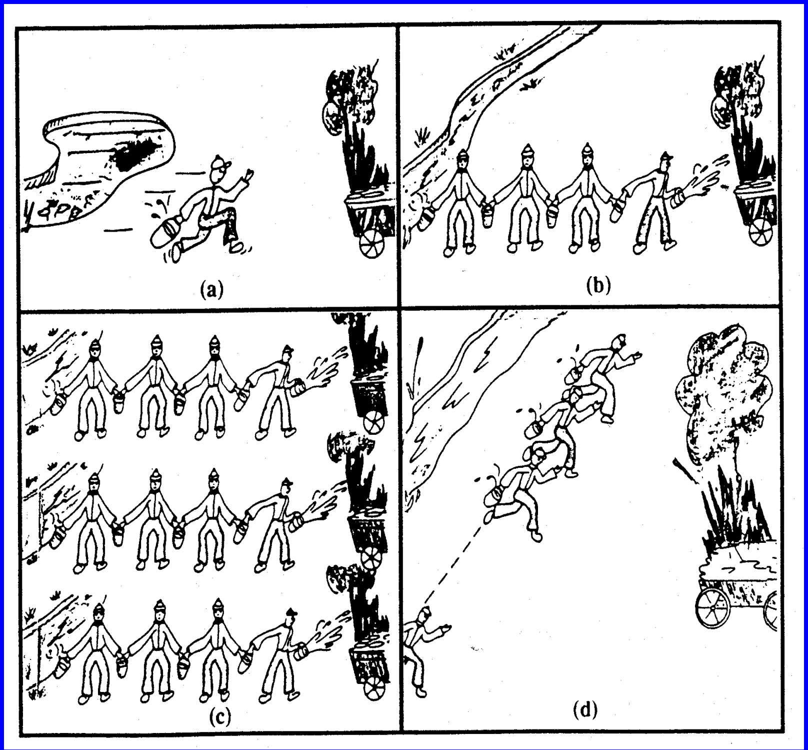
Depth Migrated Data



- Migration (FBF)
- Migration (FPF)

Parallel Processing

- Comparison of Scalar,Vector, Parallel-Vector and Parallel Processing



SEG/EAGE Salt Model

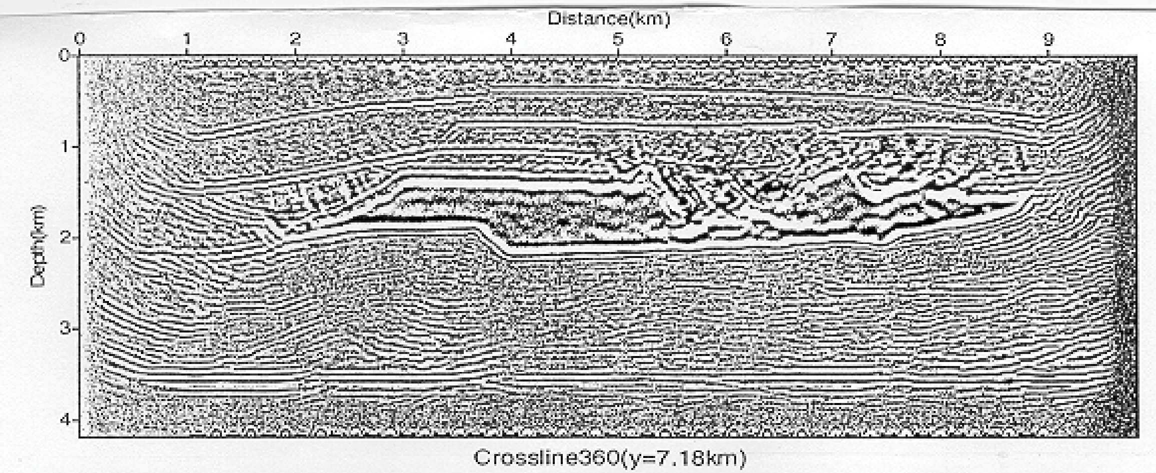


Figure 3. 3-D reverse-time migration image of SEG/EAGE salt data at crossline360, y=7.18km.

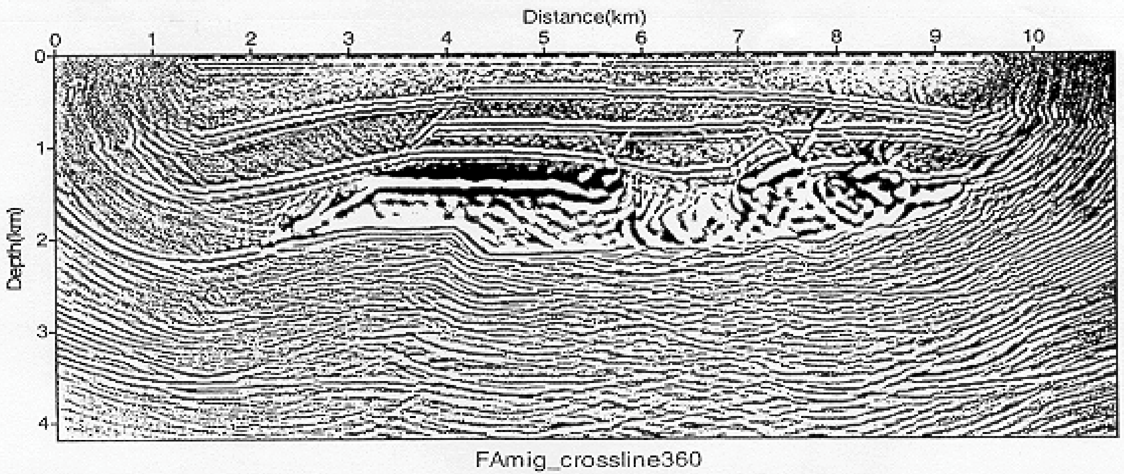
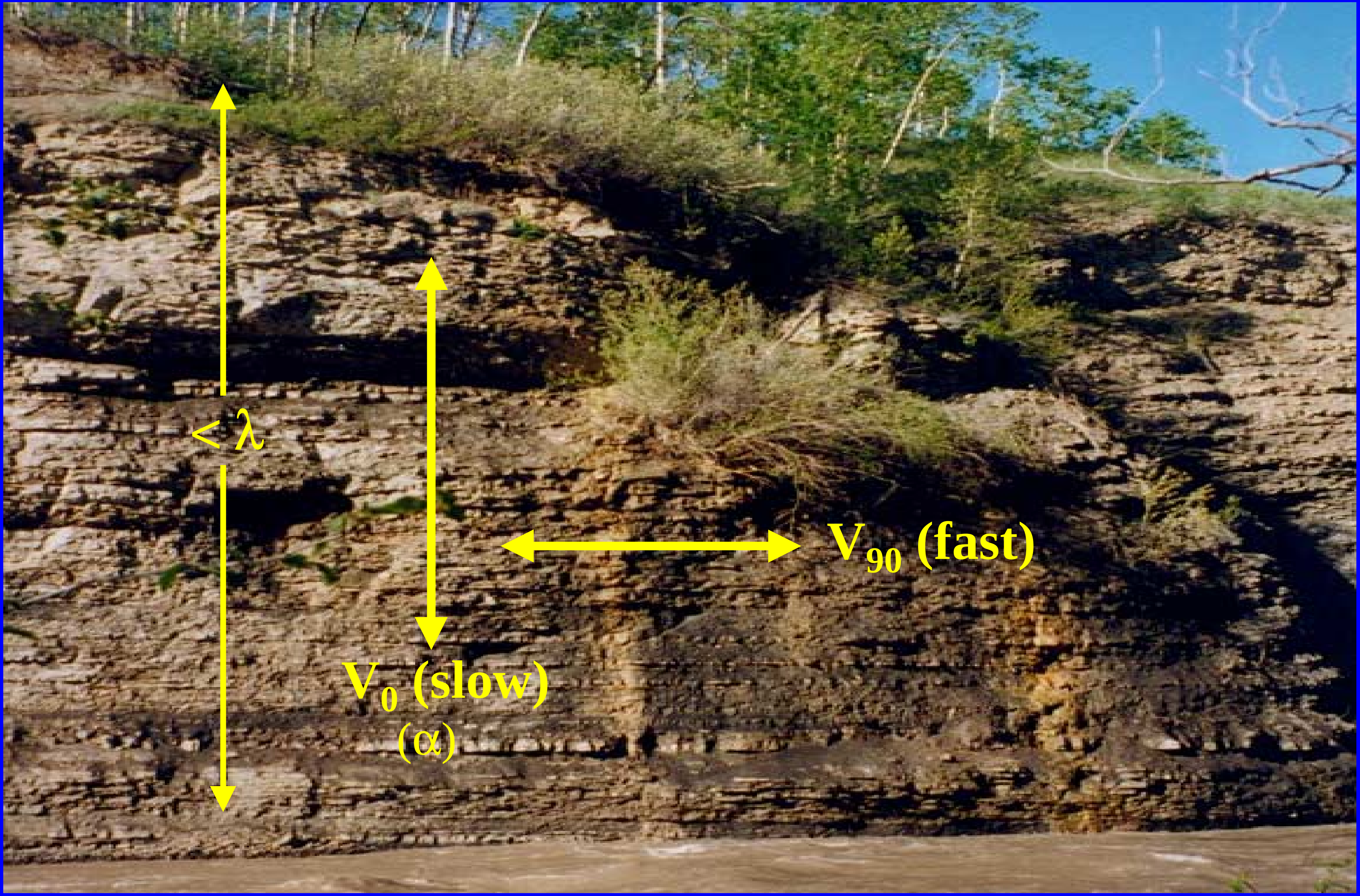
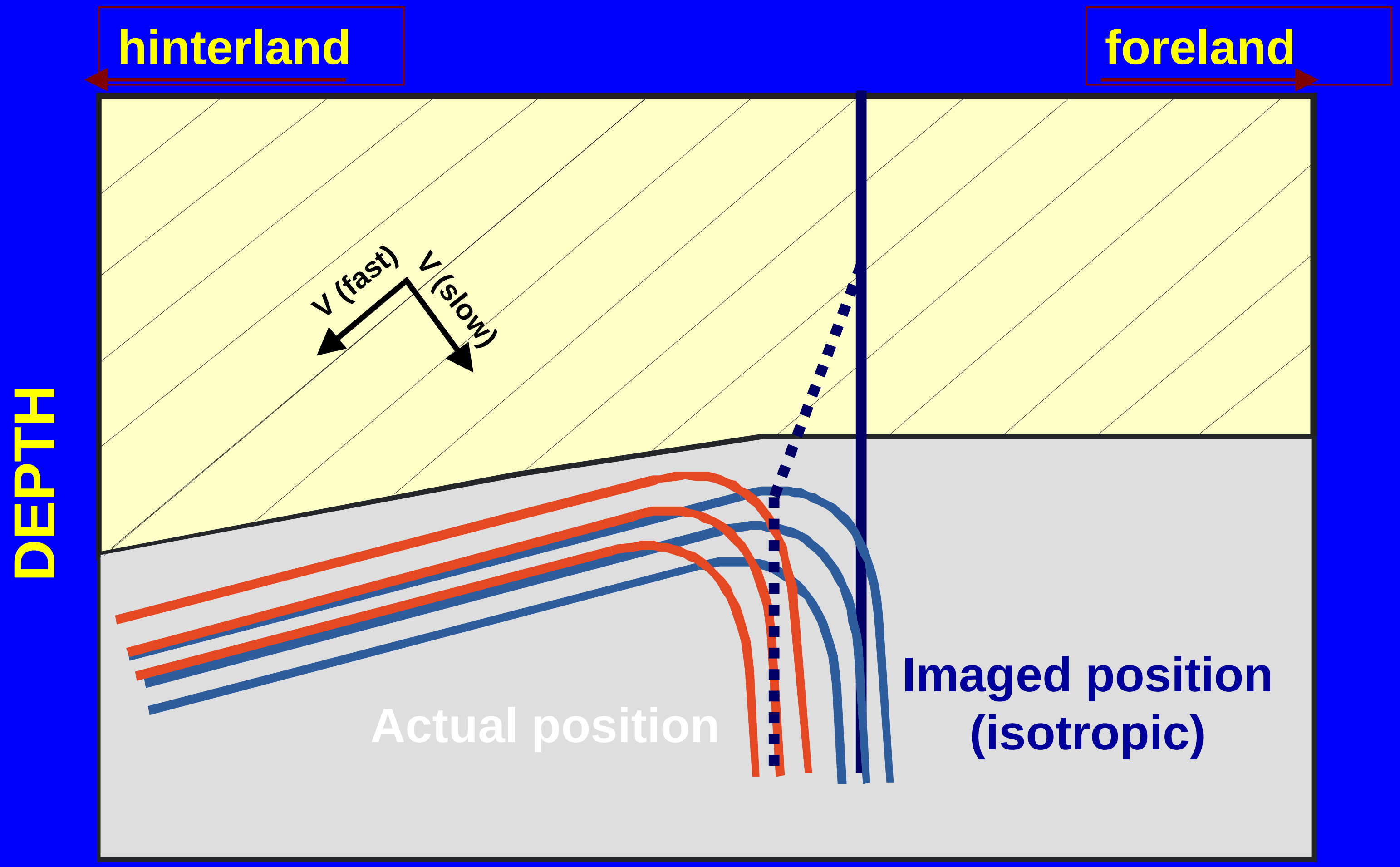


Figure 4. 3-D first arrival Kirchhoff migration image of SEG/EAGE salt data at crossline360, y=7.18km.

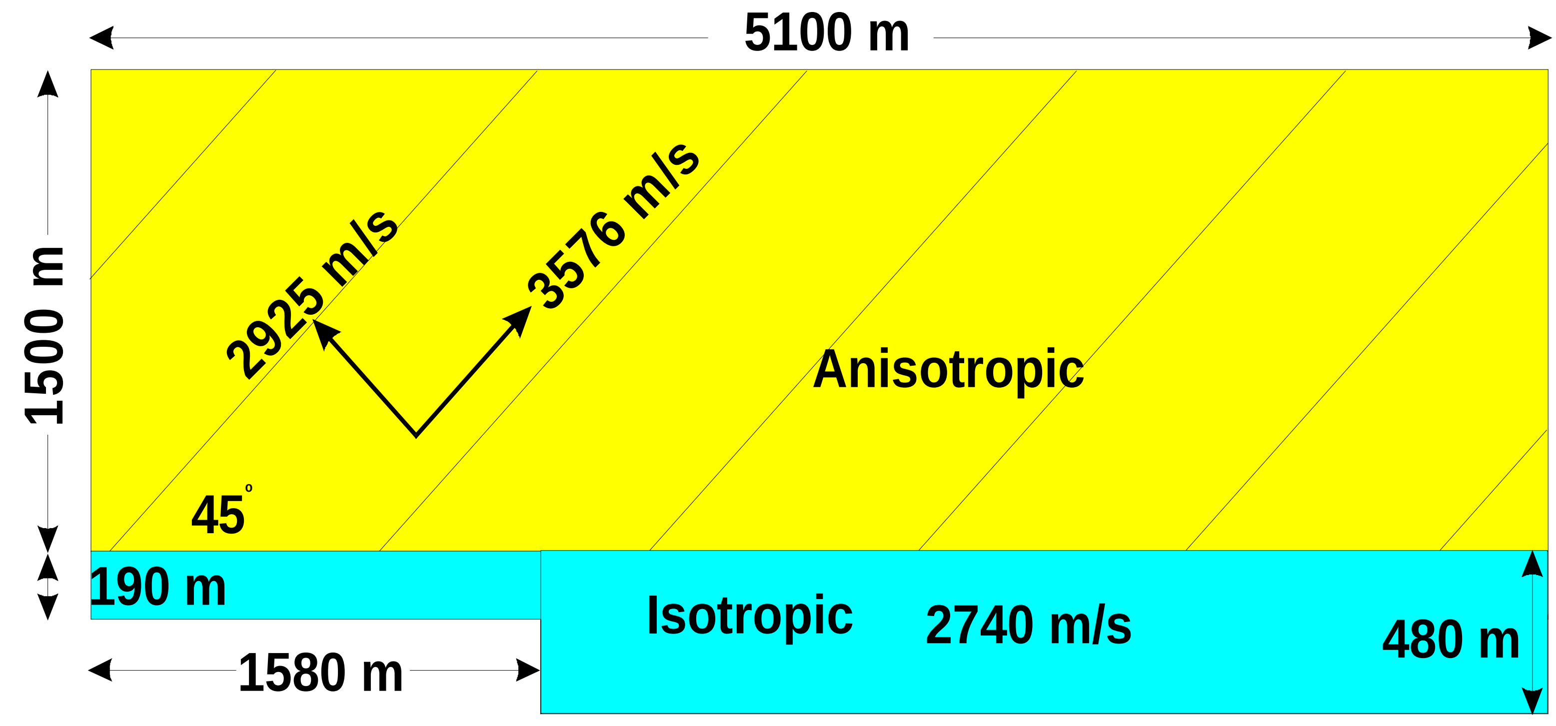
Vertical transverse isotropy (VTI)



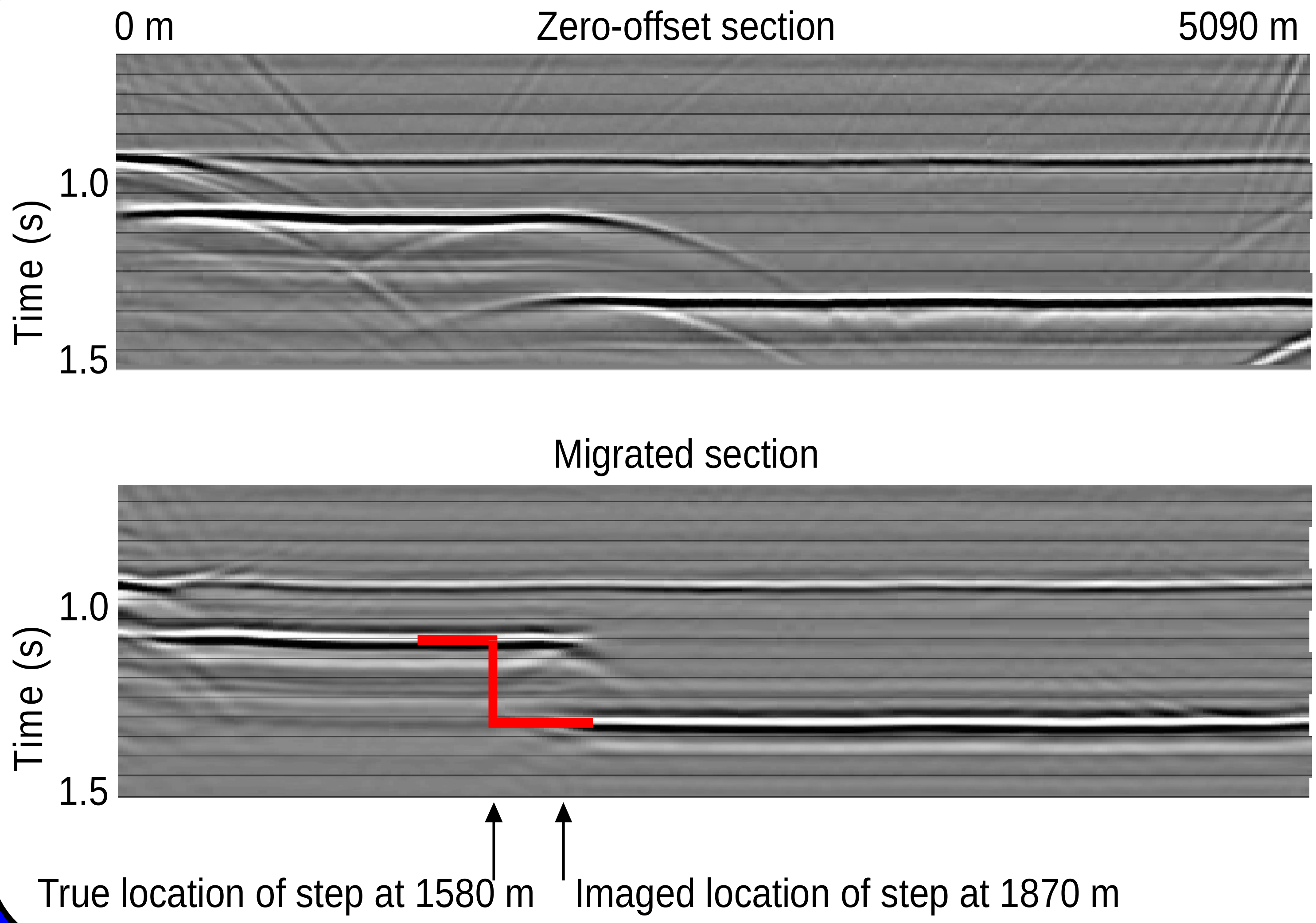
Lateral position error in target



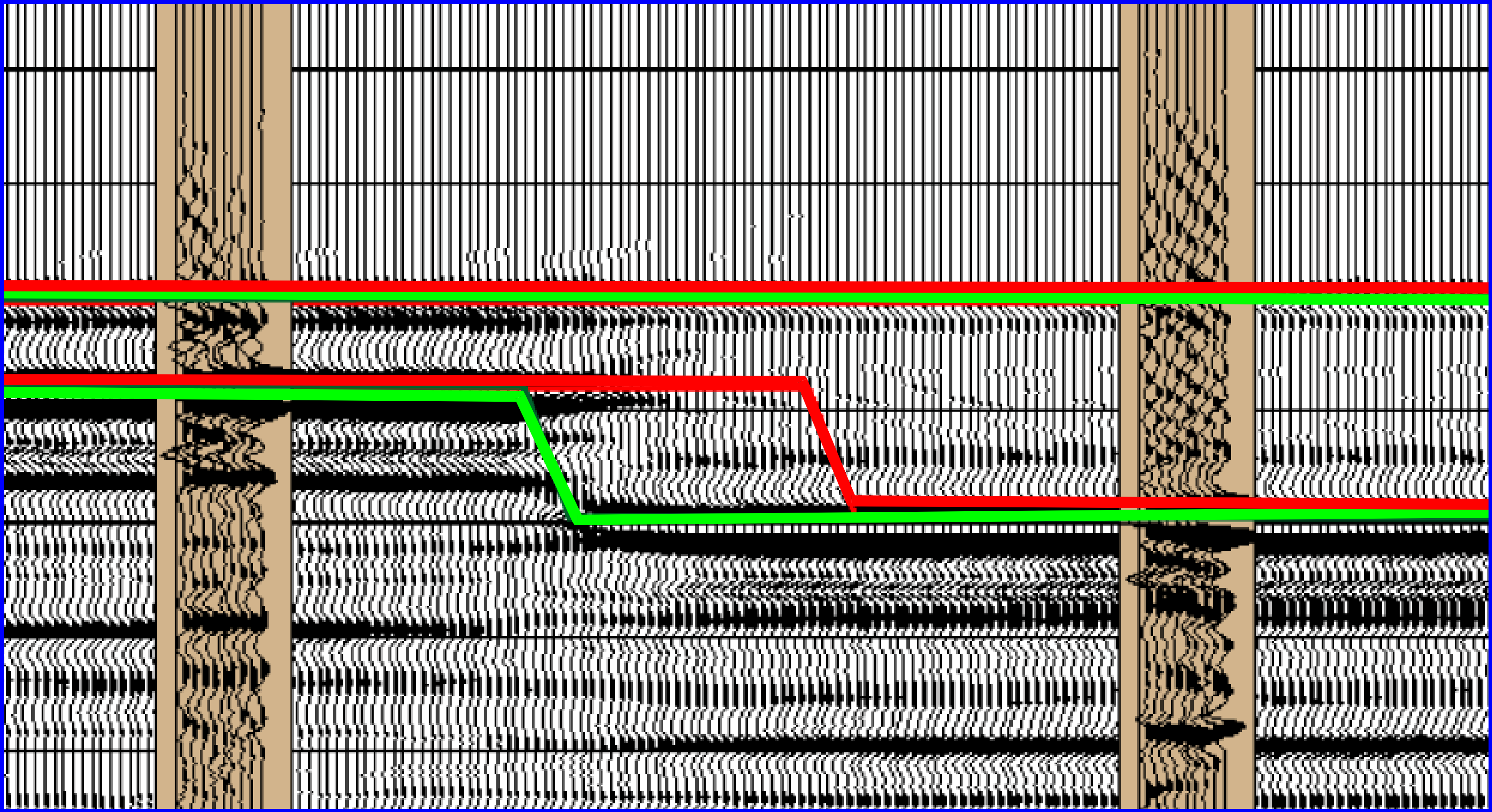
TTI overburden model



TTI overburden model sections

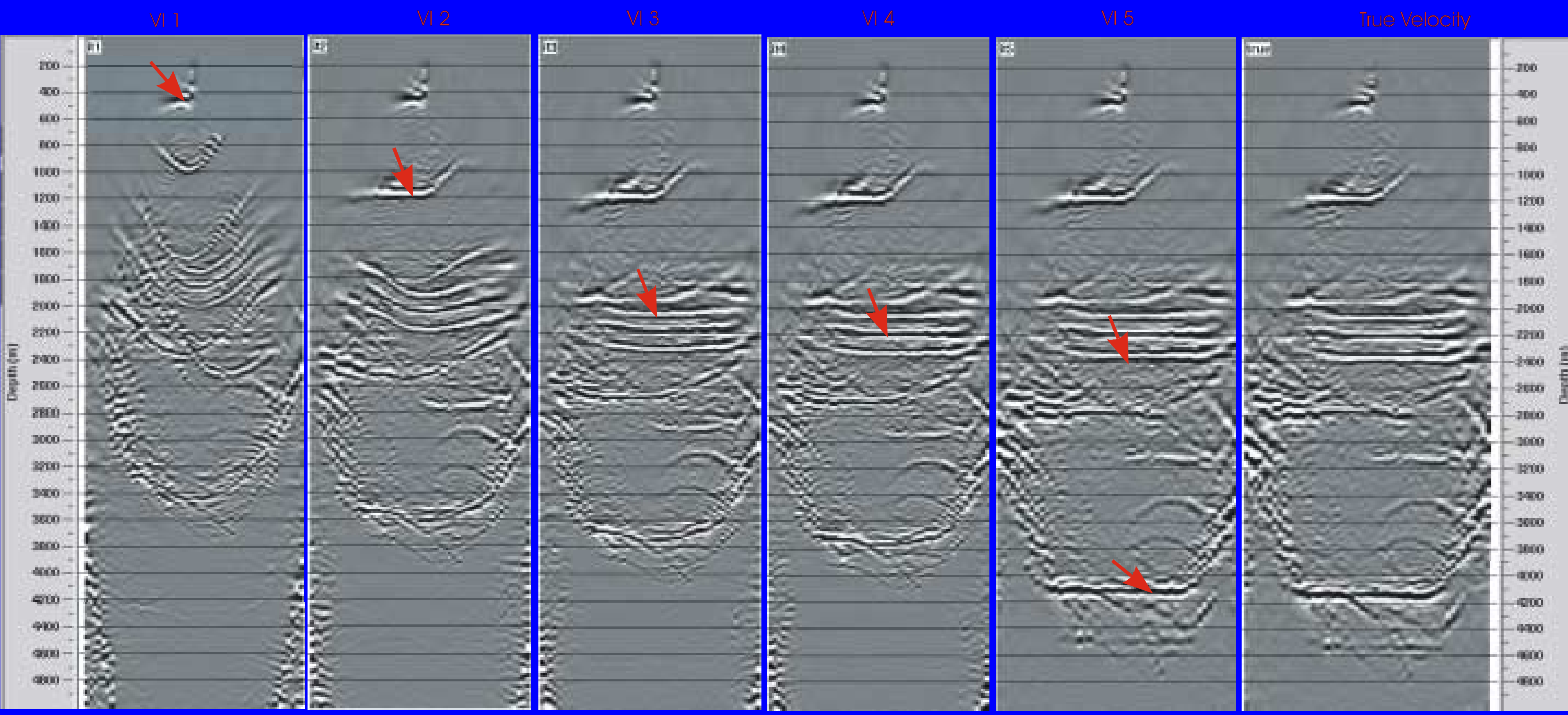


TTI overburden model
anisotropic depth migration

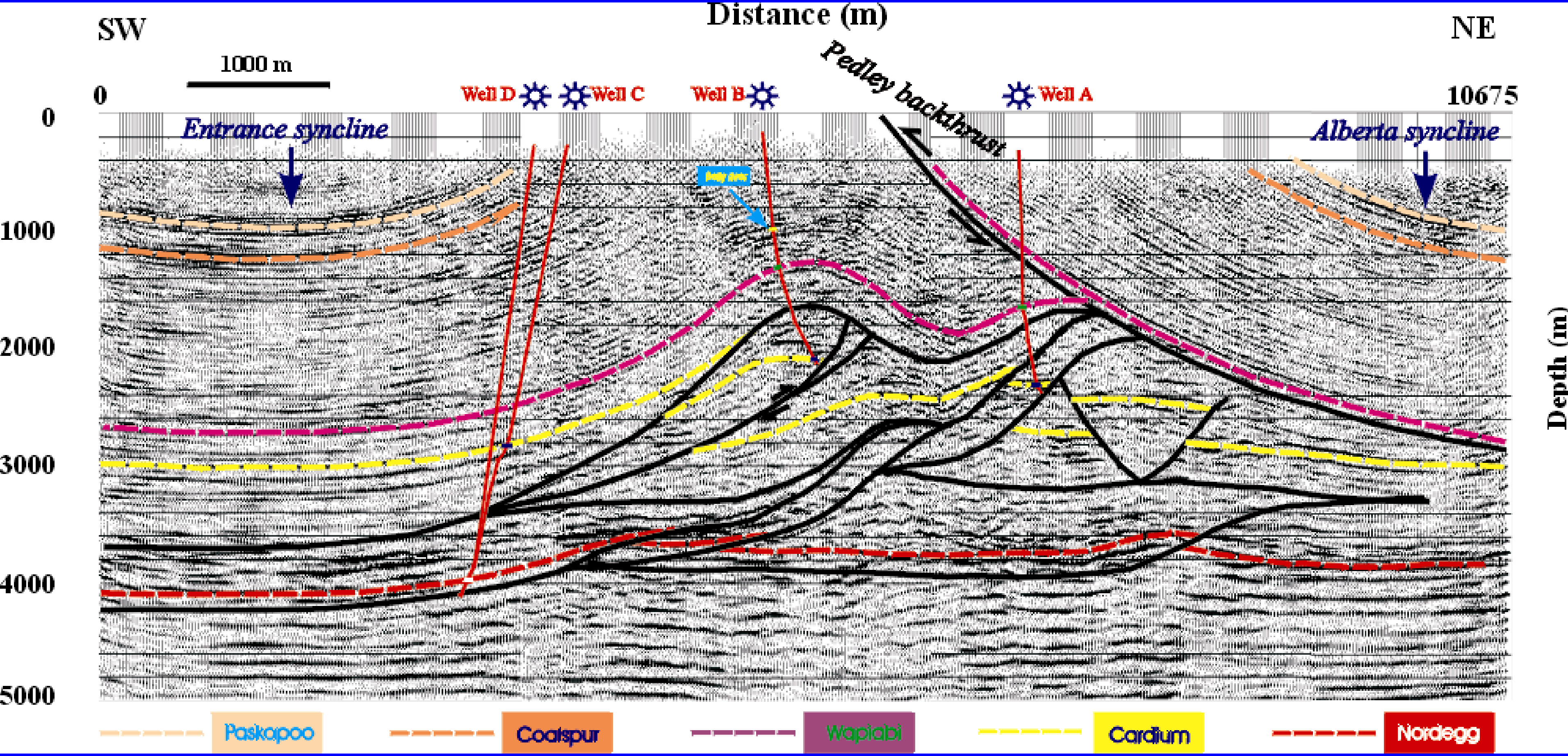


Processing Vestrum (Kelman)

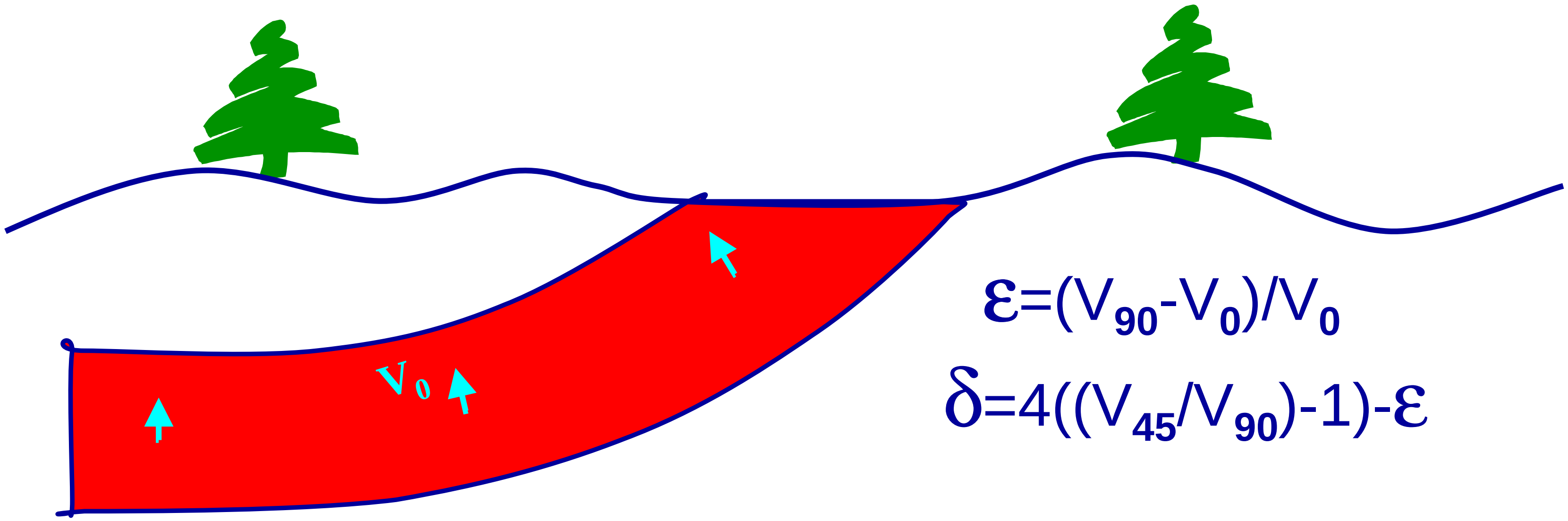
CIG displays at different velocity iterations



Seismic interpretation on the final PSDM image of the Shaw-Basing field survey

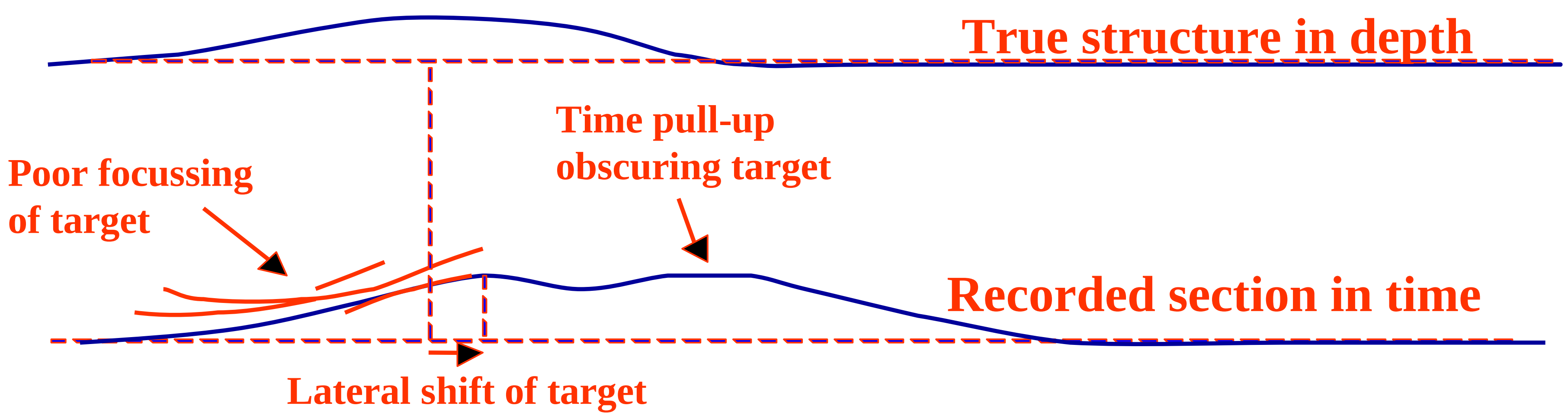


Influence of seismic anisotropy



$$\varepsilon=(V_{90}-V_0)/V_0$$

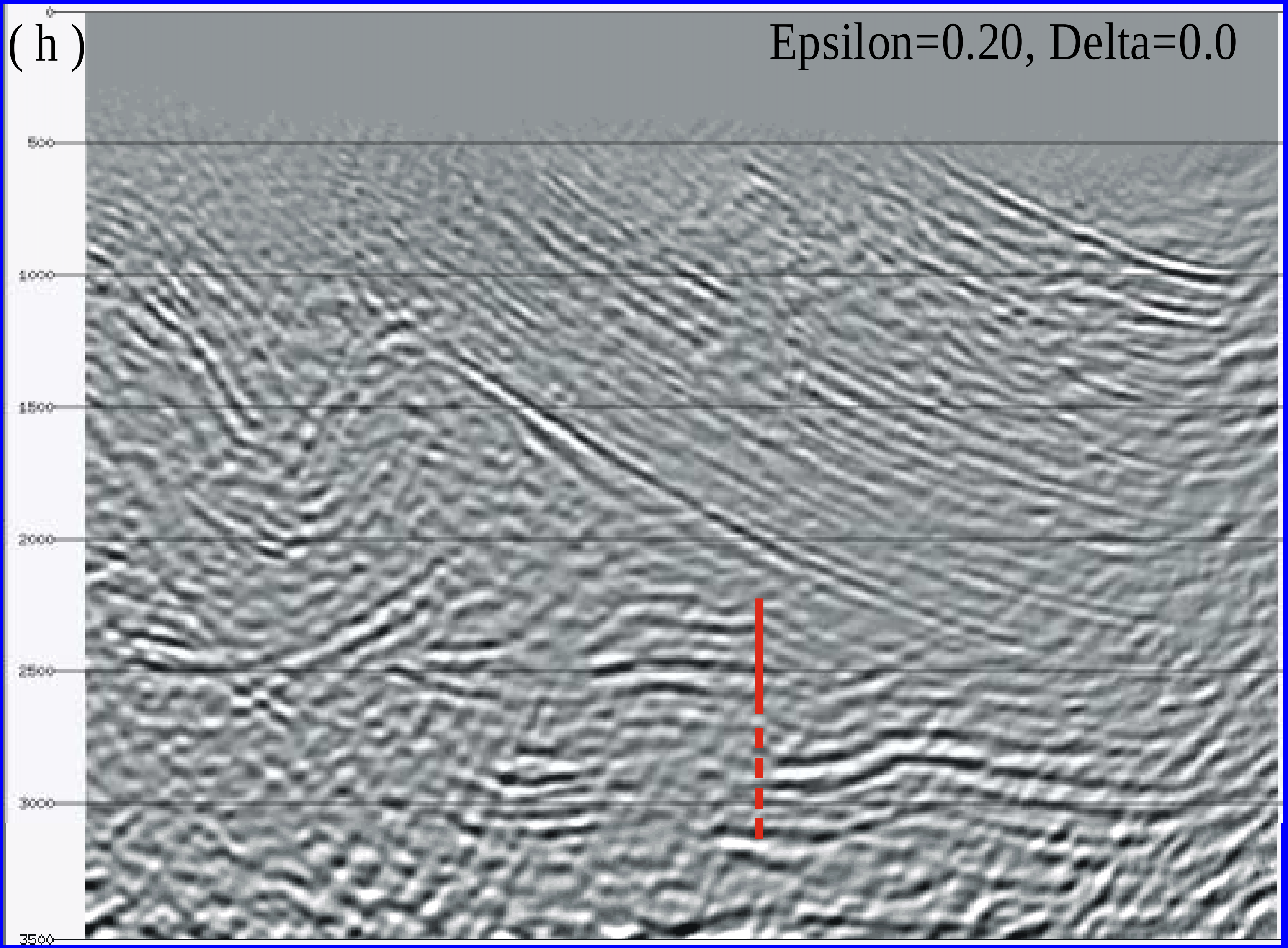
$$\delta=4((V_{45}/V_{90})-1)-\varepsilon$$



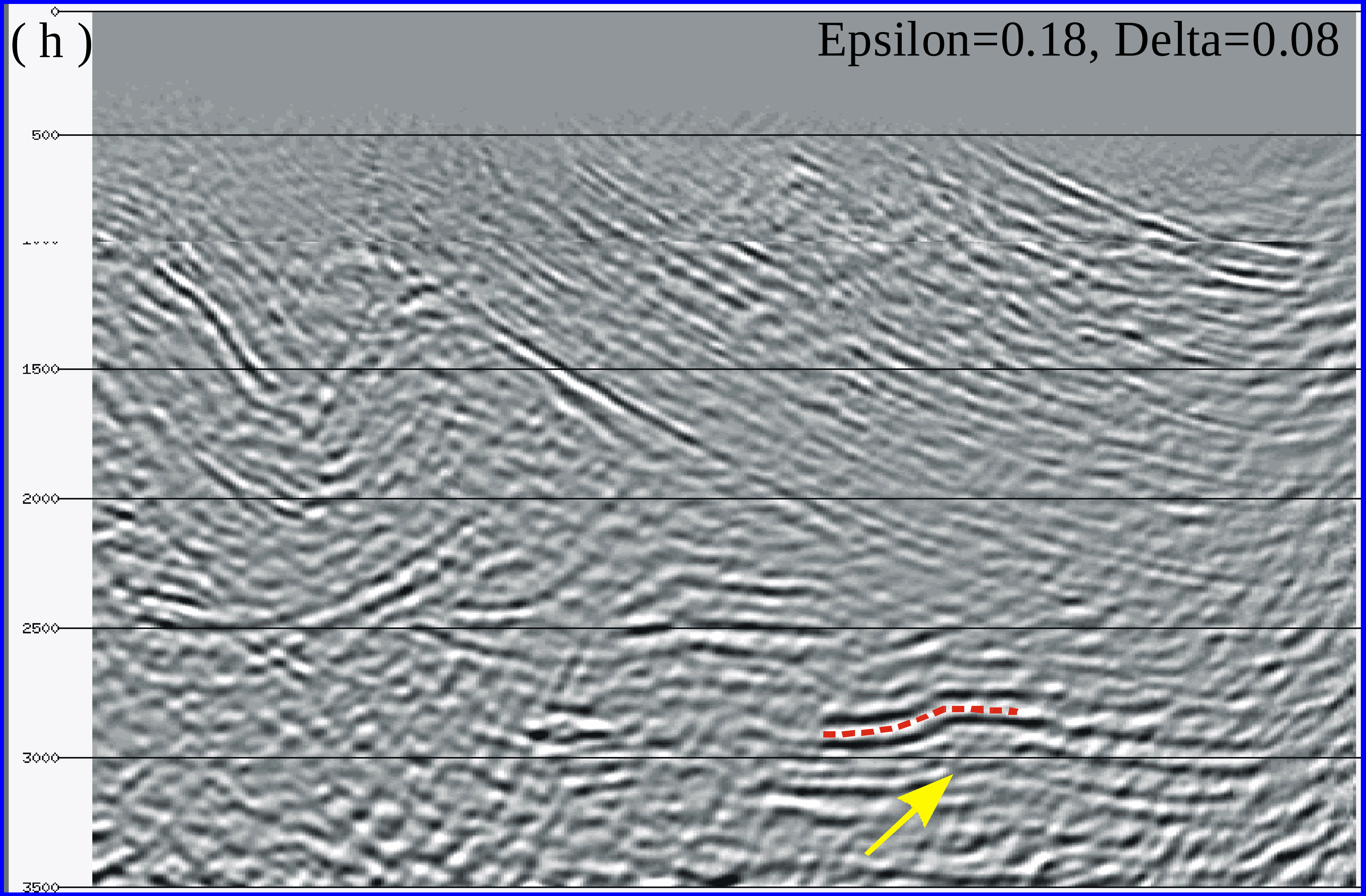
Building anisotropic velocity model (V_o, ε, δ, θ)

- ★ Lab
- ★ Refraction seismic and Multi-offset VSP surveys
- ★ Logging method
- ★ Inversions of surface seismic data
- ★ Parameter scanning technique

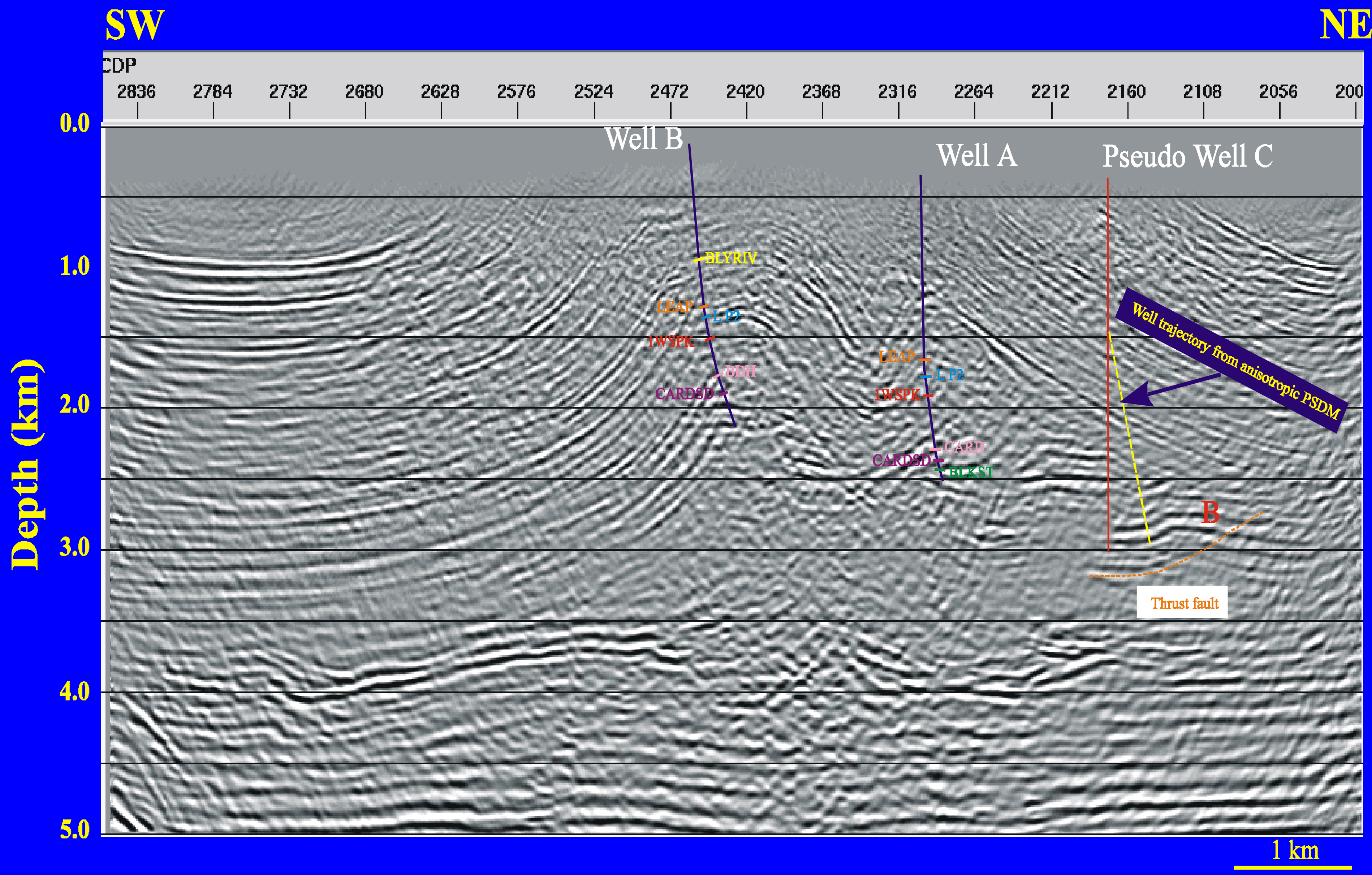
Parameter scanning of epsilon



Parameter scanning of delta



Correlation between well information and anisotropic PSDM



Theory – AVO

Use linear approximation of the Zoeppritz equations (Aki and Richards, 1980)

$$\begin{bmatrix} d(\theta_1) \\ d(\theta_2) \\ \vdots \\ d(\theta_N) \end{bmatrix} = \begin{bmatrix} \left(\frac{1}{2}\sec^2\theta_1\right) & -\left(4\gamma^2\sin^2\theta_1\right) & \frac{1}{2}\left(1-4\gamma^2\sin^2\theta_1\right) \\ \left(\frac{1}{2}\sec^2\theta_2\right) & -\left(4\gamma^2\sin^2\theta_2\right) & \frac{1}{2}\left(1-4\gamma^2\sin^2\theta_2\right) \\ \vdots & \vdots & \vdots \\ \left(\frac{1}{2}\sec^2\theta_N\right) & -\left(4\gamma^2\sin^2\theta_N\right) & \frac{1}{2}\left(1-4\gamma^2\sin^2\theta_N\right) \end{bmatrix} \begin{bmatrix} R_{Vp} \\ R_{Vs} \\ R_d \end{bmatrix}$$

Or

Where θ = average angle of incidence, $d(\theta)$ is offset dependant data

γ ratio of S velocity to P velocity

R_{Vp}, R_{Vs}, R_d are the change over the average p-wave velocity, s-wave velocity and density respectively

Conclusions

- Prestack migration from topography requires an accurate velocity model
- Seismic processing prior to migration is important
- Prestack depth migration requires velocity model iteration and interpretation
- When seismic anisotropy is significant, use anisotropic depth migration

Conclusions

- Reverse-time depth migration is general, accurate and effective.
- Reverse-time depth migration is expensive and time consuming.
- The migrations can be made tractable and affordable by parallel processing.

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Look forward to future applications