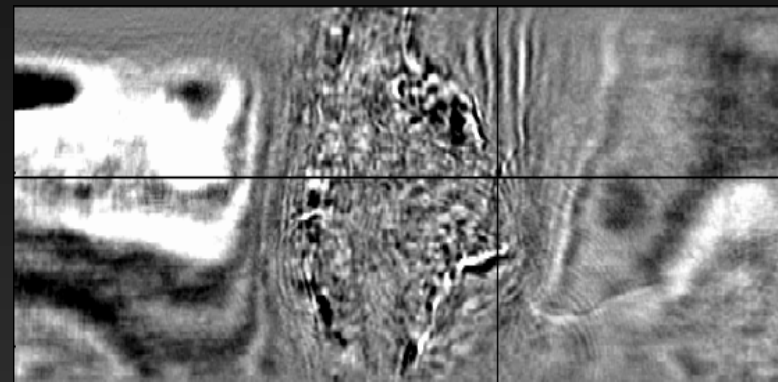
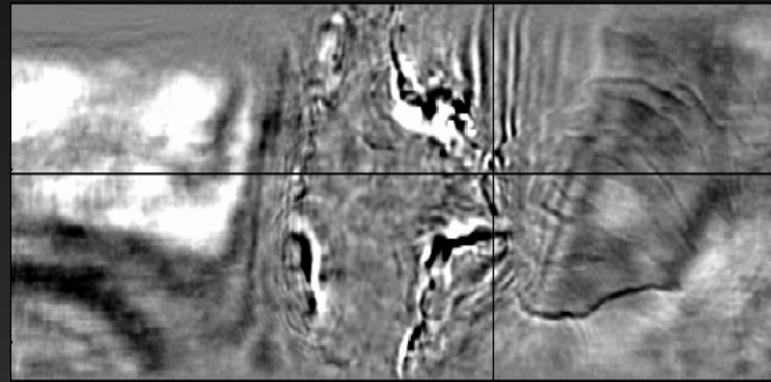


Migration-velocity analysis using image-space generalized wavefields

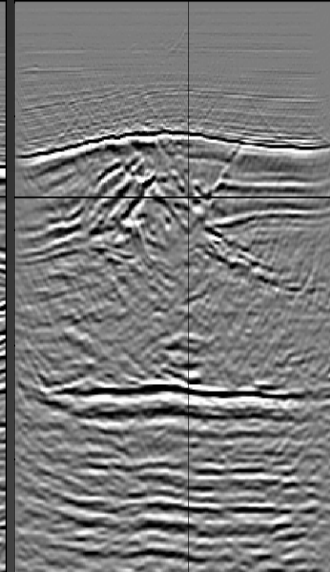
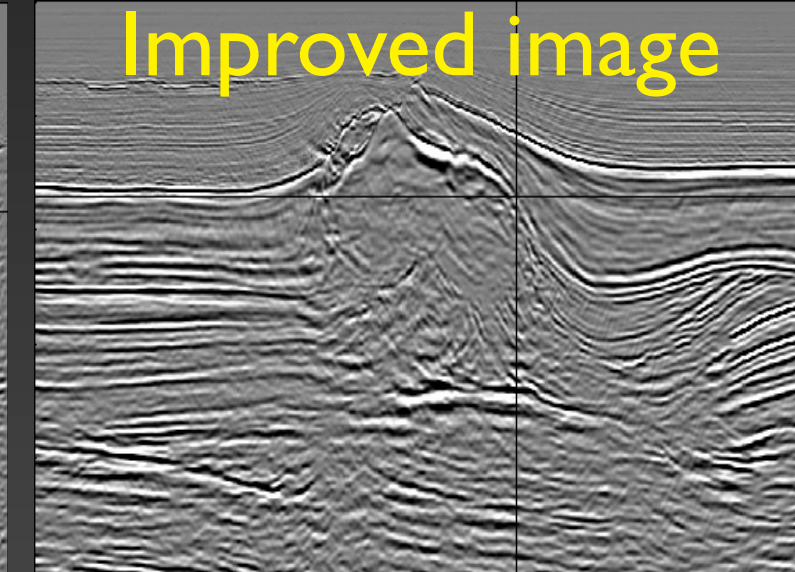
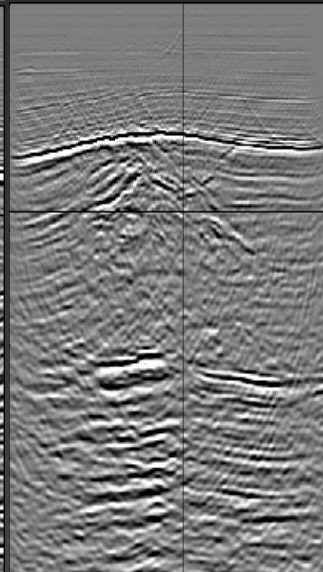
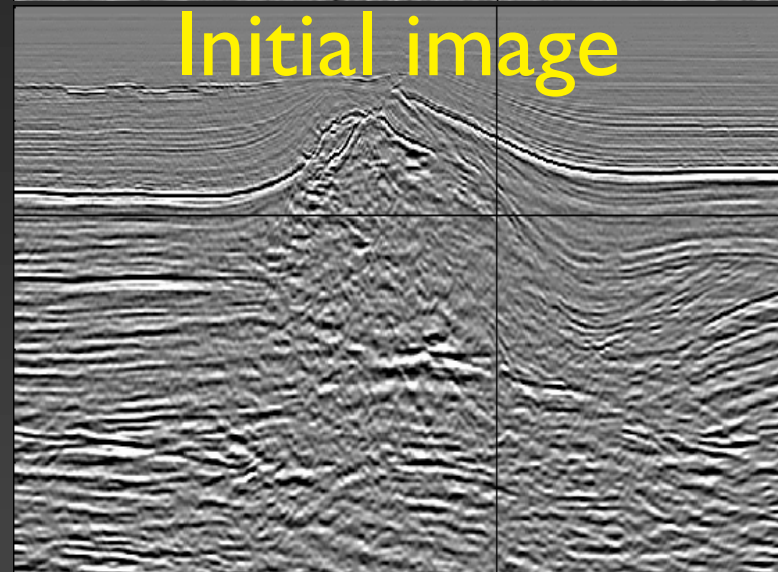
Claudio Guerra



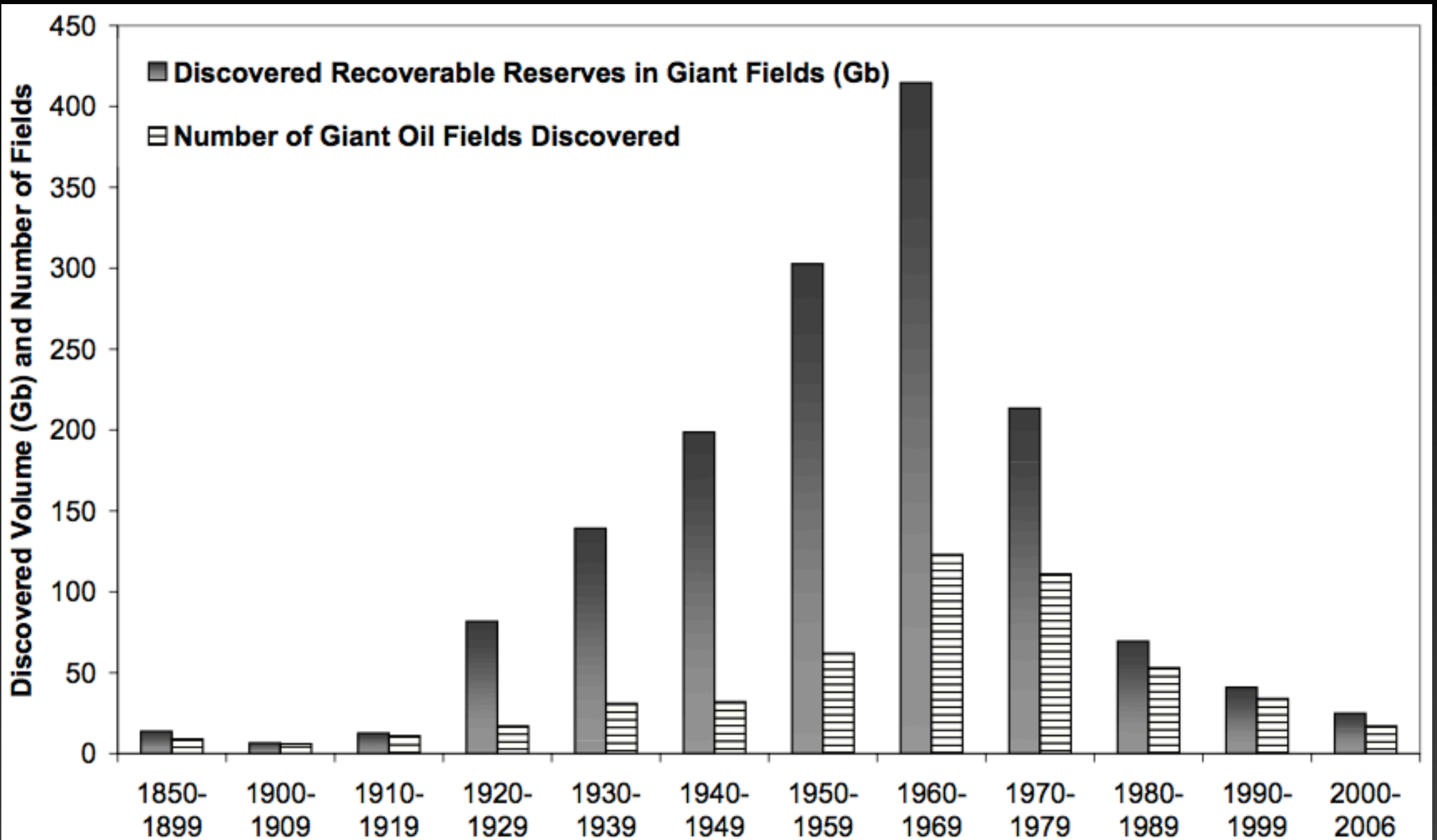
Initial image



Improved image



End of 'easy' oil



Robelius, Fredrik: Giant Oil Fields - The Highway to Oil: Giant Oil Fields and their Importance for Future Oil Production

Offshore oil production & prospectivity ...



Modified from <http://pubs.usgs.gov/fs/fs-062-03/FS-062-03.pdf>

and location of salt provinces



Modified from <http://pubs.usgs.gov/fs/fs-062-03/FS-062-03.pdf> and <http://truman.seg.org/TLEreview/November/Sayers.pdf>

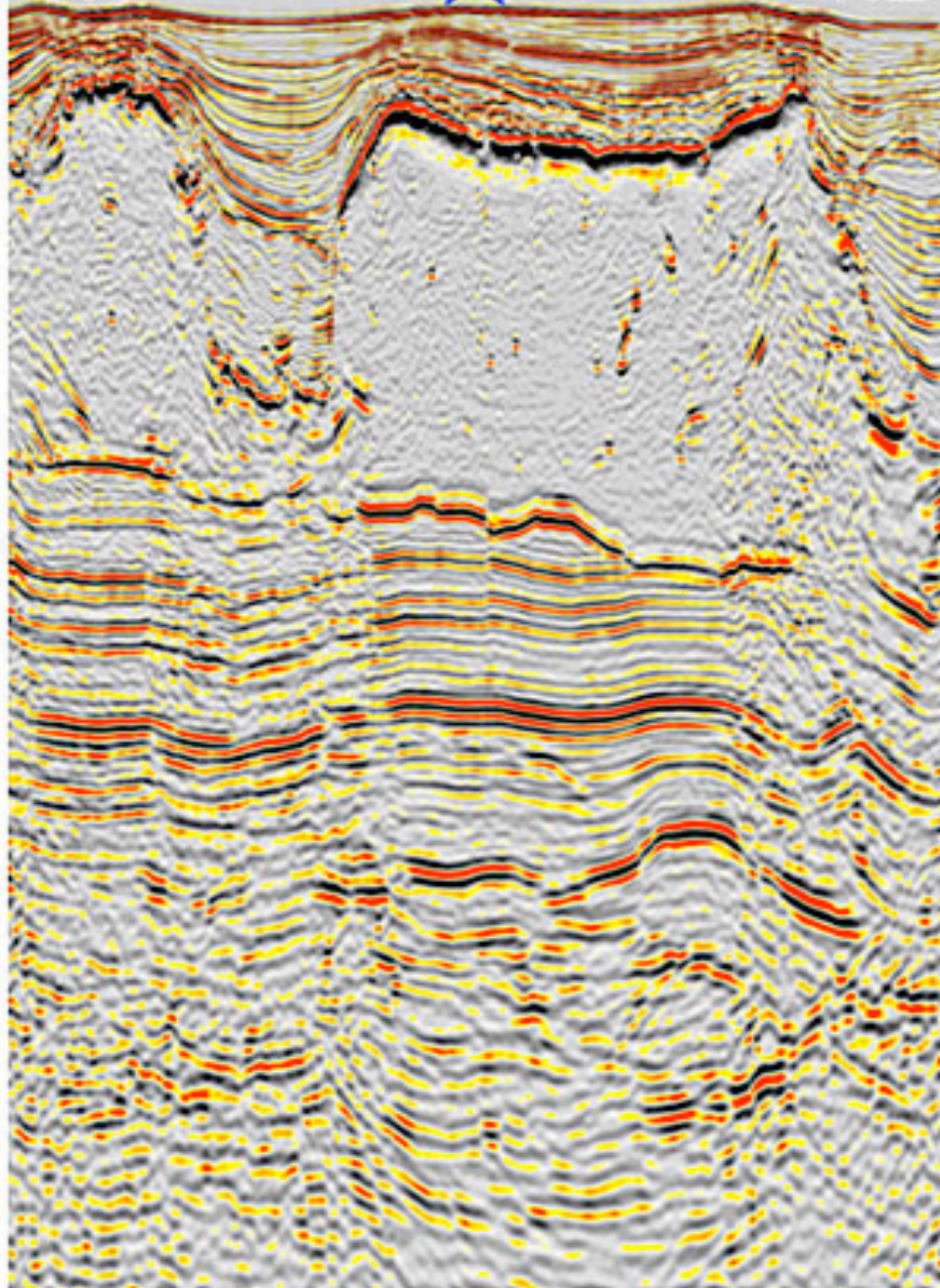
distance

Tiber



SW

NE

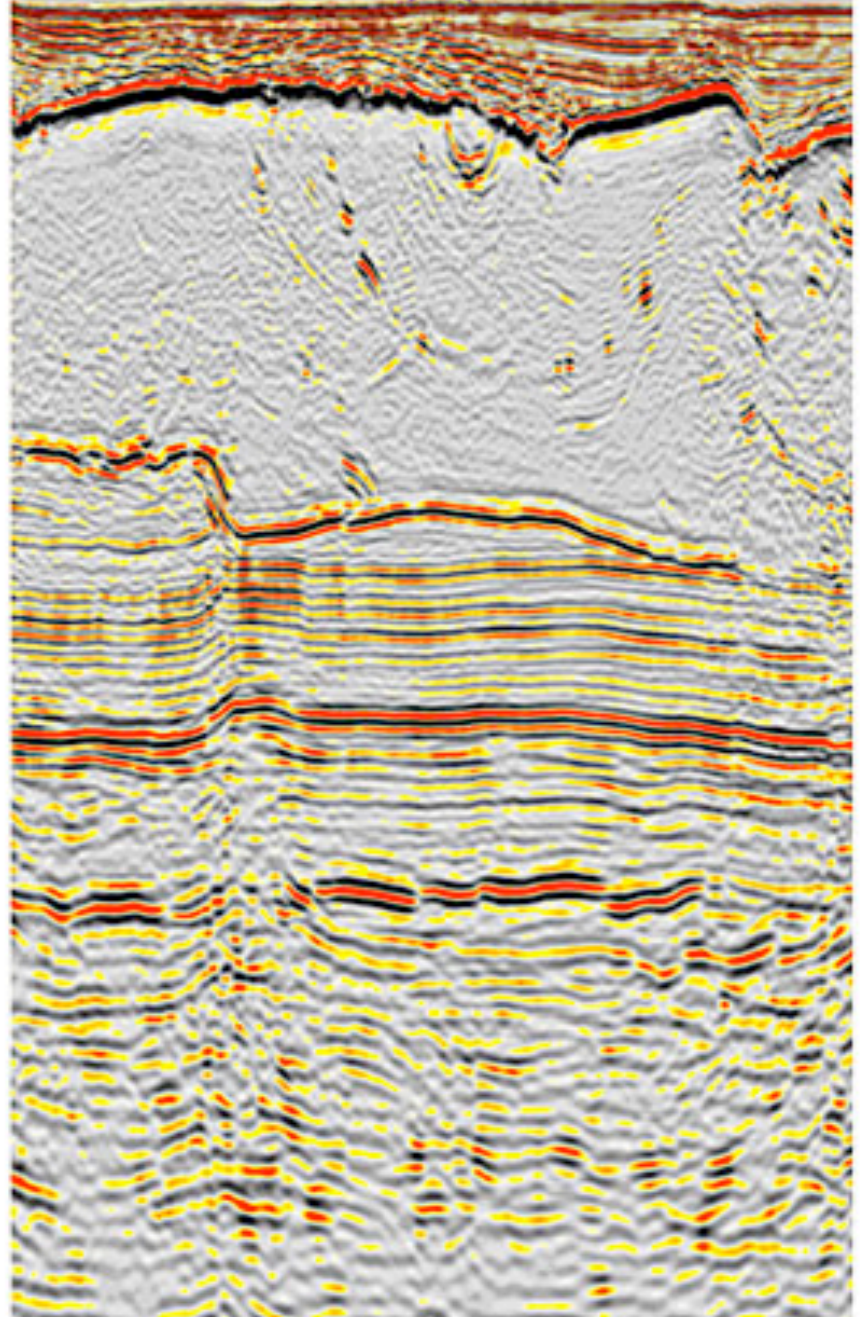


Tiber



SE

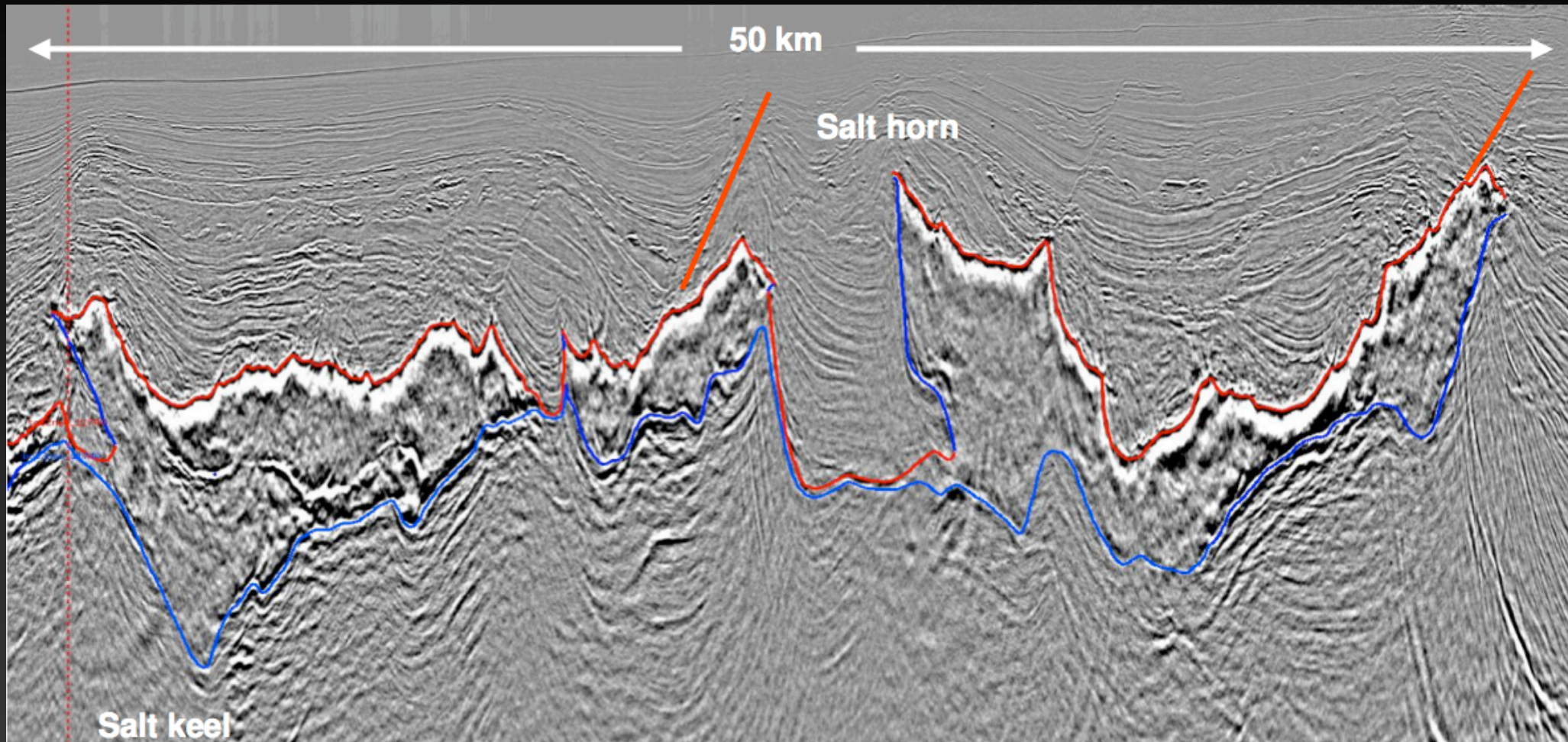
NW



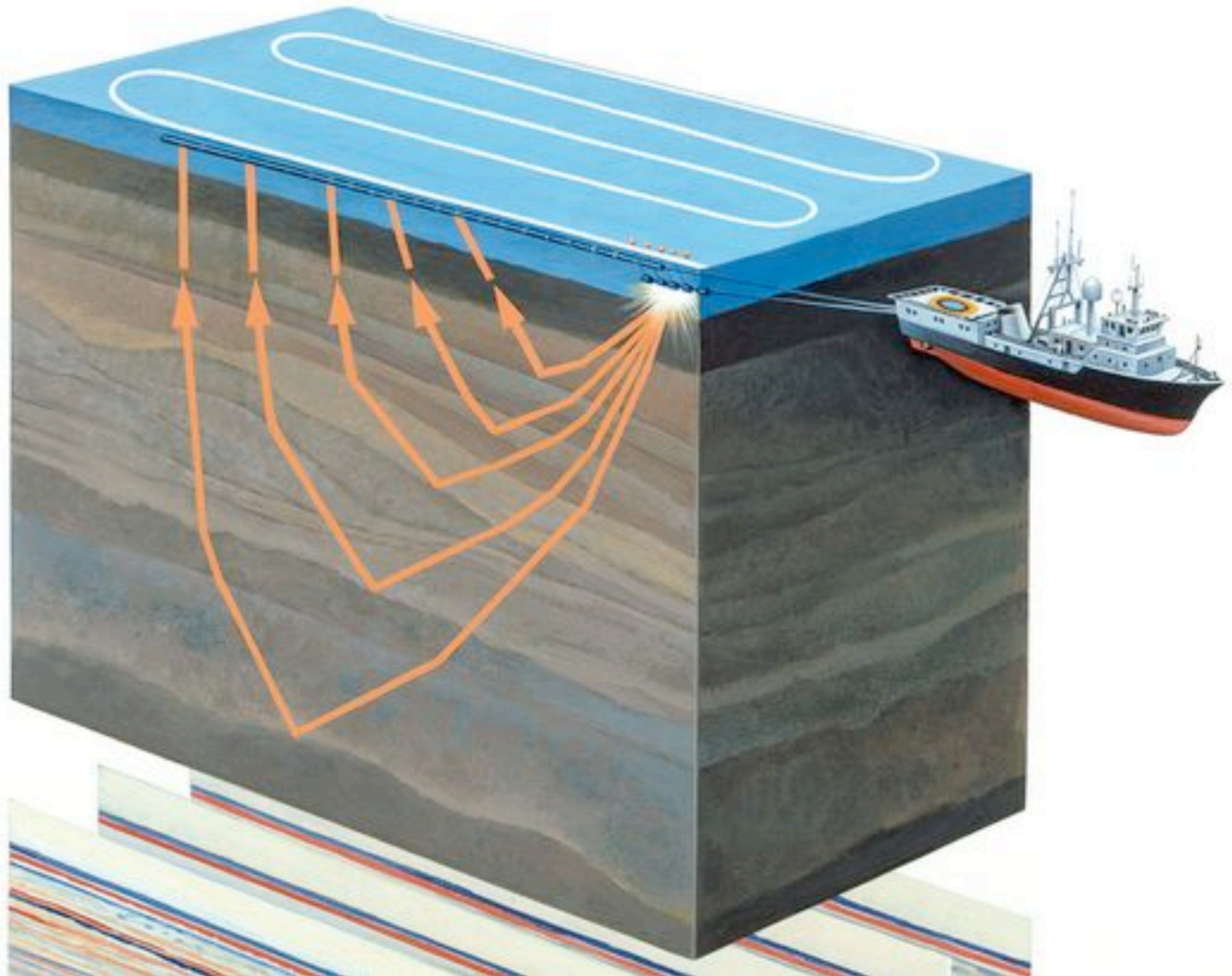
depth

distance

depth

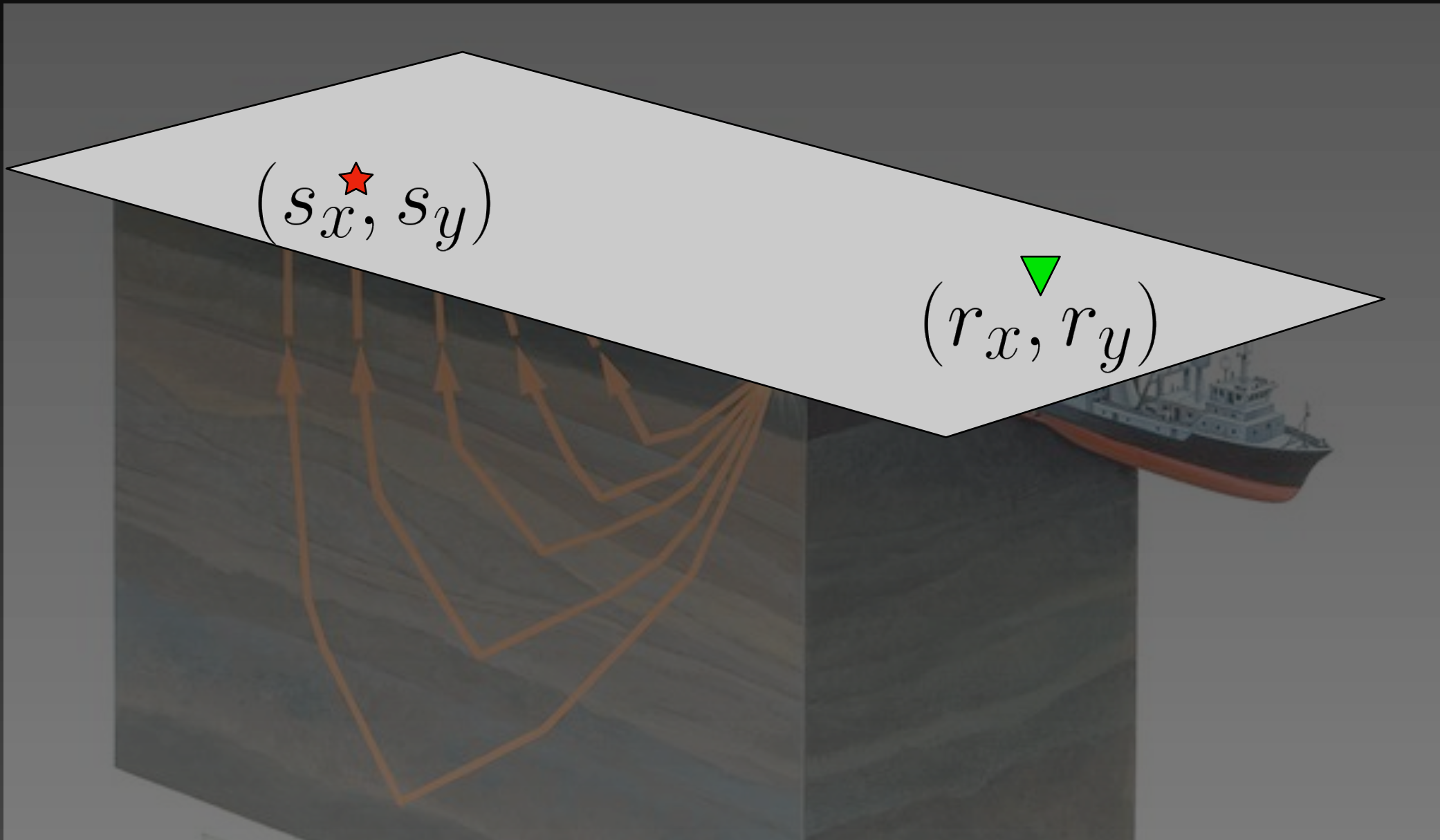


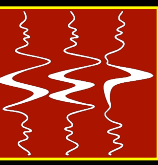
Li et al., 2009



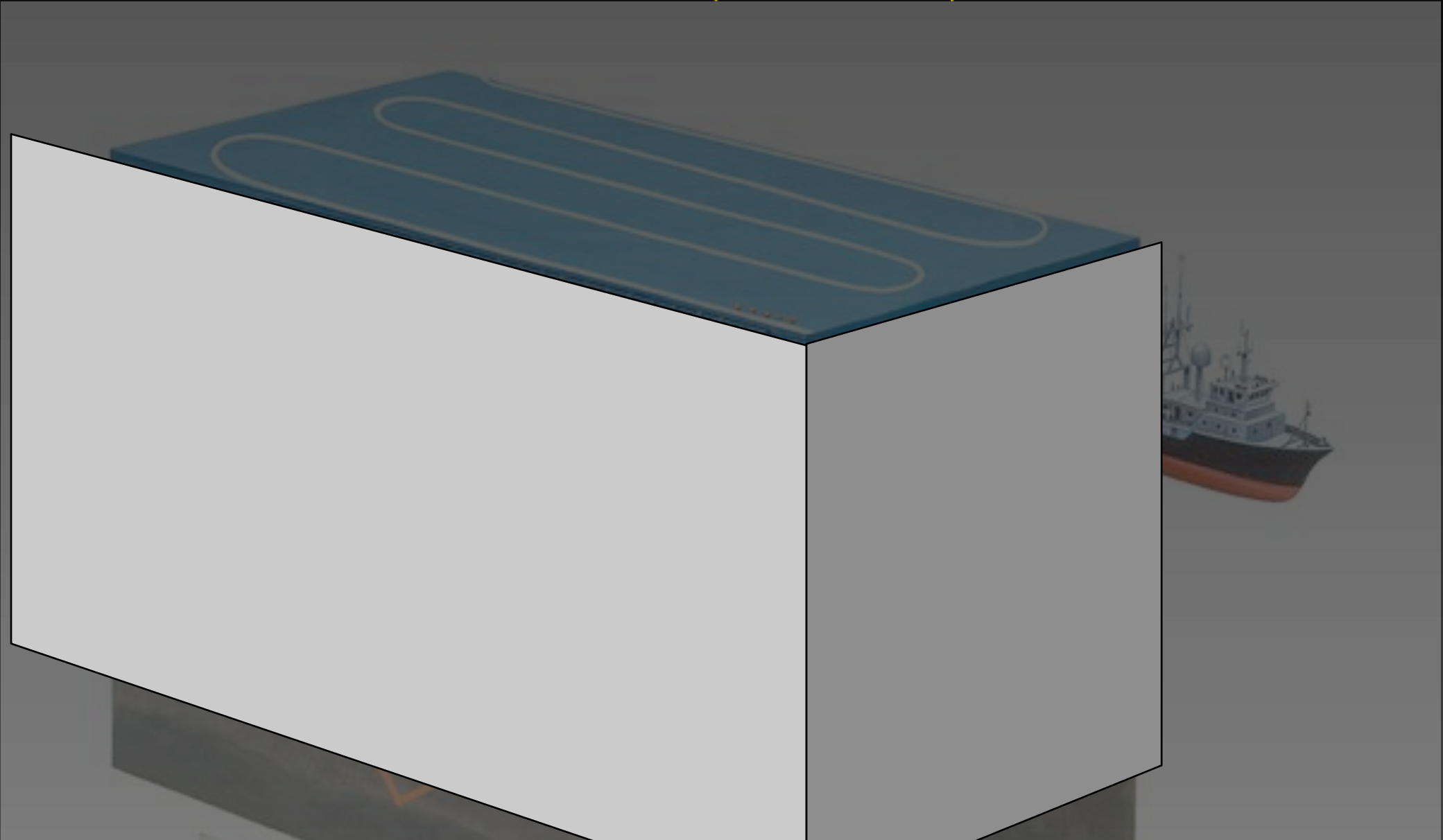


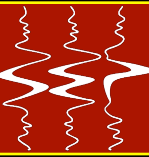
$$d = d(\mathbf{s}, \mathbf{r}, t)$$





$$I = I(\mathbf{x}, \mathbf{h})$$

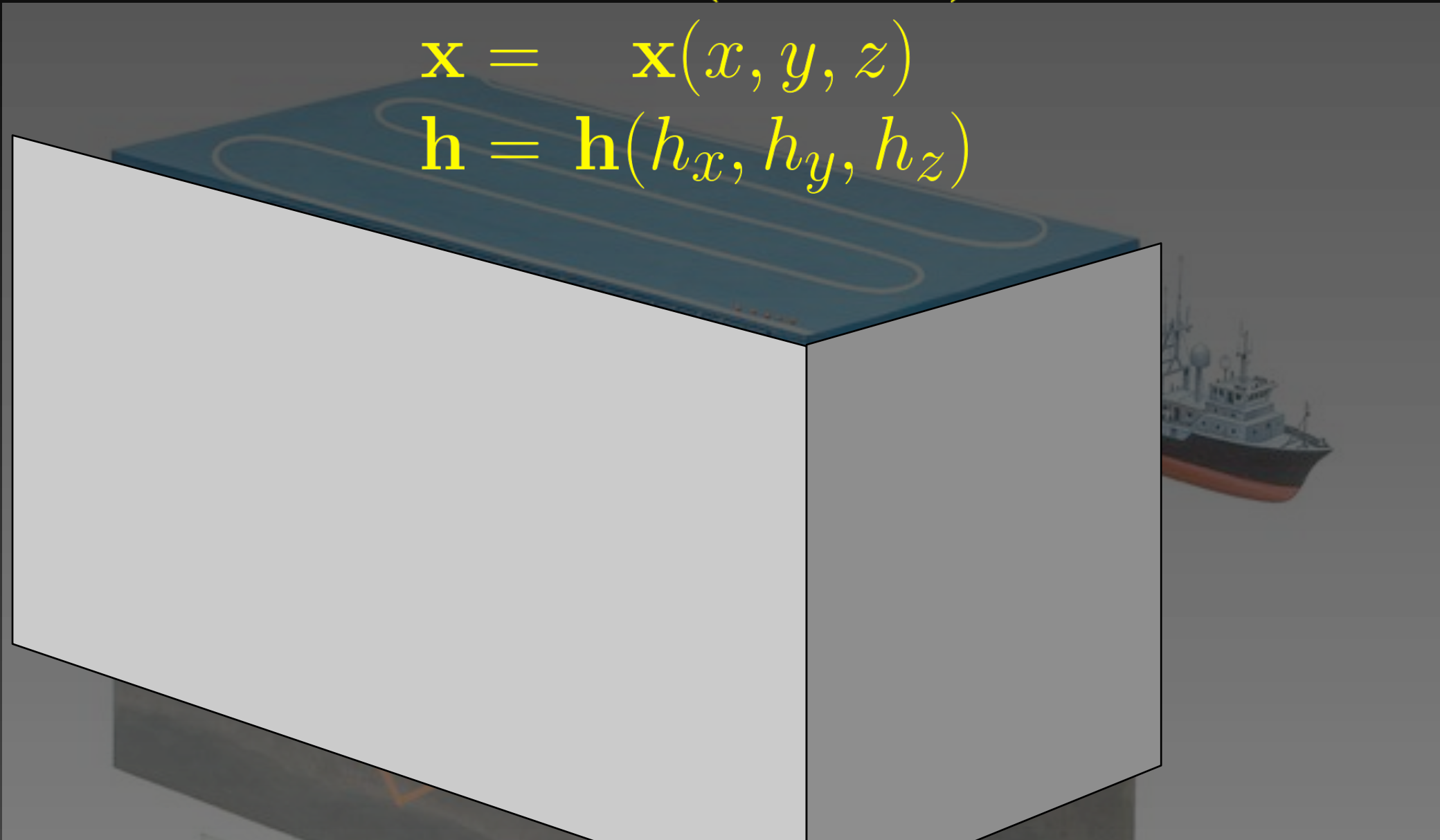


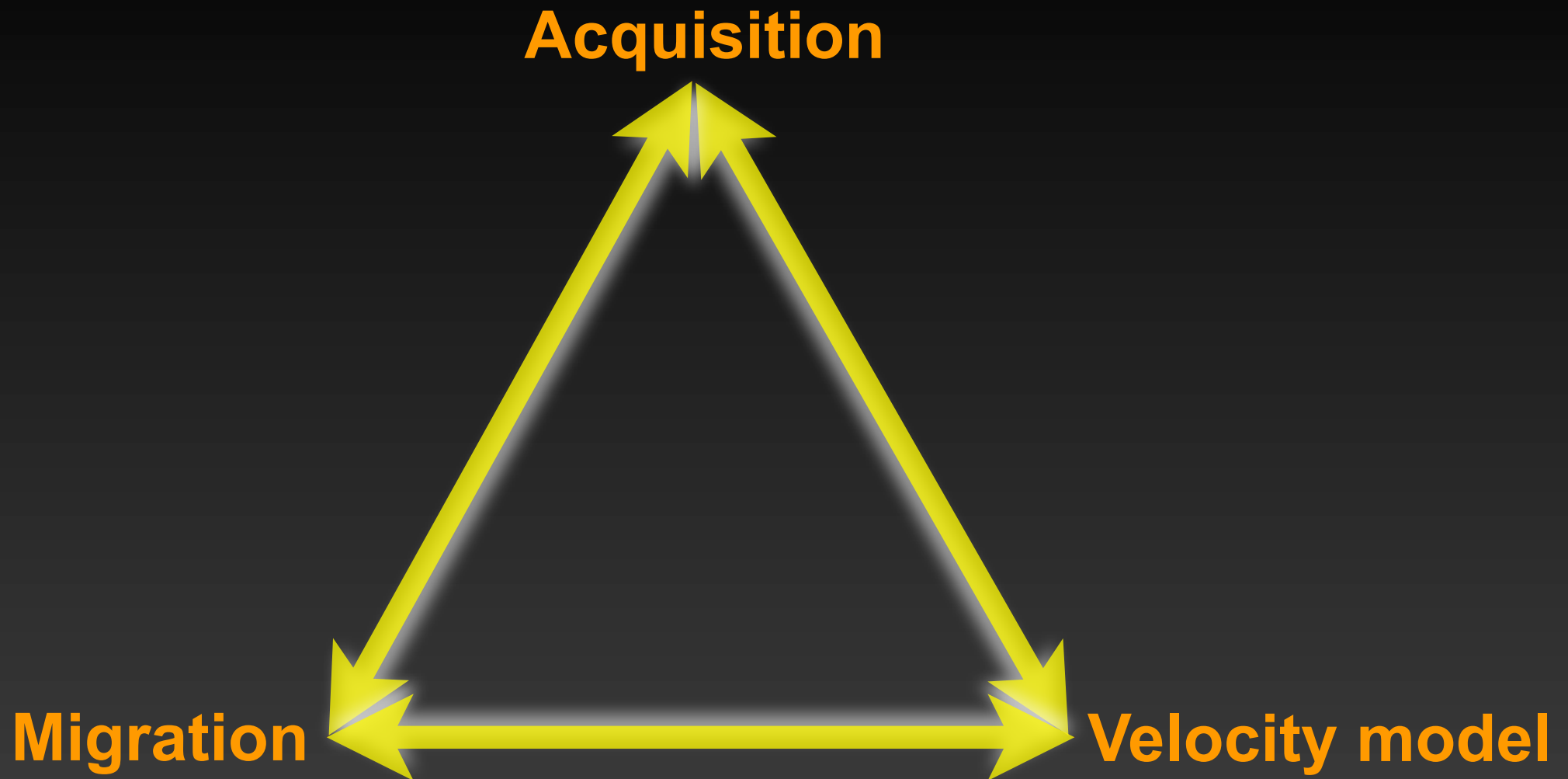
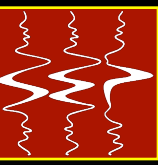


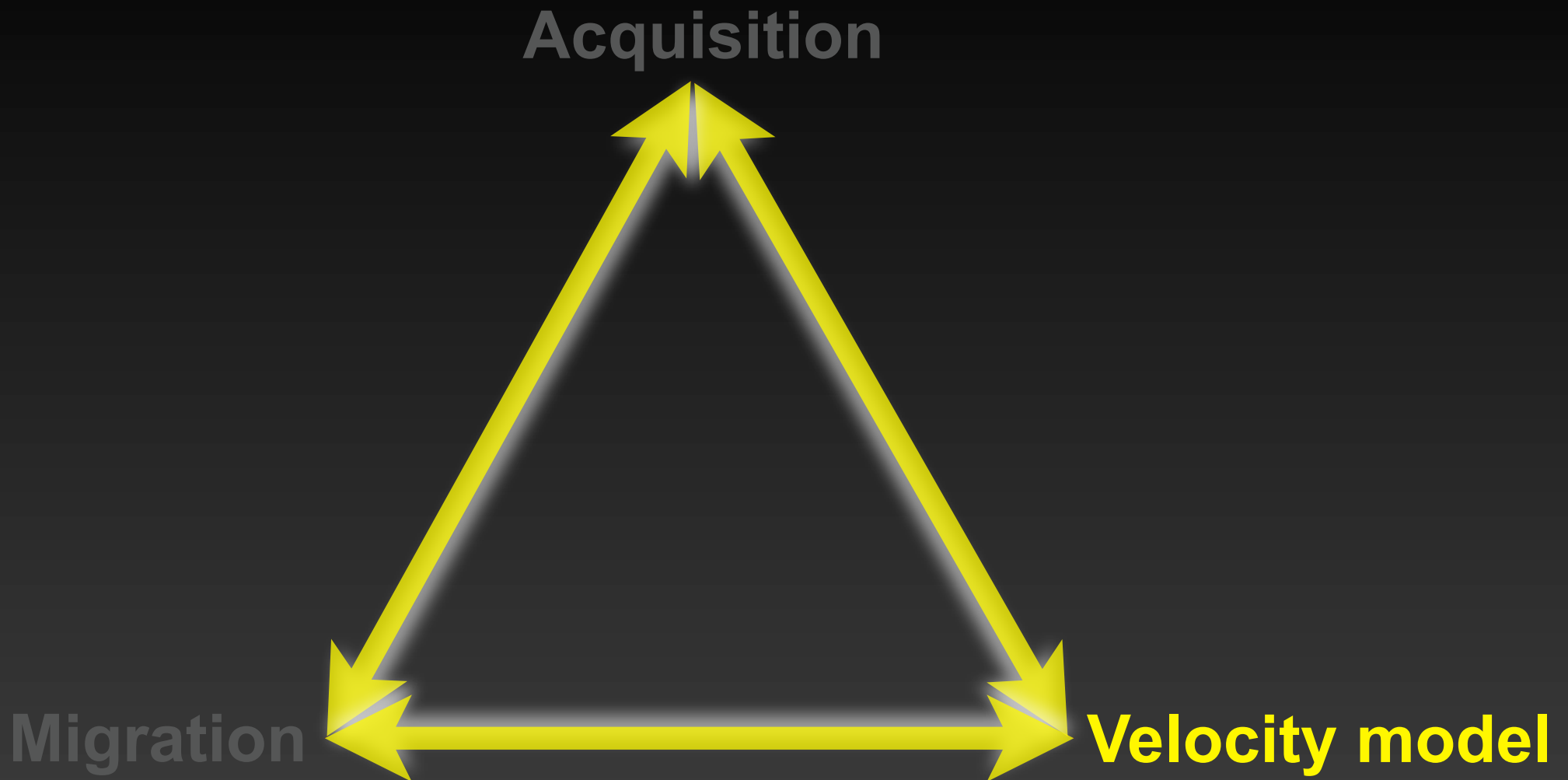
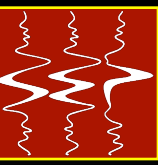
$$I = I(\mathbf{x}, \mathbf{h})$$

$$\mathbf{x} = \mathbf{x}(x, y, z)$$

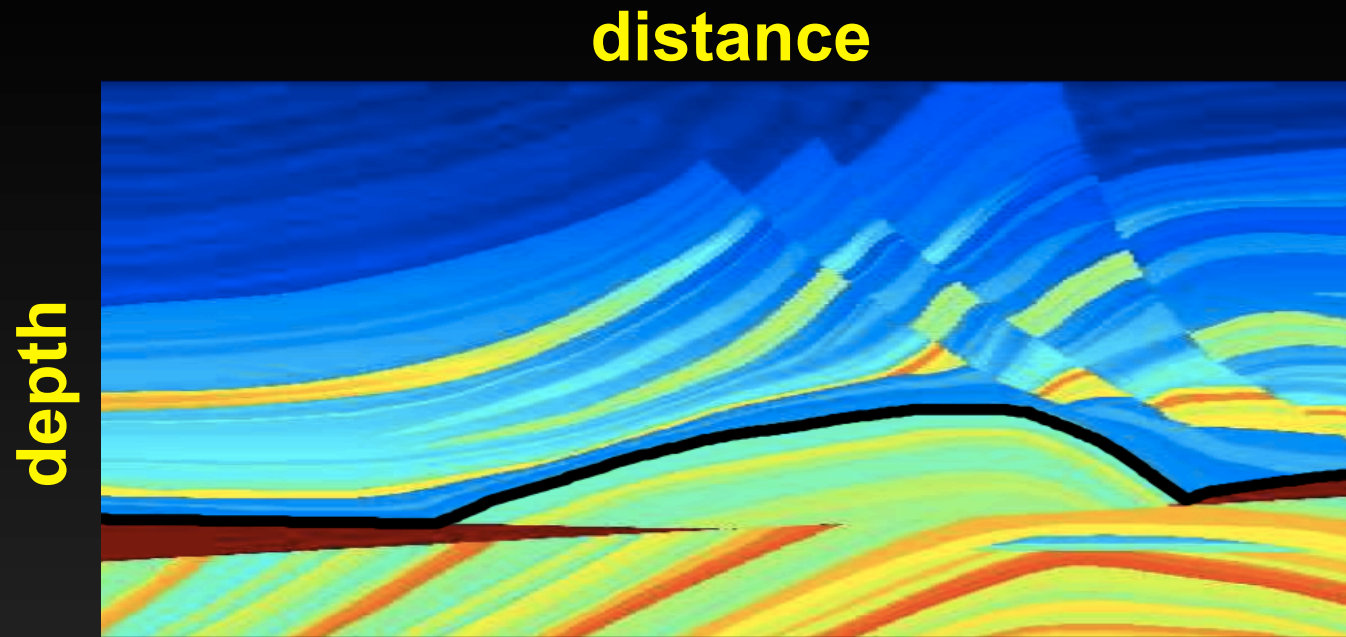
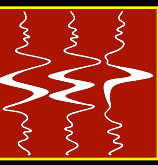
$$\mathbf{h} = \mathbf{h}(h_x, h_y, h_z)$$



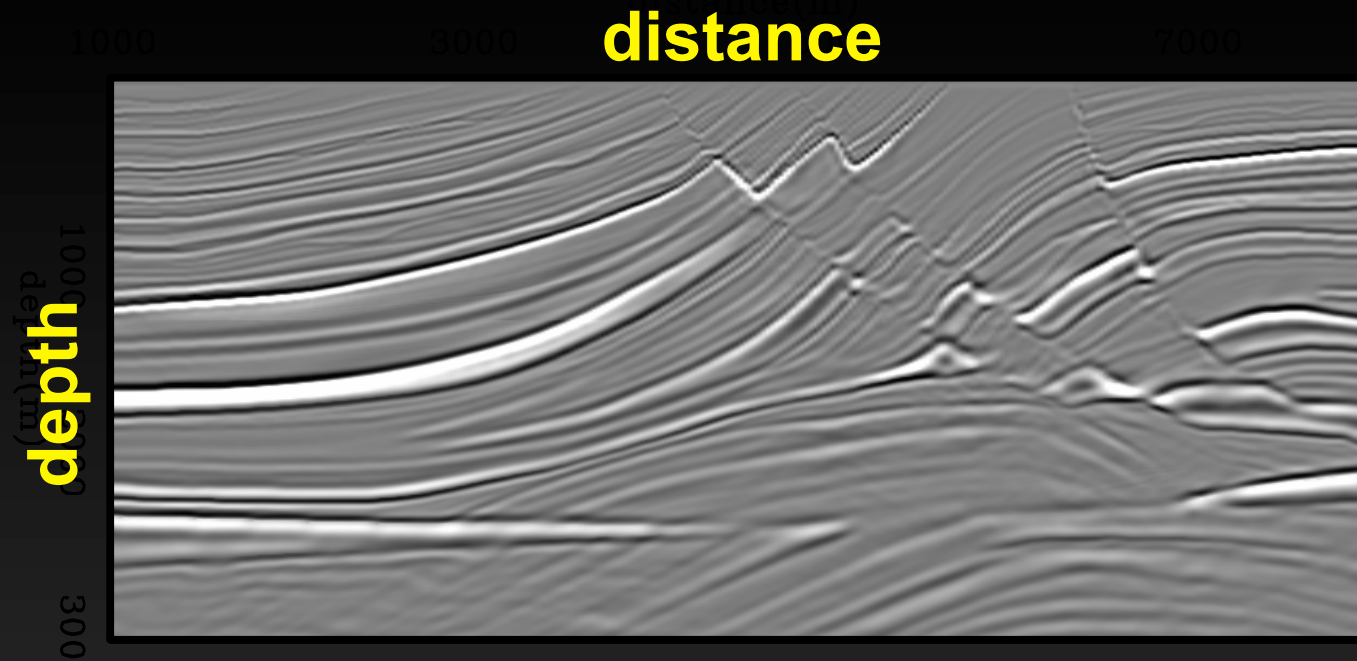
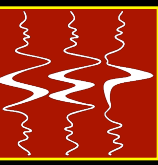




Importance of migration velocity

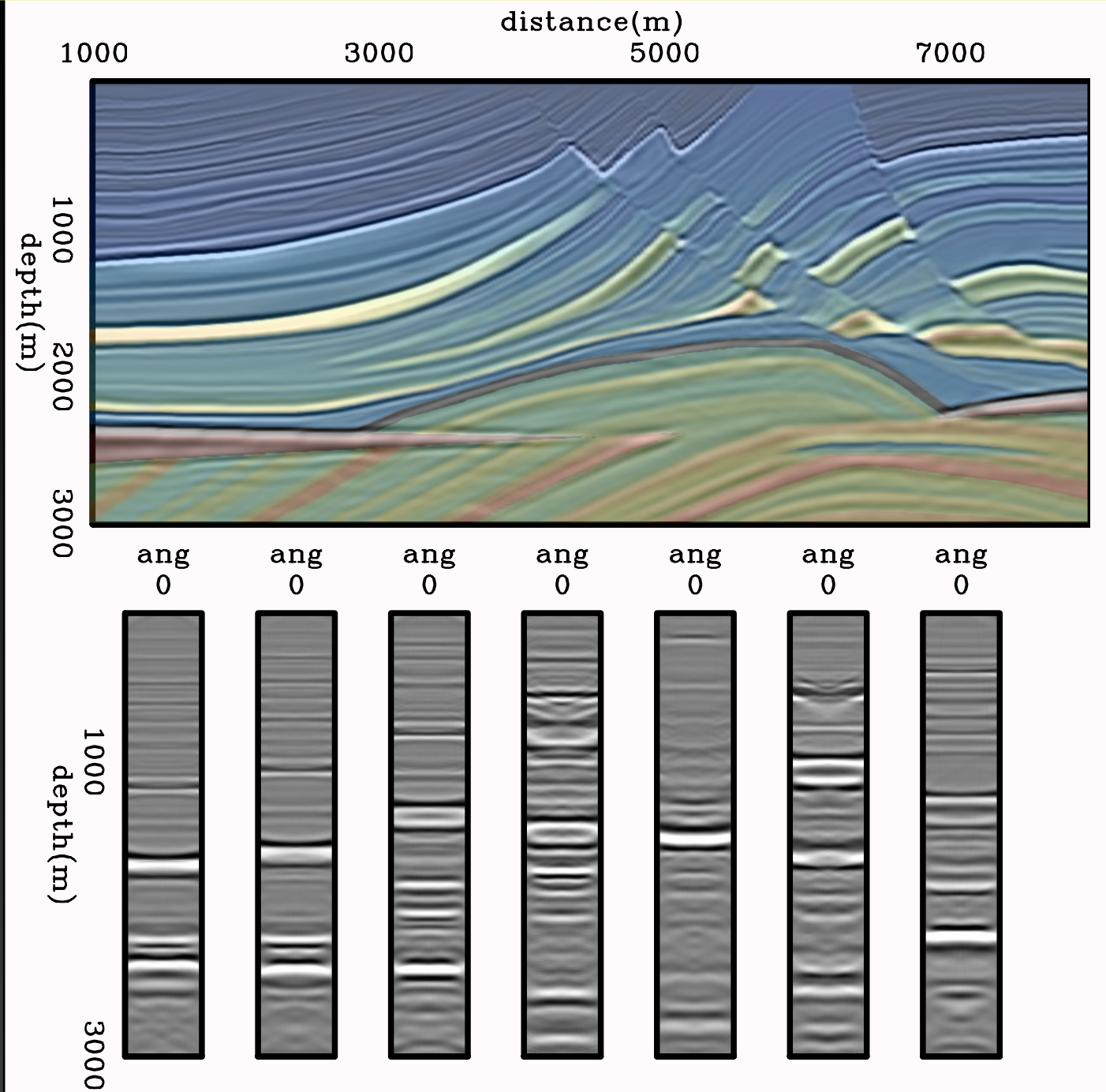


Migration with true velocity

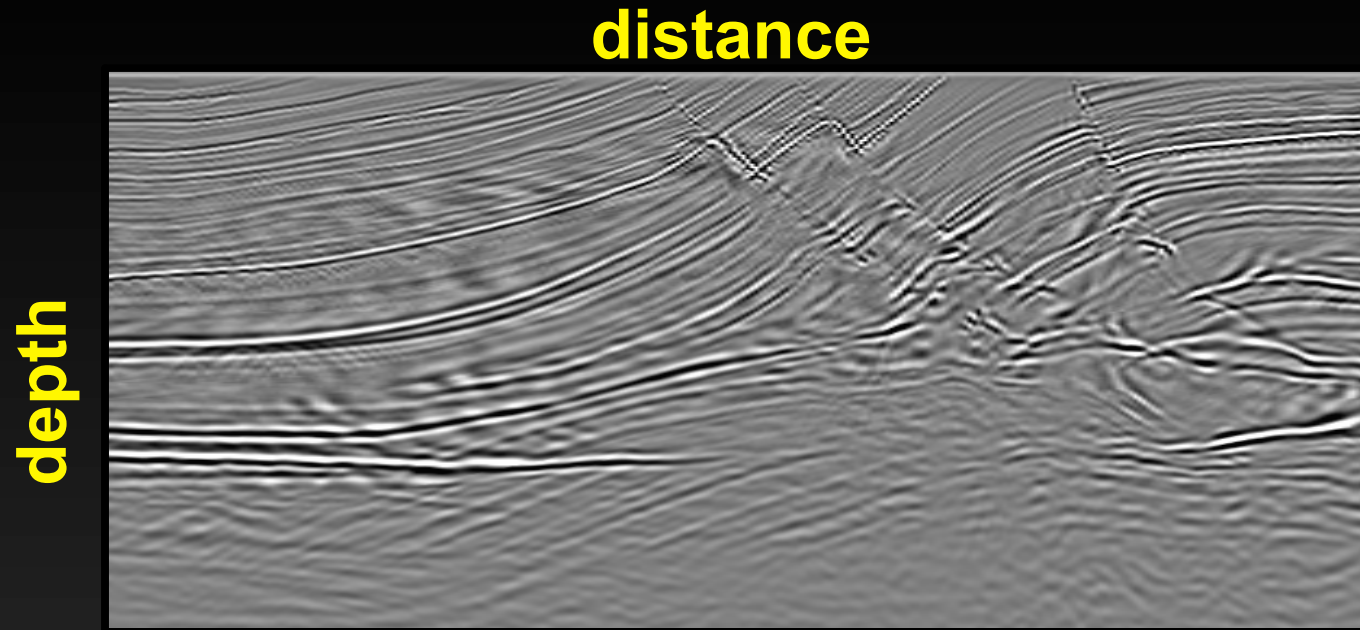
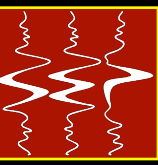


Reasonable reconstruction of the
subsurface

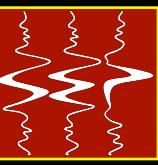
Flat reflectors in the angle gathers



Migration with wrong velocity

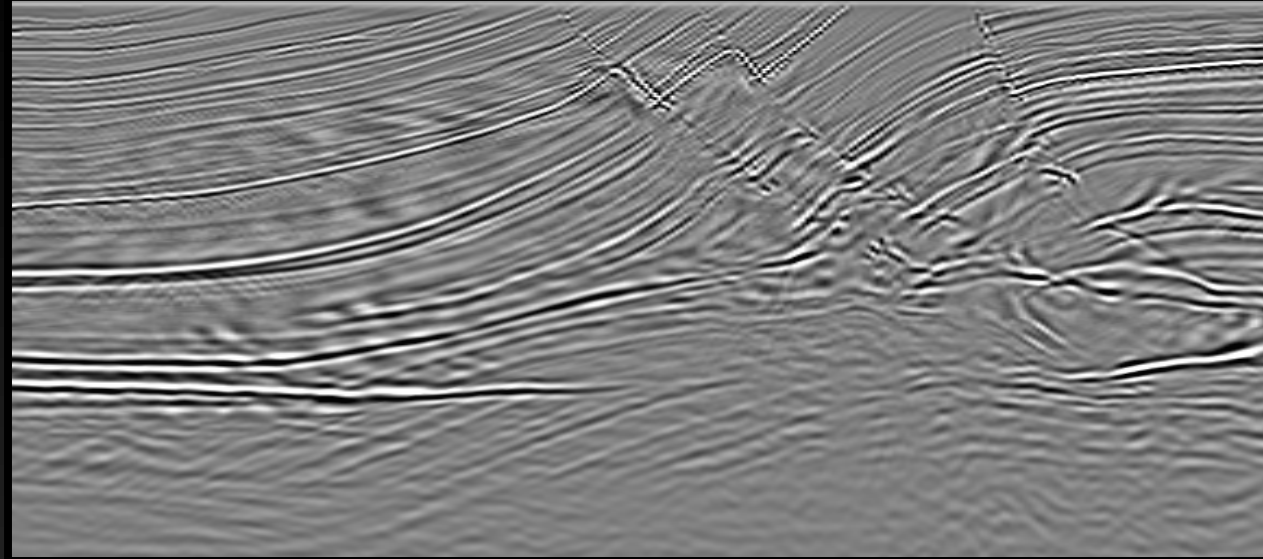


Unfocused image, wrong positioning

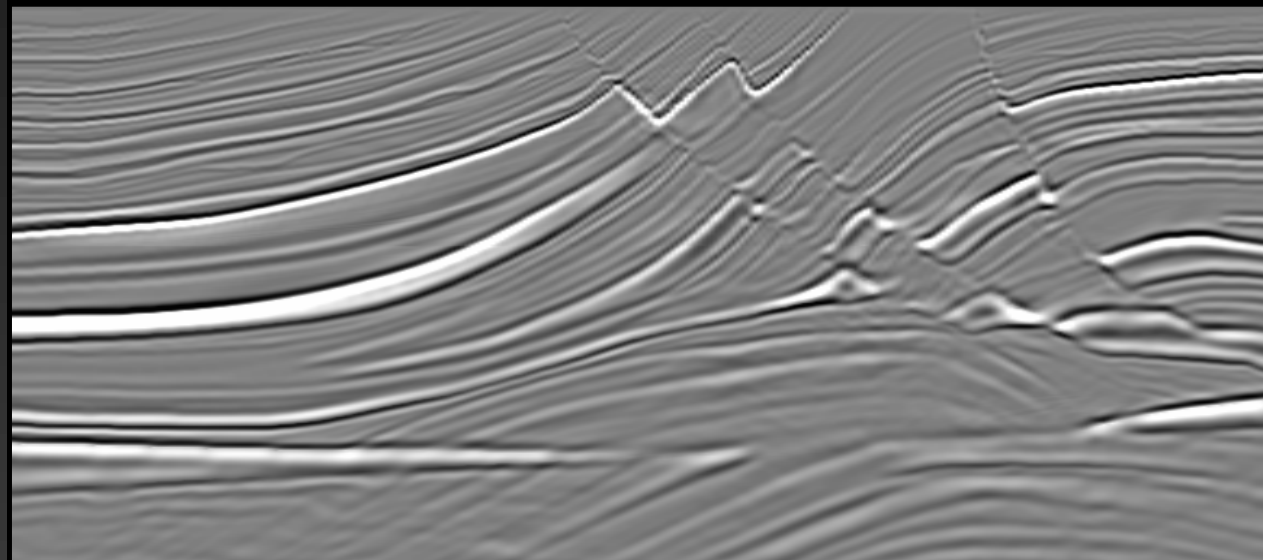


distance

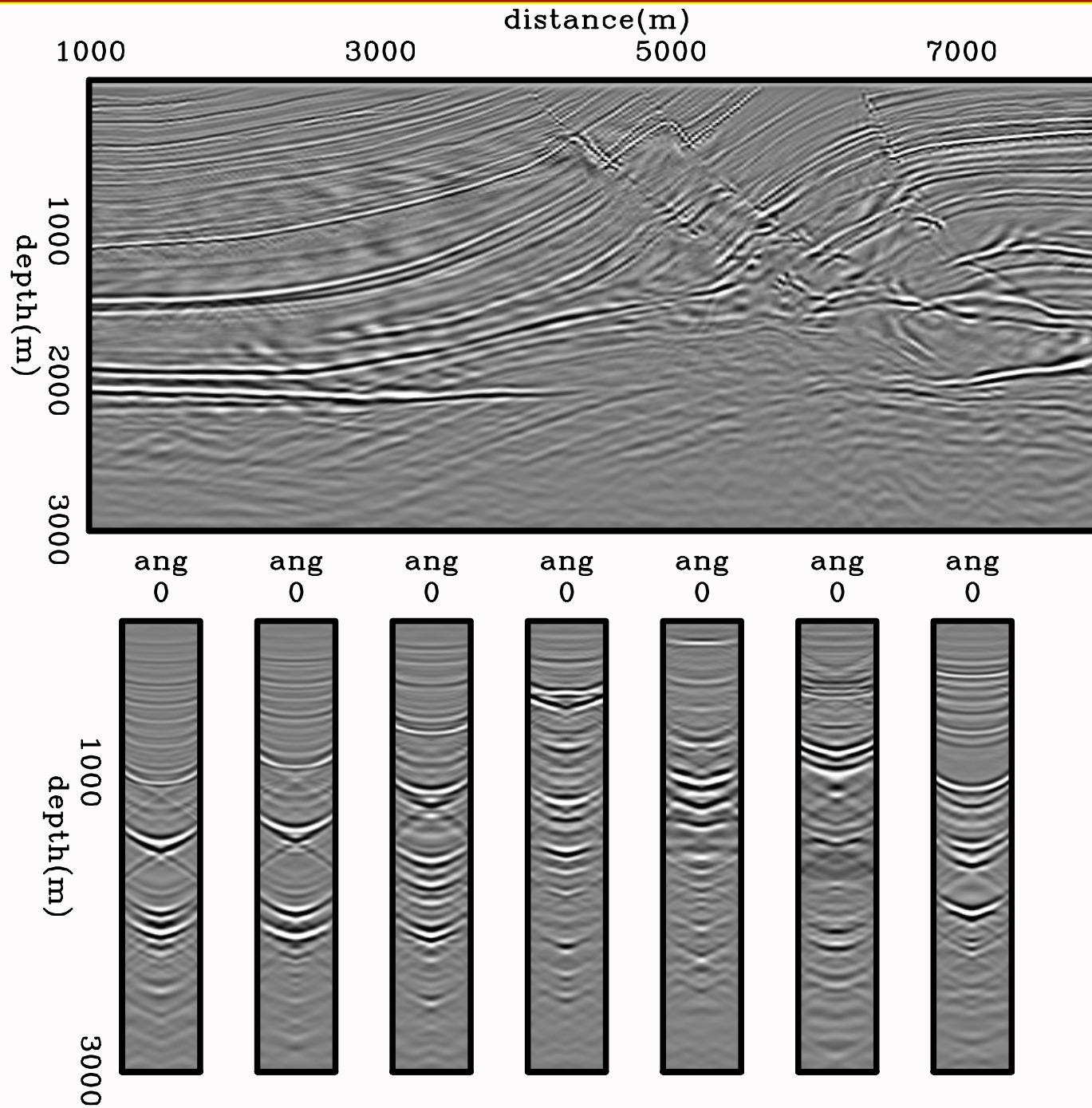
depth



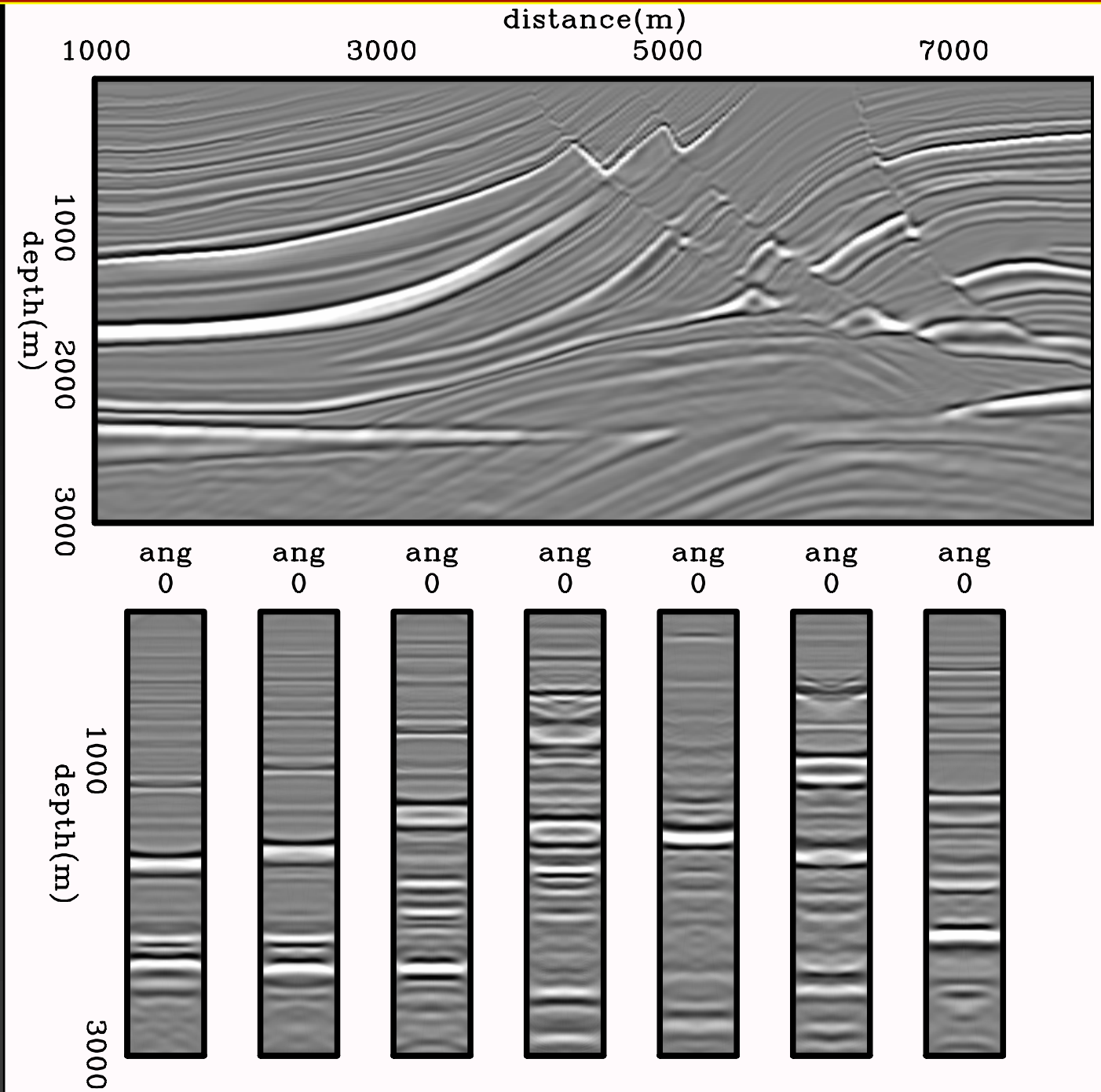
depth



Curved reflectors in the angle gathers

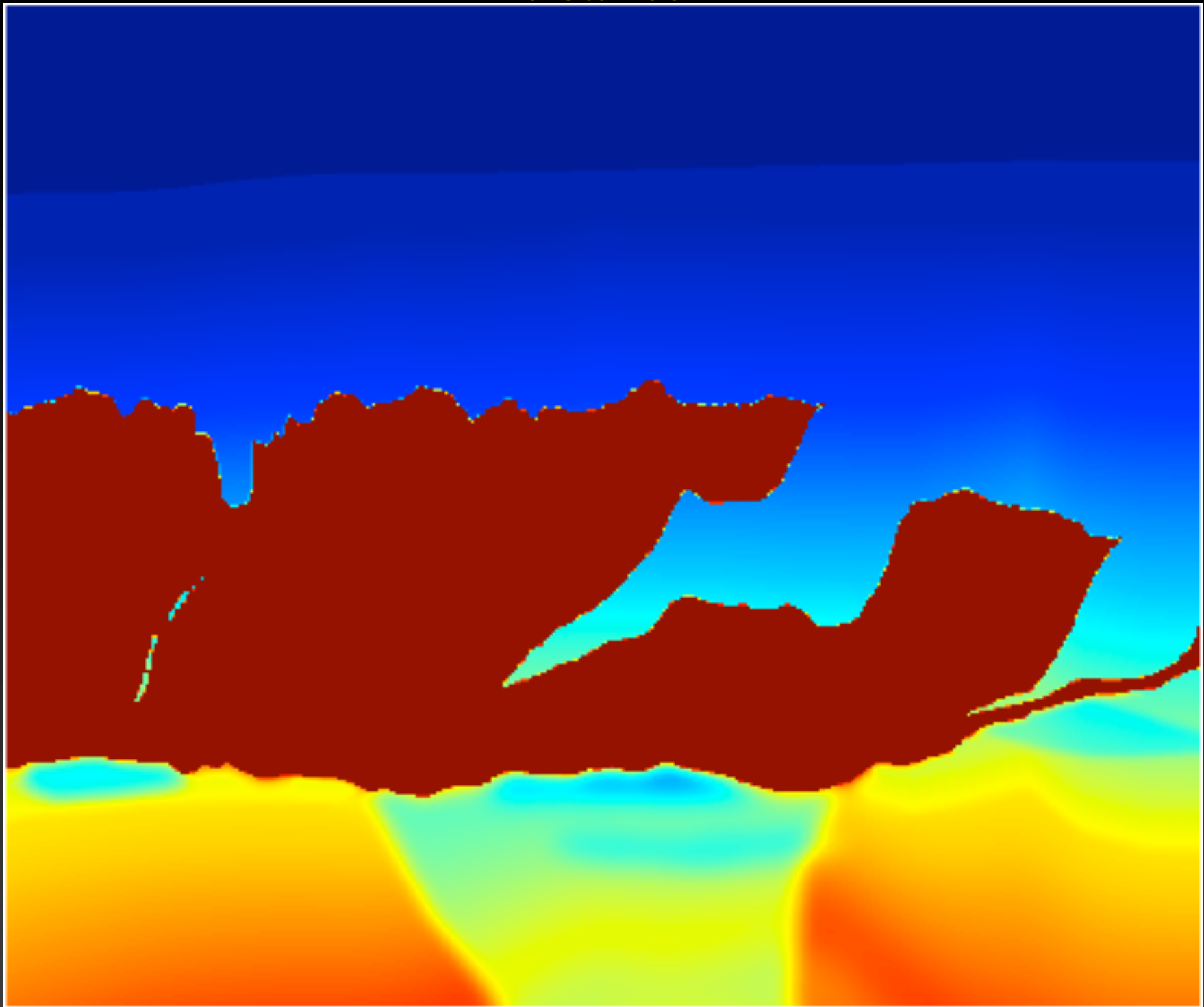


Flat reflectors in the angle gathers



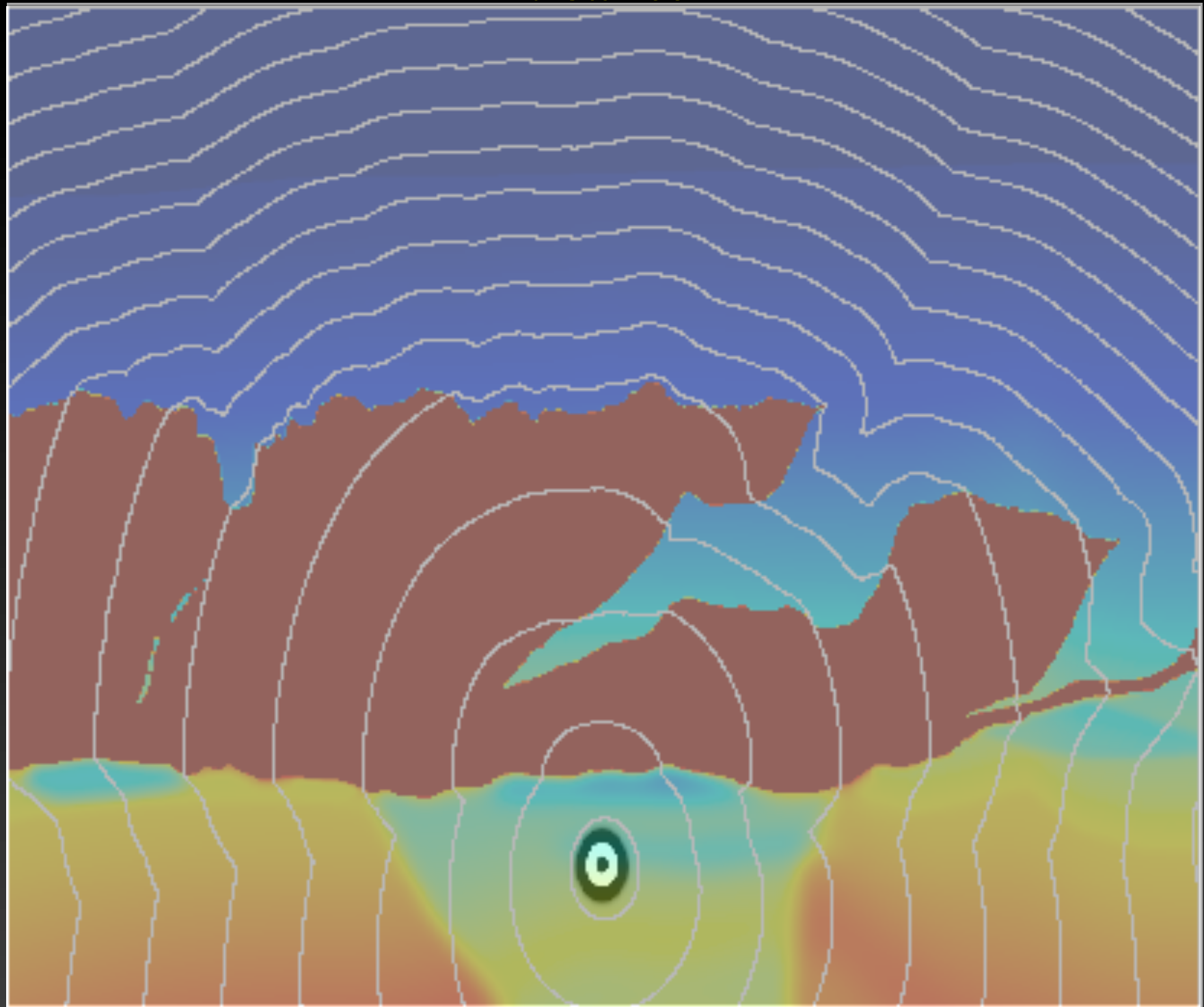
distance

depth



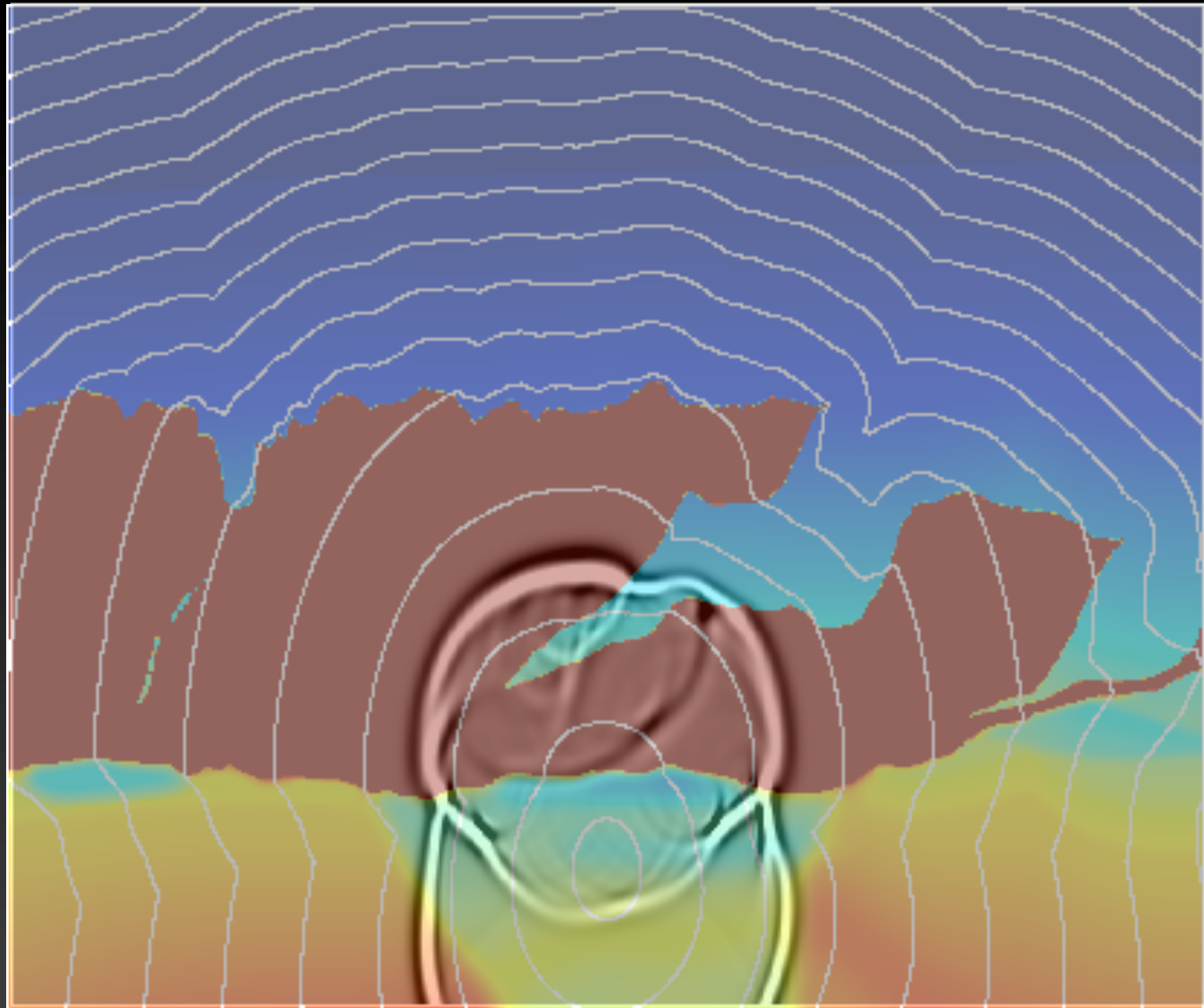
distance

depth



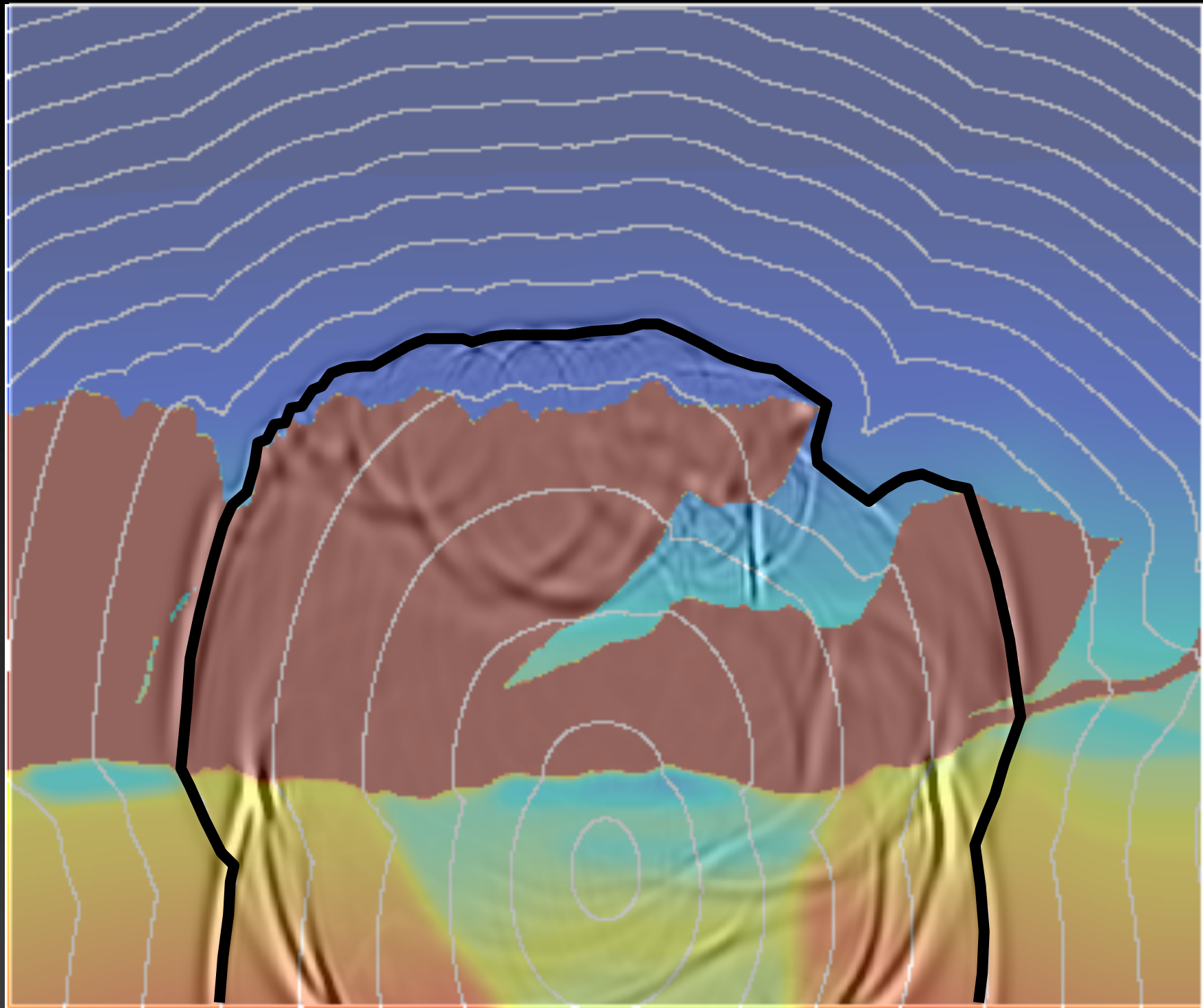
distance

depth



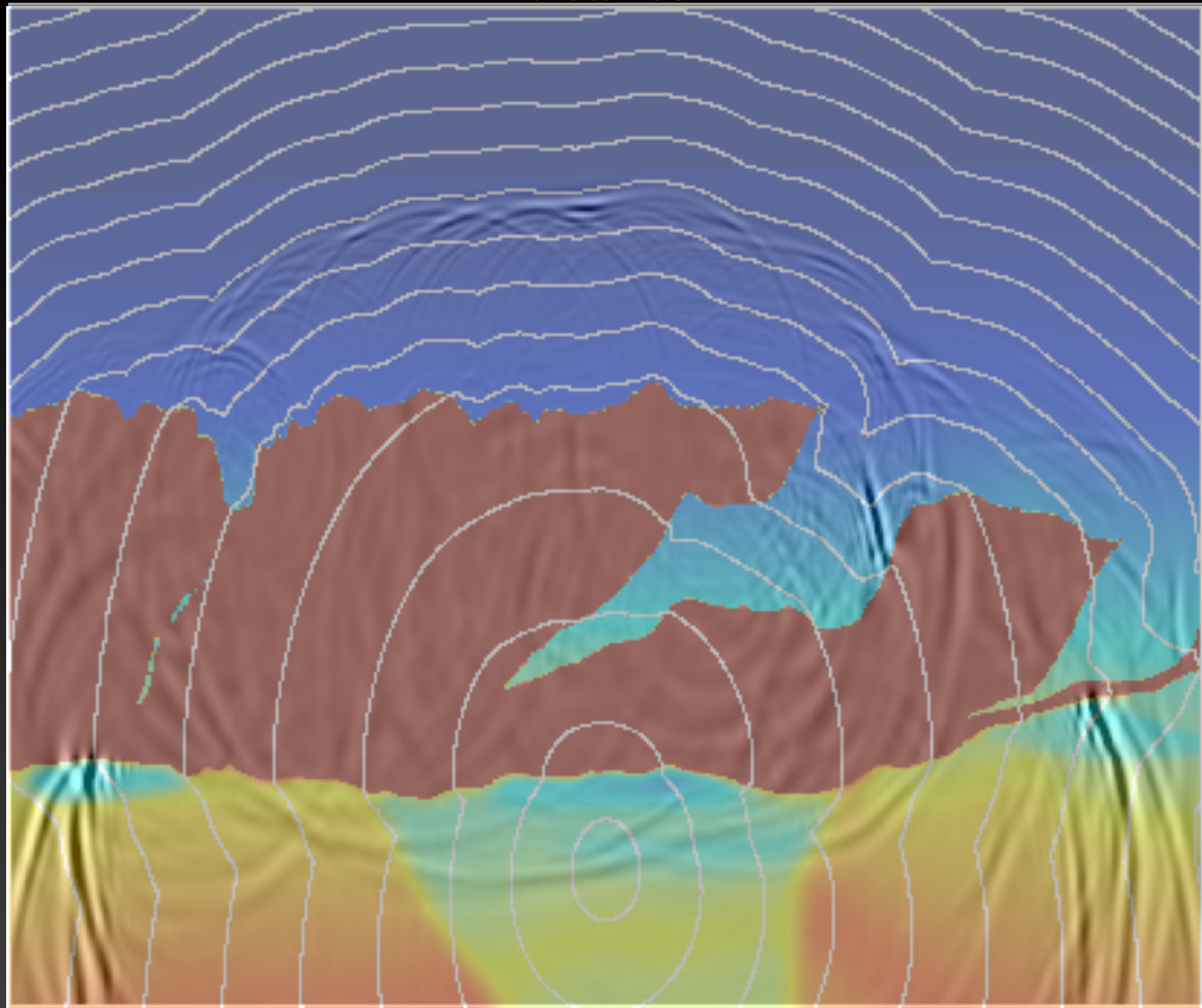
distance

depth



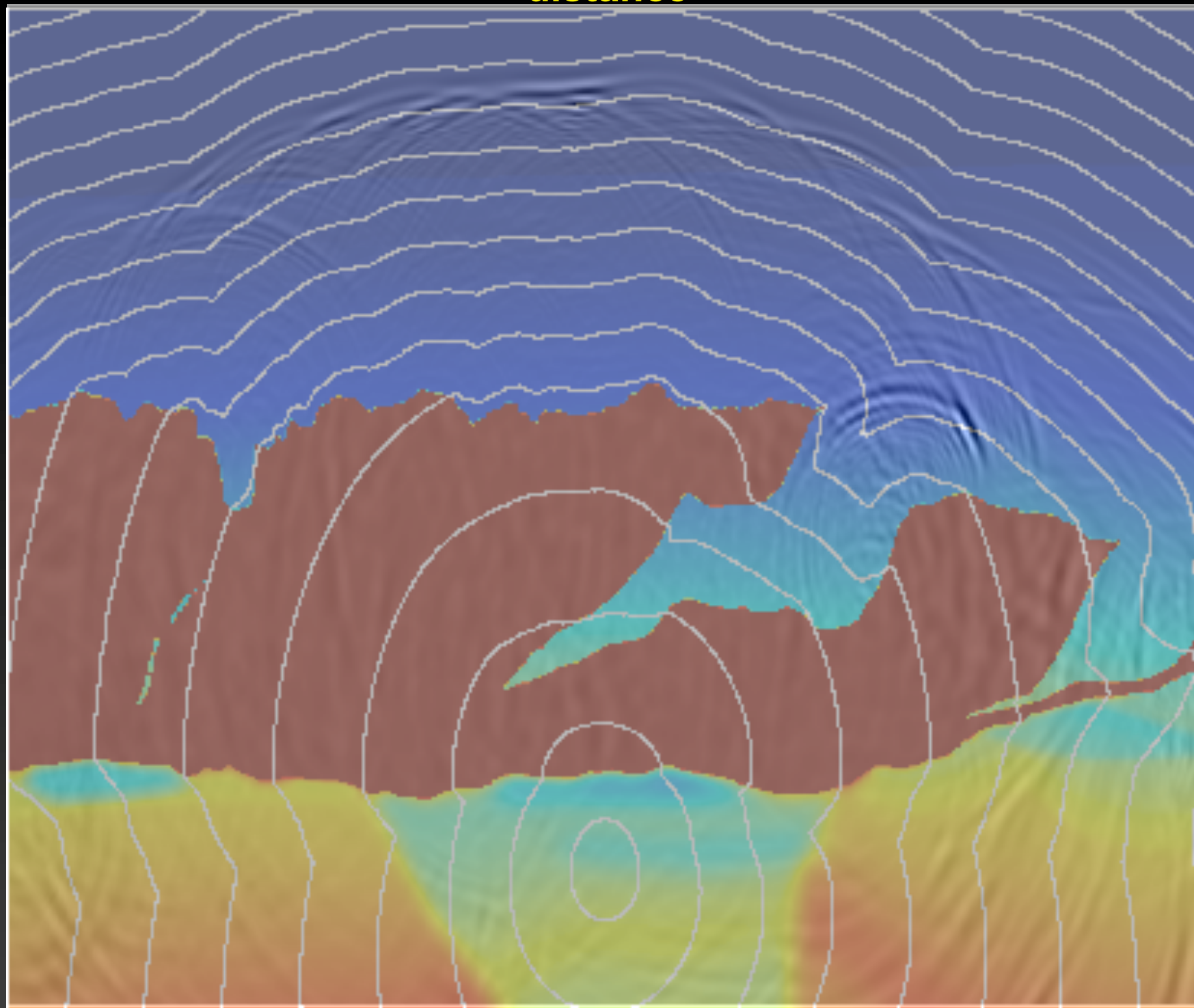
distance

depth



distance

depth





- **Data space**
 - waveform inversion

$$J(s) = \|\mathbf{F}[s] - d_{obs}\|_n$$

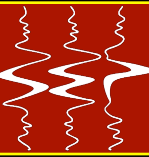
J = objective function

\mathbf{F} = nonlinear operator

n = norm

s = slowness

d_{obs} = observed data



- **Image space (ISWET)**

$$I(s) \approx I_o + \left. \frac{\partial I}{\partial s} \right|_{s=s_o} \Delta s$$

$$\Delta I(s) = \mathbf{T} \Delta s$$

s = slowness

s_o = background slowness

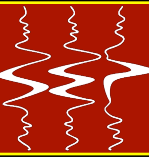
Δs = slowness perturbation

\mathbf{T} = IS – tomographic operator

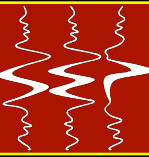
I = image

I_o = background image

ΔI = image perturbation

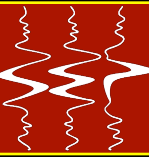


- **Image space (ISWET)**
 - wave-equation migration-velocity analysis (WEMVA) (Sava and Biondi, 2004)
 - differential-semblance velocity analysis (DVSA) (Shen and Symes, 2008)

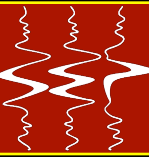


- **Image space (ISWET)**
 - wave-equation migration-velocity analysis (WEMVA) (Sava and Biondi, 2004)
 - **differential-semblance velocity analysis (DVSA)** (Shen and Symes, 2008)

For complex geology ...

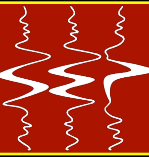


- **ISWET is more robust than ray-based methods**



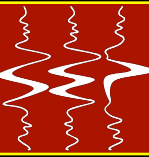
- **ISWET is more robust than ray-based methods**
- **Rarely been applied in 3D**
 - **High cost and lower flexibility than ray-based methods**

3D-ISWET as routine processing



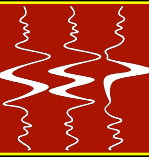
- **Reduce cost**

3D-ISWET as routine processing



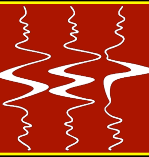
- **Reduce cost**
- **Improve flexibility**

3D-ISWET as routine processing

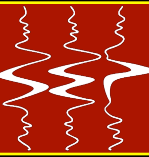


- **Reduce cost**
- **Improve flexibility**
- **Keep robustness**

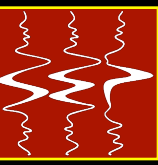
Reducing 3D-ISWET cost



- **Decrease data size**

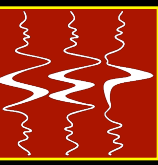


- **Decrease data size**
- **Solve in a target-oriented manner**
 - **Wavefield propagation restricted to the inaccurate velocity region**

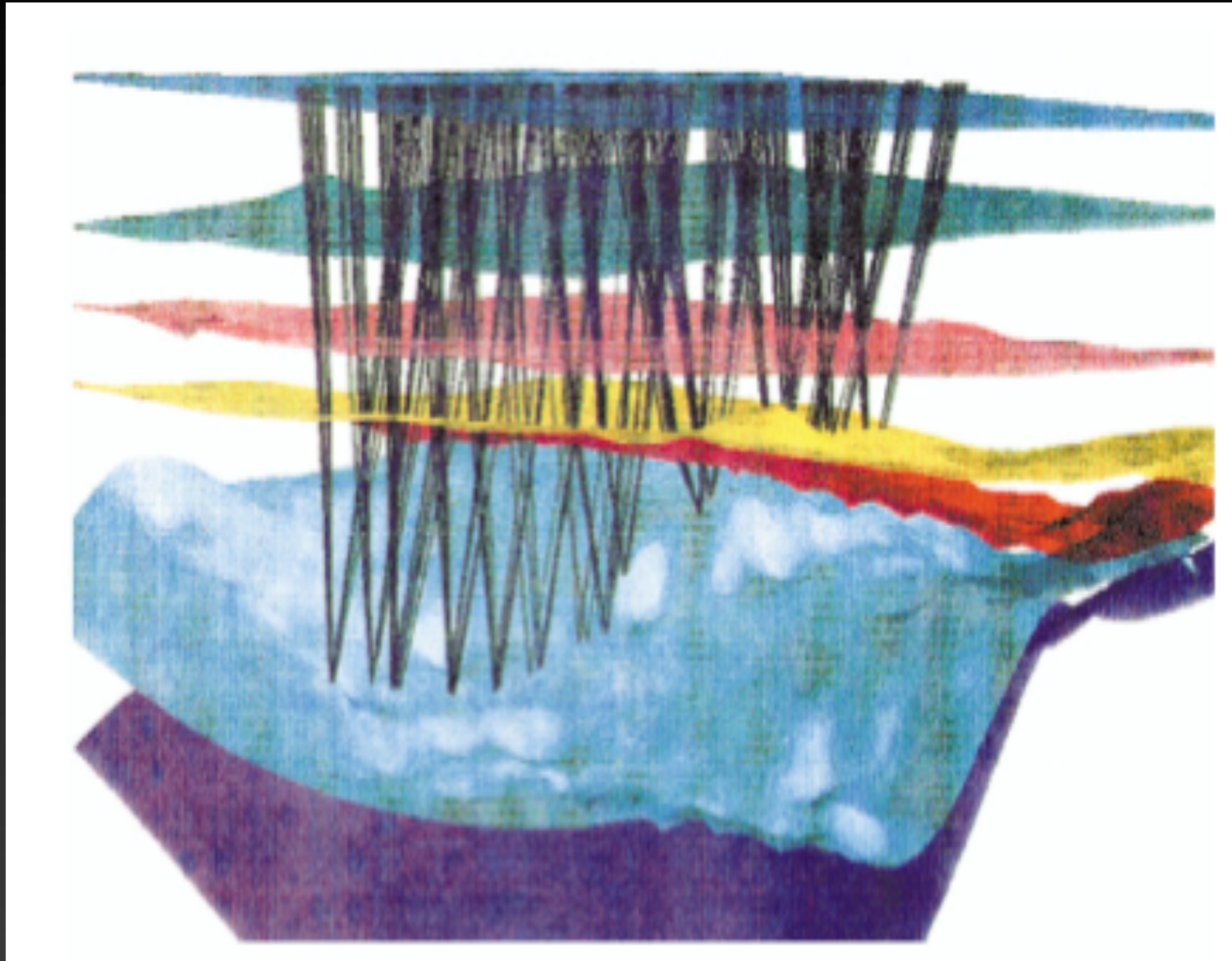


- **Incorporate strategies from ray-based methods into ISWET**

Ray-based strategies

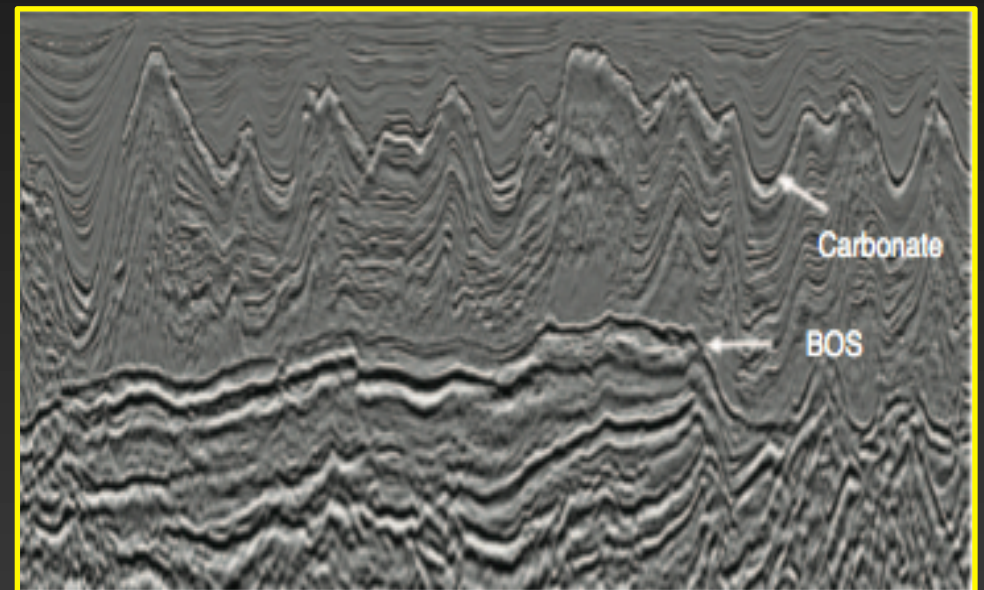
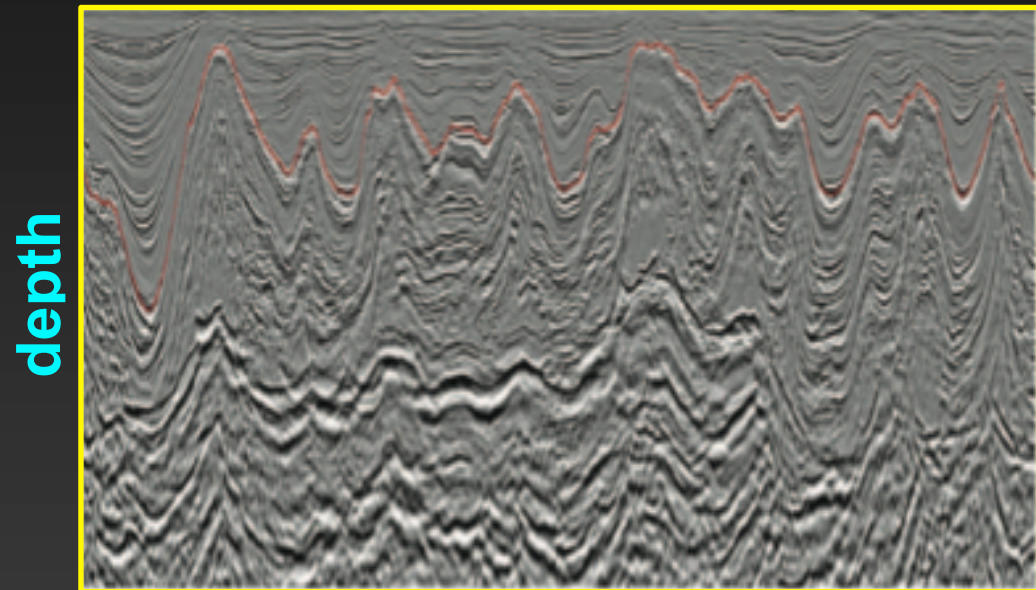
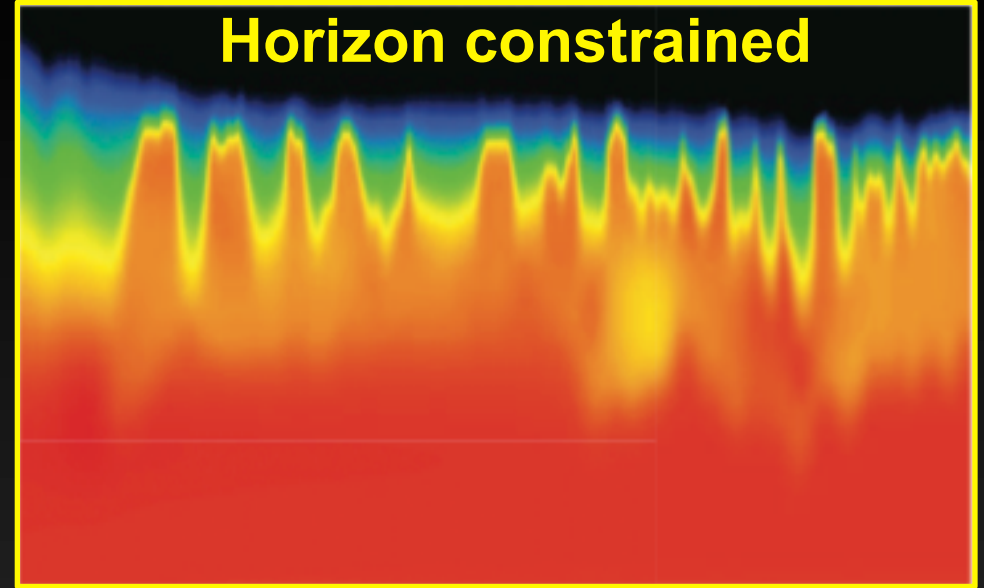
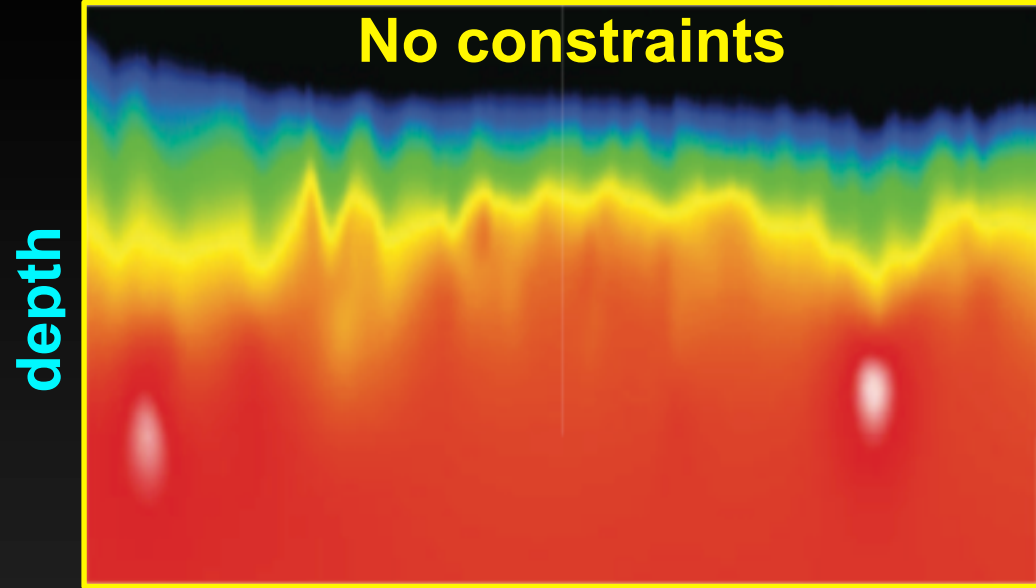
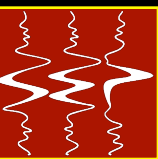


Horizon-based



Jones et al., 1998

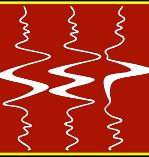
Ray-based strategies



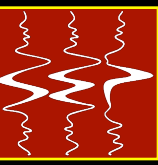
distance

Wang et al., 2008

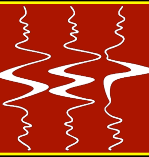
distance



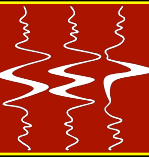
- **Incorporate strategies from ray-based methods into ISWET**
 - **Use image-space generalized wavefields**



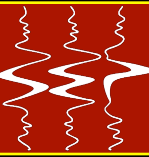
- **Guarantee correct kinematics and reasonable amplitudes**



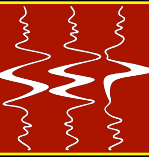
- **Wavefields combined using linearity of wavefield propagation**



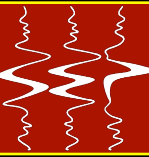
- **Wavefields combined using linearity of wavefield propagation**
 - **Smaller number of seismic experiments**



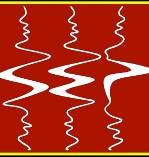
- **Wavefields combined using linearity of wavefield propagation**
 - **Smaller number of seismic experiments**
 - **Keeping intact kinematic information**



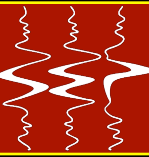
- **Wavefields combined using linearity of wavefield propagation**
 - **Smaller number of seismic experiments**
 - **Keeping intact kinematic information**
- **Seismic acquisition**
 - **Simultaneous sources**



- **Wavefields combined using linearity of wavefield propagation**
 - **Smaller number of seismic experiments**
 - **Keeping intact kinematic information**
- **Seismic acquisition**
 - **Simultaneous sources**
- **Seismic processing**
 - **plane-wave encoding (Whitmore, 1995)**
 - **random-phase encoding (Romero et al., 2000)**

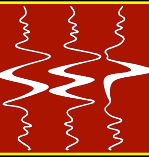


- **Data-space generalized sources**
 - plane-wave encoding
 - random-phase encoding



- **Data-space generalized sources**
 - plane-wave encoding
 - random-phase encoding

- **Image-space generalized sources**
 - Pre-stack exploding-reflector modeling - PERM (Biondi, 2006)
 - Image-space phase-encoded wavefields - ISPEW (Guerra and Biondi, 2008)



**Generalized-source
domain**

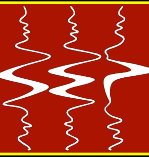


Data space

- plane waves
- random phases

Image space

- PERM wavefields
- ISPEW



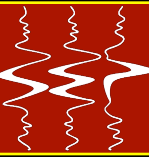
**Generalized-source
domain**

Data space

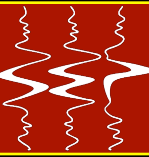
- plane waves
- random phases

Image space

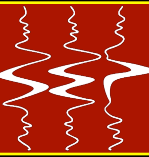
- PERM wavefields
- ISPEW



- **Chapter 2: Pre-stack exploding-reflector model**
- **Chapter 3: Image-space phase-encoded wavefields**
- **Chapter 4: MVA using image-space generalized sources**
- **Chapter 5: 3D-field data example**

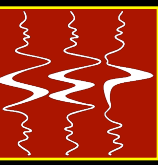


- **The exploding-reflector model synthesizes zero offset data, assuming focused reflectors at zero subsurface offset**



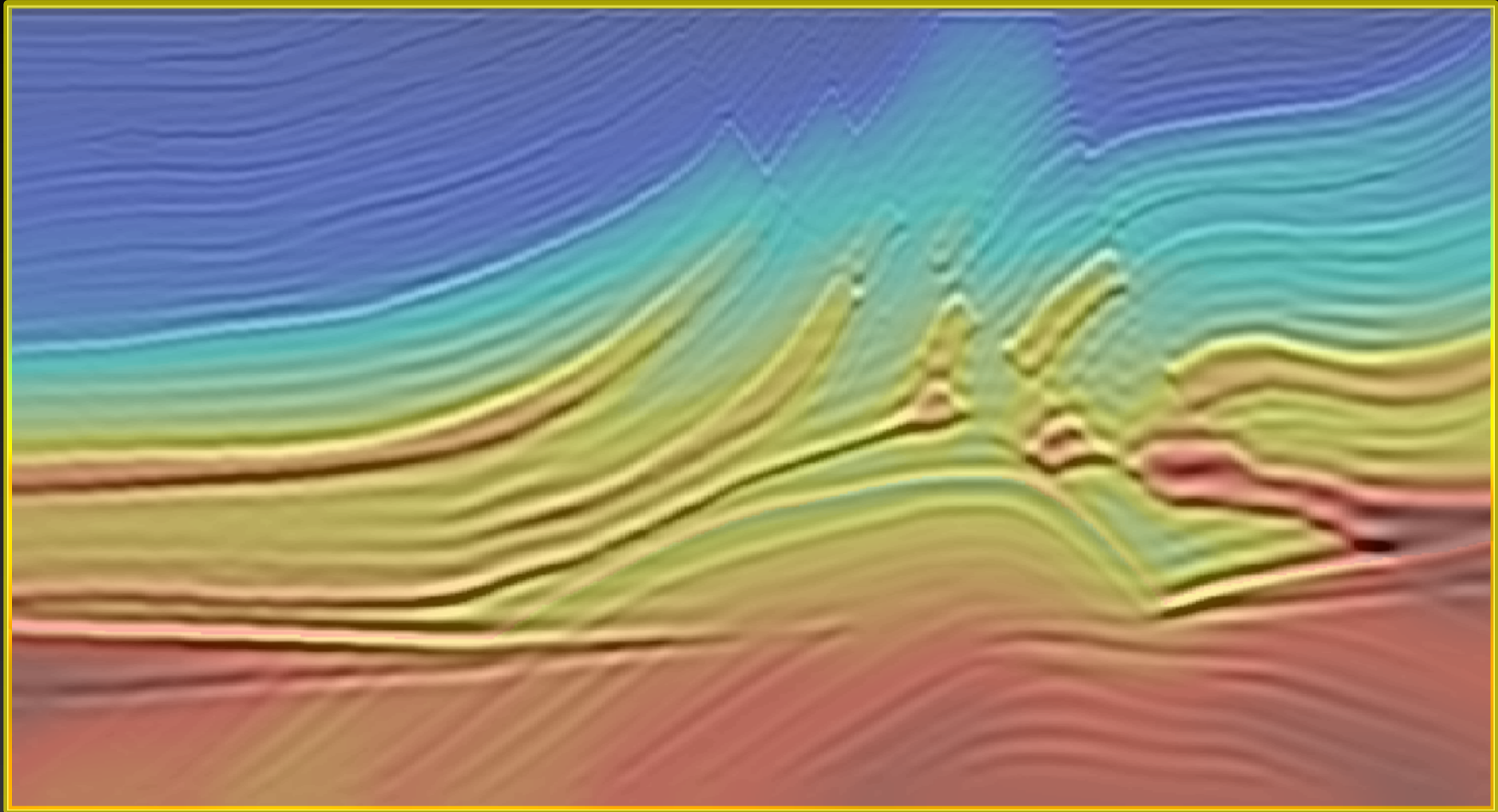
- **The exploding-reflector model synthesizes zero offset data, assuming focused reflectors at zero subsurface offset**
 - **Accurate velocity and complete illumination**

Exploding reflectors

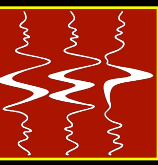


distance

depth

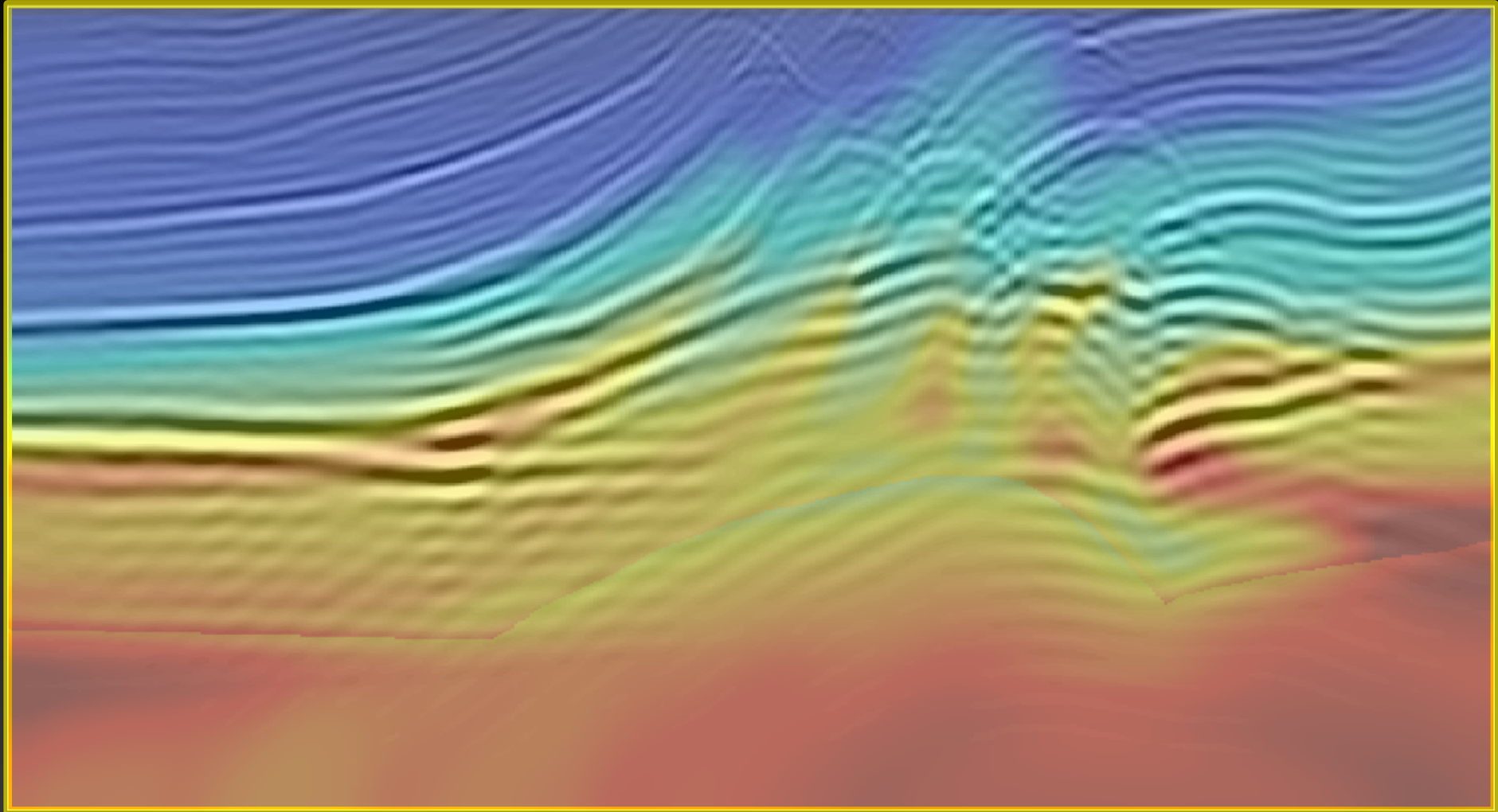


Exploding reflectors

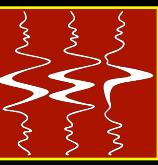


distance

depth

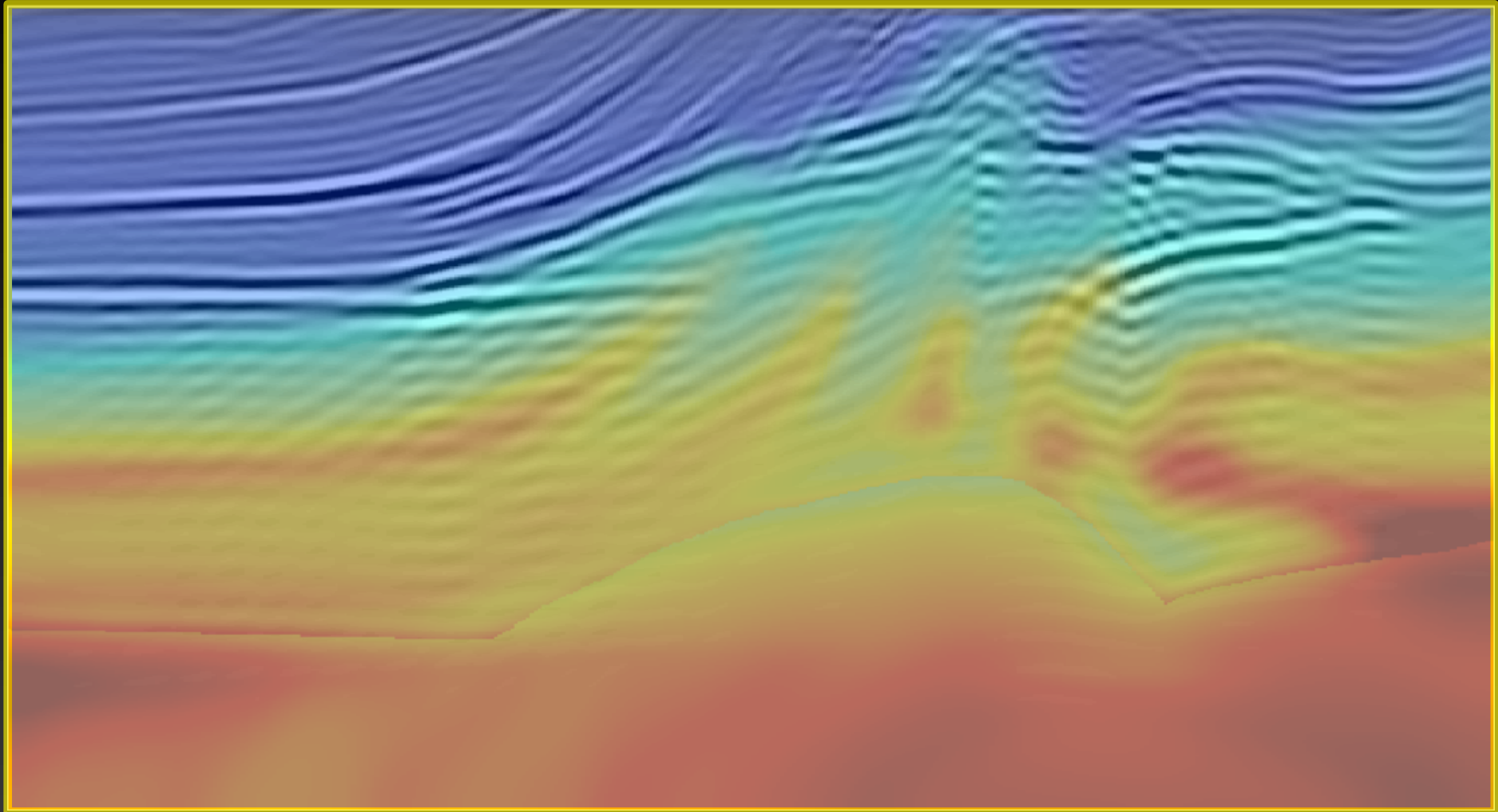


Exploding reflectors

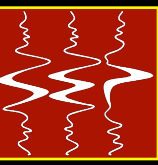


distance

depth

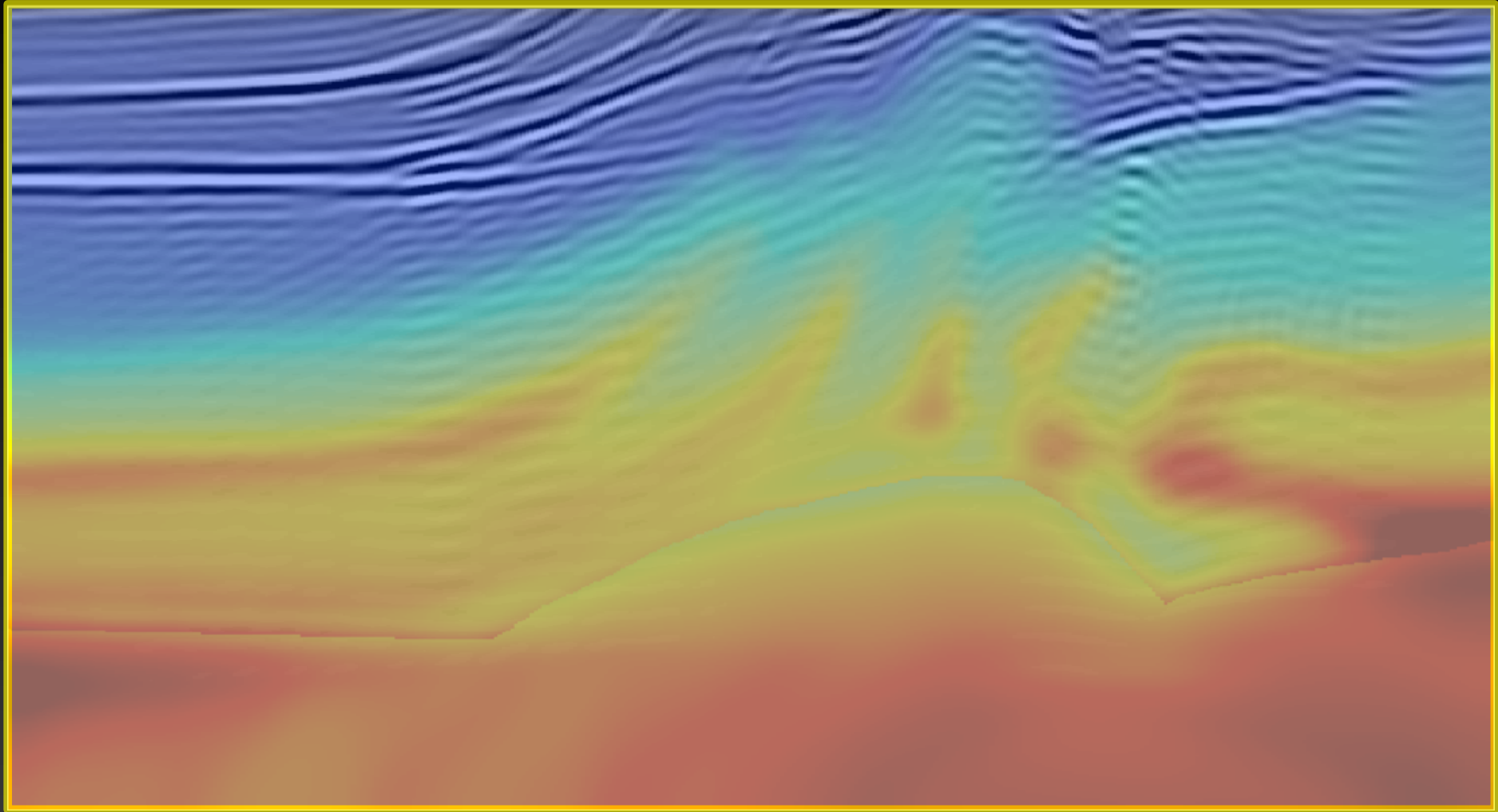


Exploding reflectors

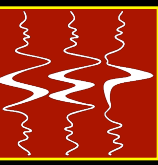


distance

depth

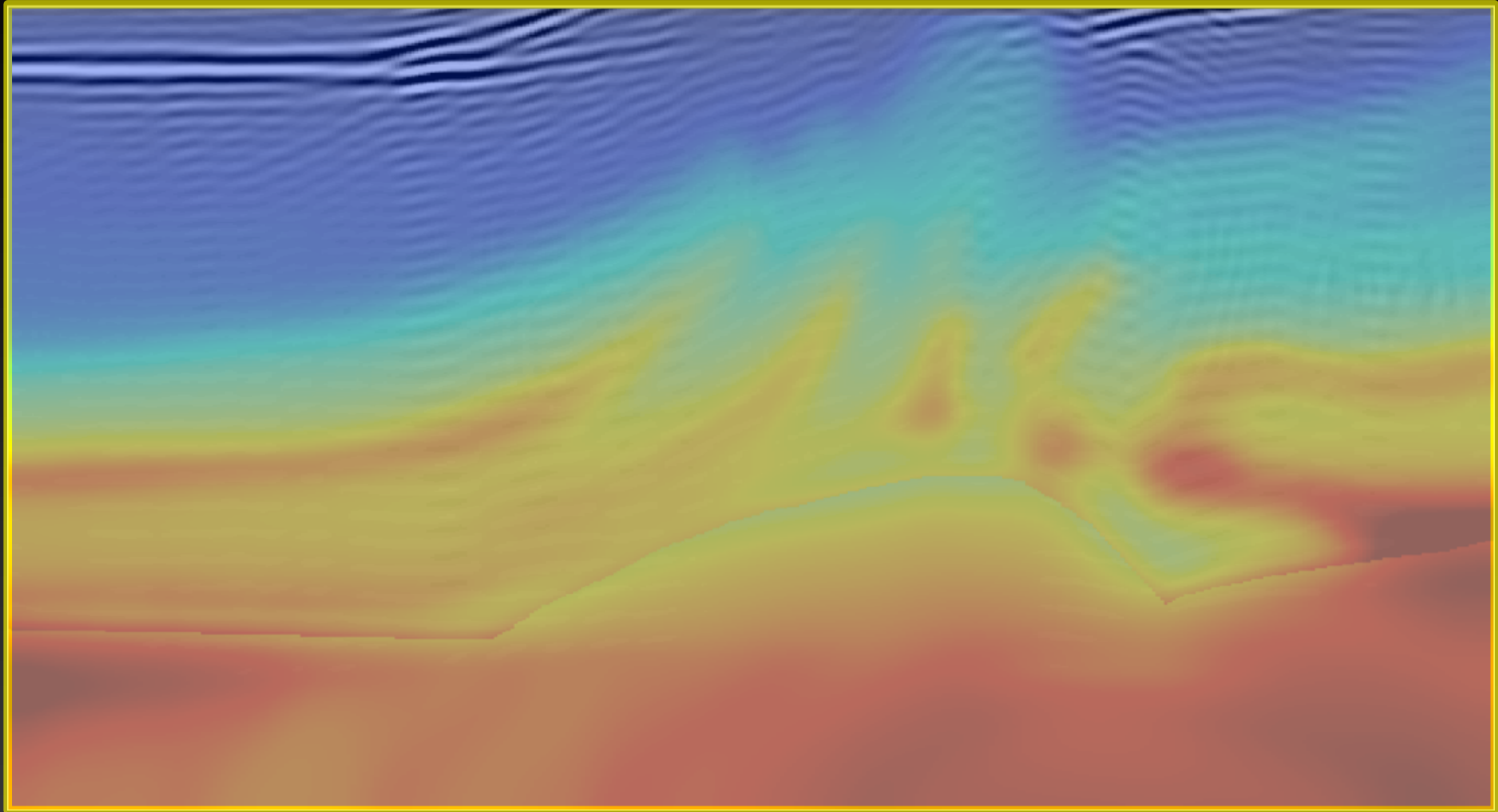


Exploding reflectors

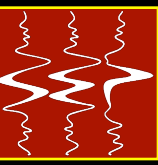


distance

depth

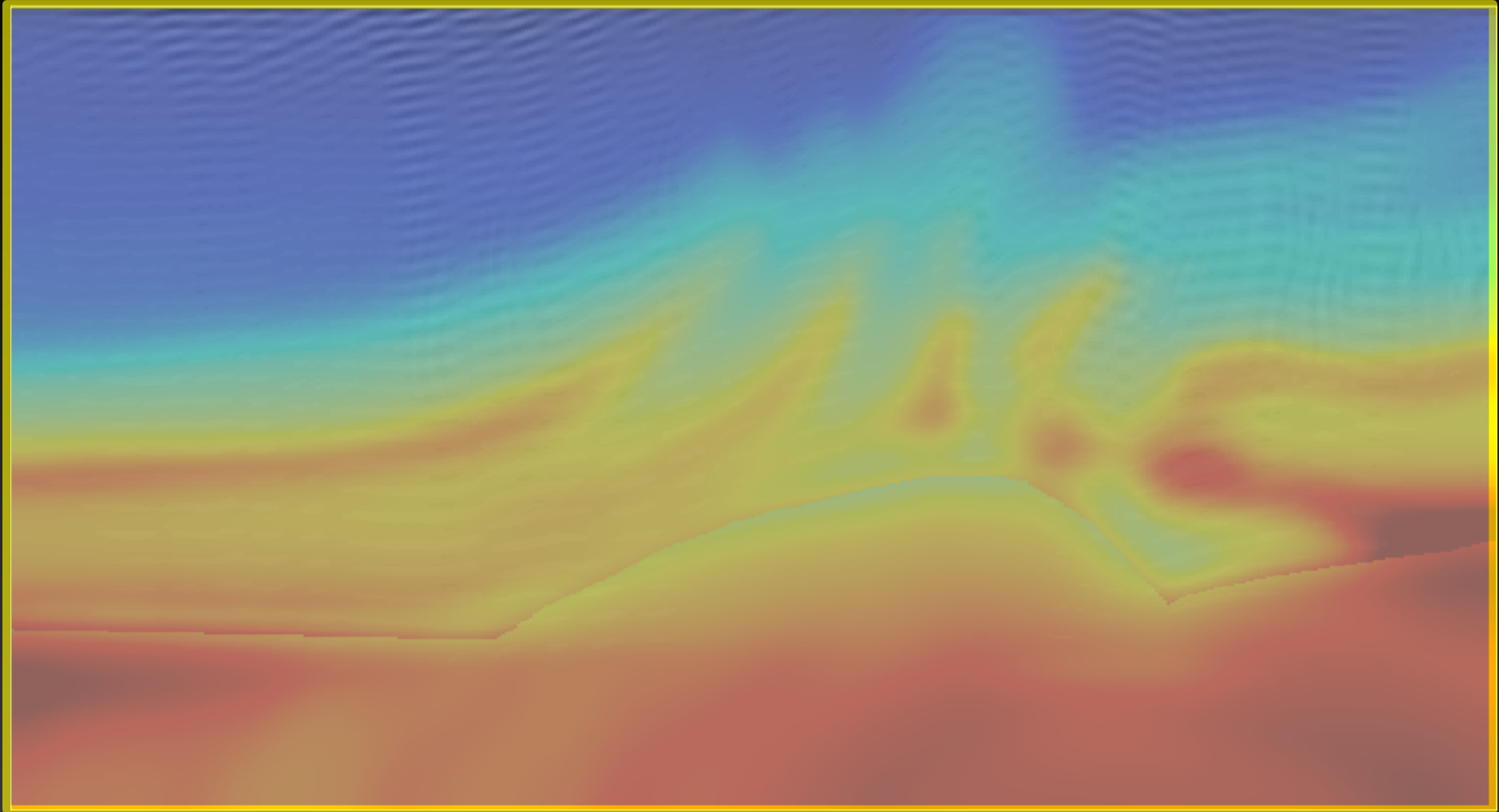


Exploding reflectors

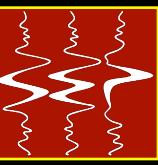


distance

depth

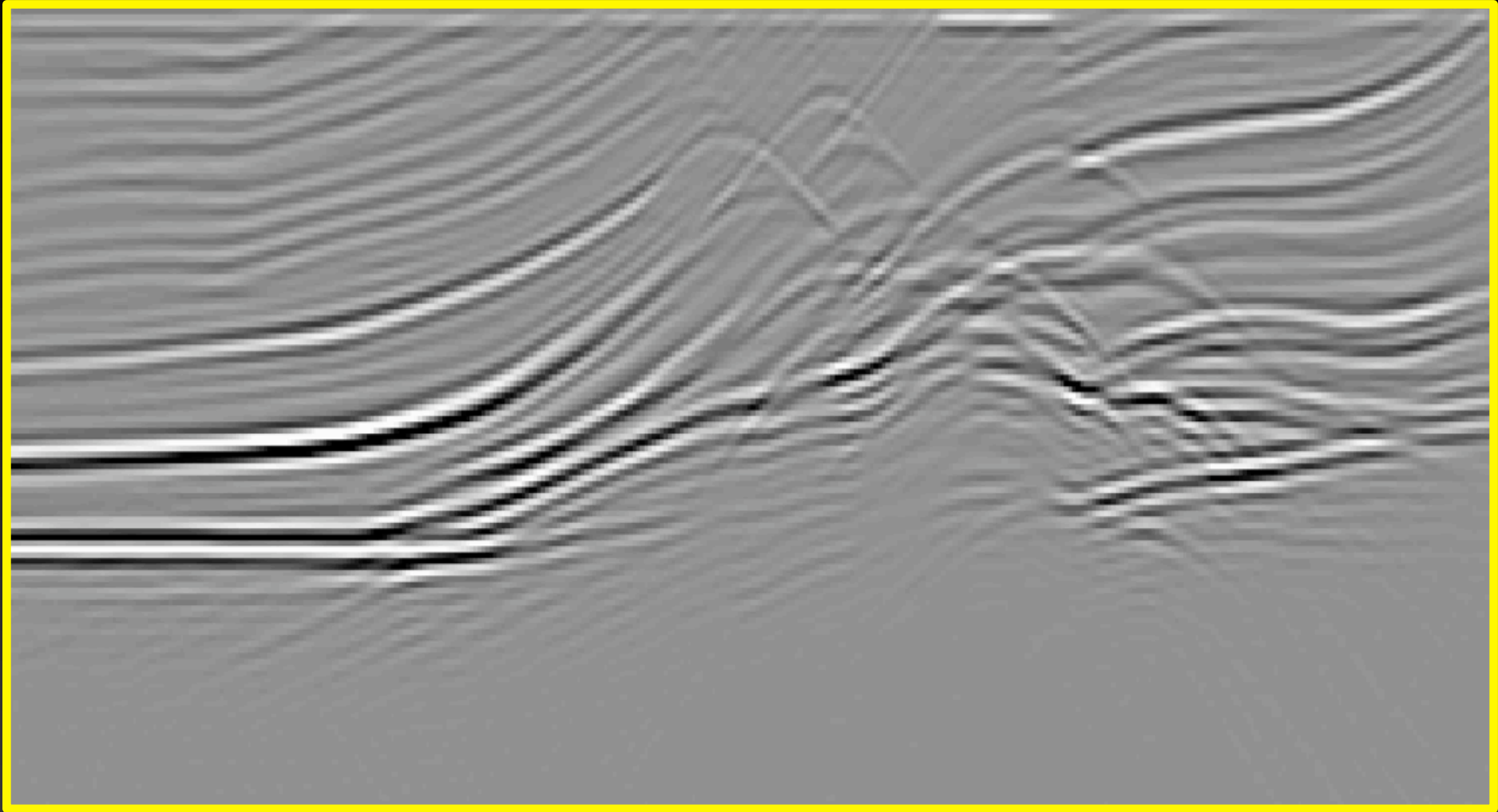


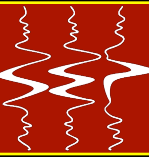
Zero-offset section



distance

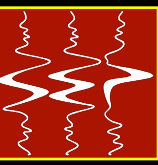
time





- **Generalizes the exploding-reflector model**
 - **Subsurface-offset gathers are used to model source and receiver wavefields**

Subsurface-offset gathers

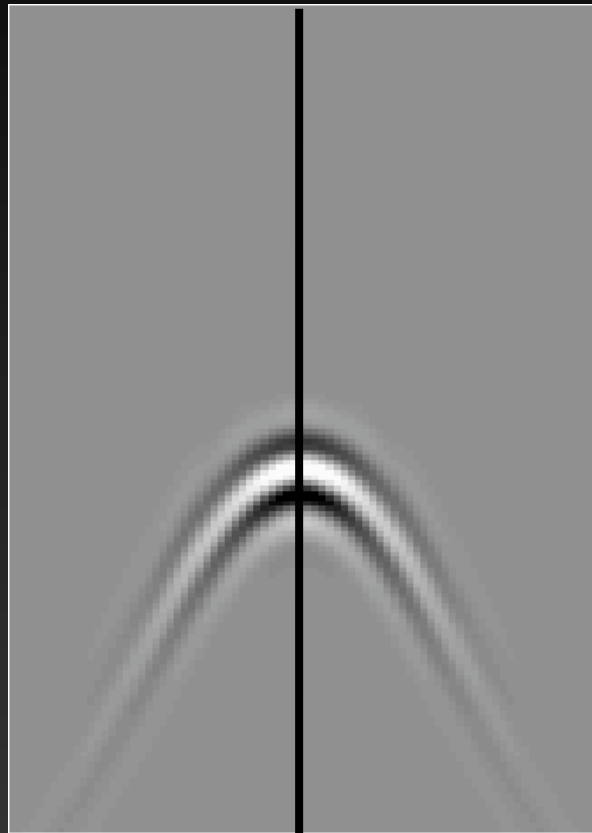


**SLOWER
VELOCITY**

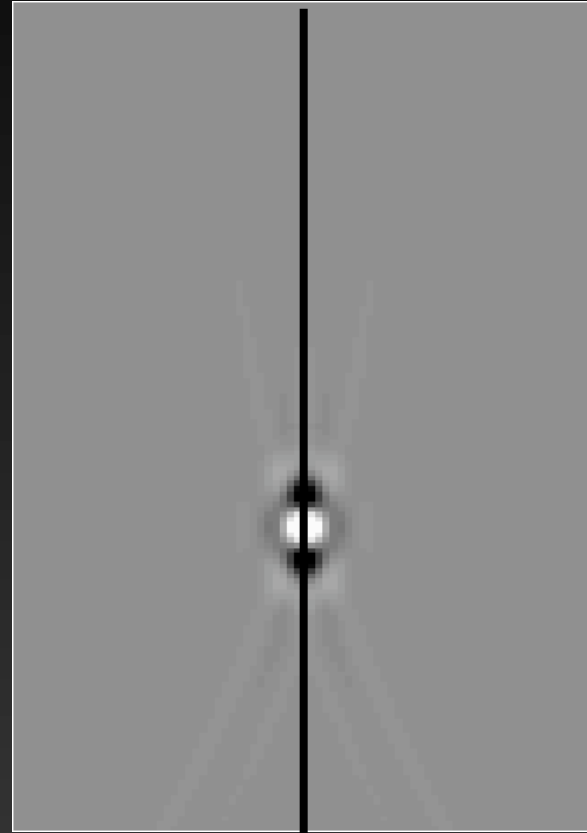
**CORRECT
VELOCITY**

**FASTER
VELOCITY**

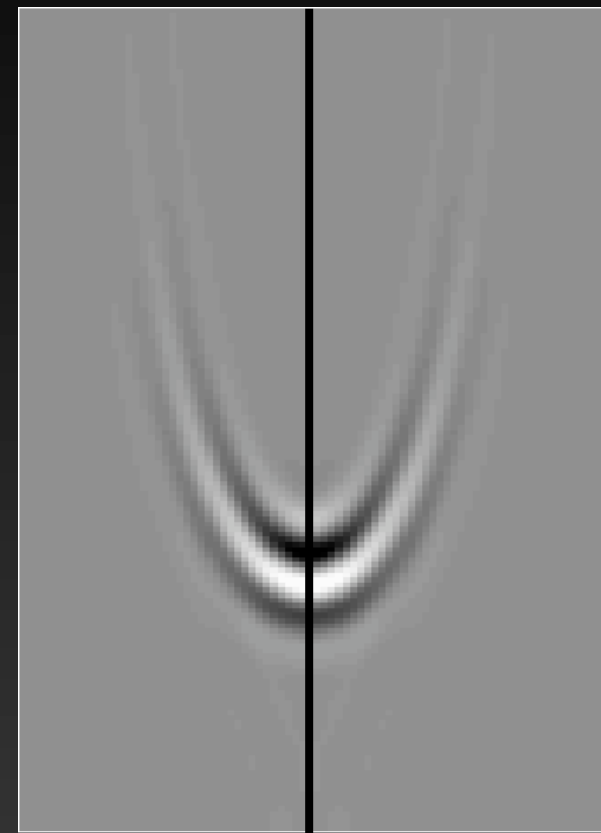
depth



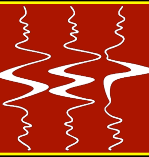
offset



offset

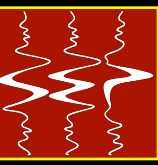


offset



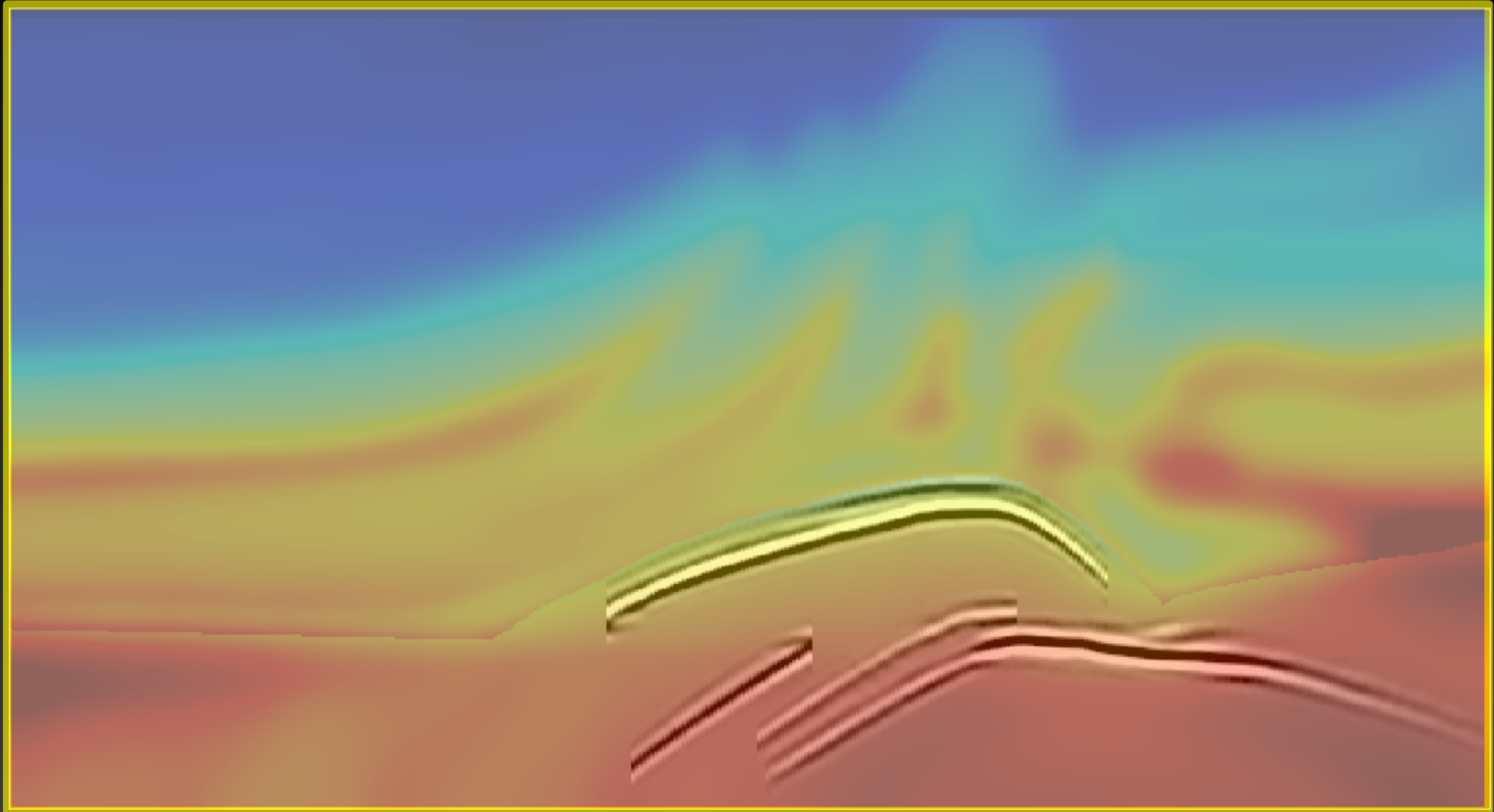
- **Generalizes the exploding-reflector model**
 - Subsurface-offset gathers are used to model source and receiver wavefields, allowing propagation of unfocused energy
- **Uses selected reflectors as the initial conditions**
 - Naturally incorporates a horizon-based tomography strategy into wave-extrapolation methods for velocity update

Modeling receiver wavefield



distance

depth

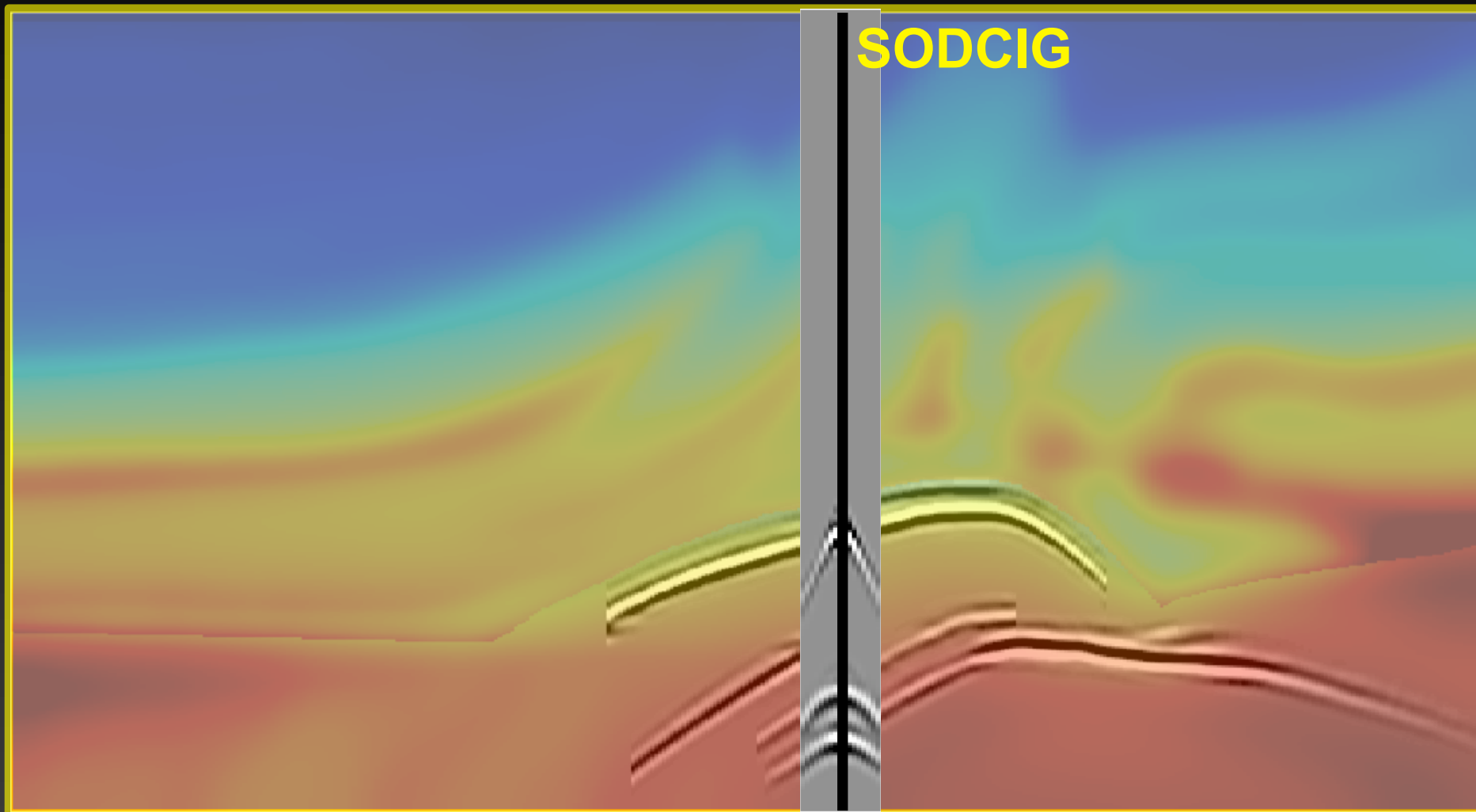


Modeling receiver wavefield

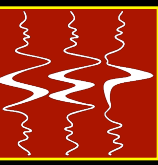


distance

depth

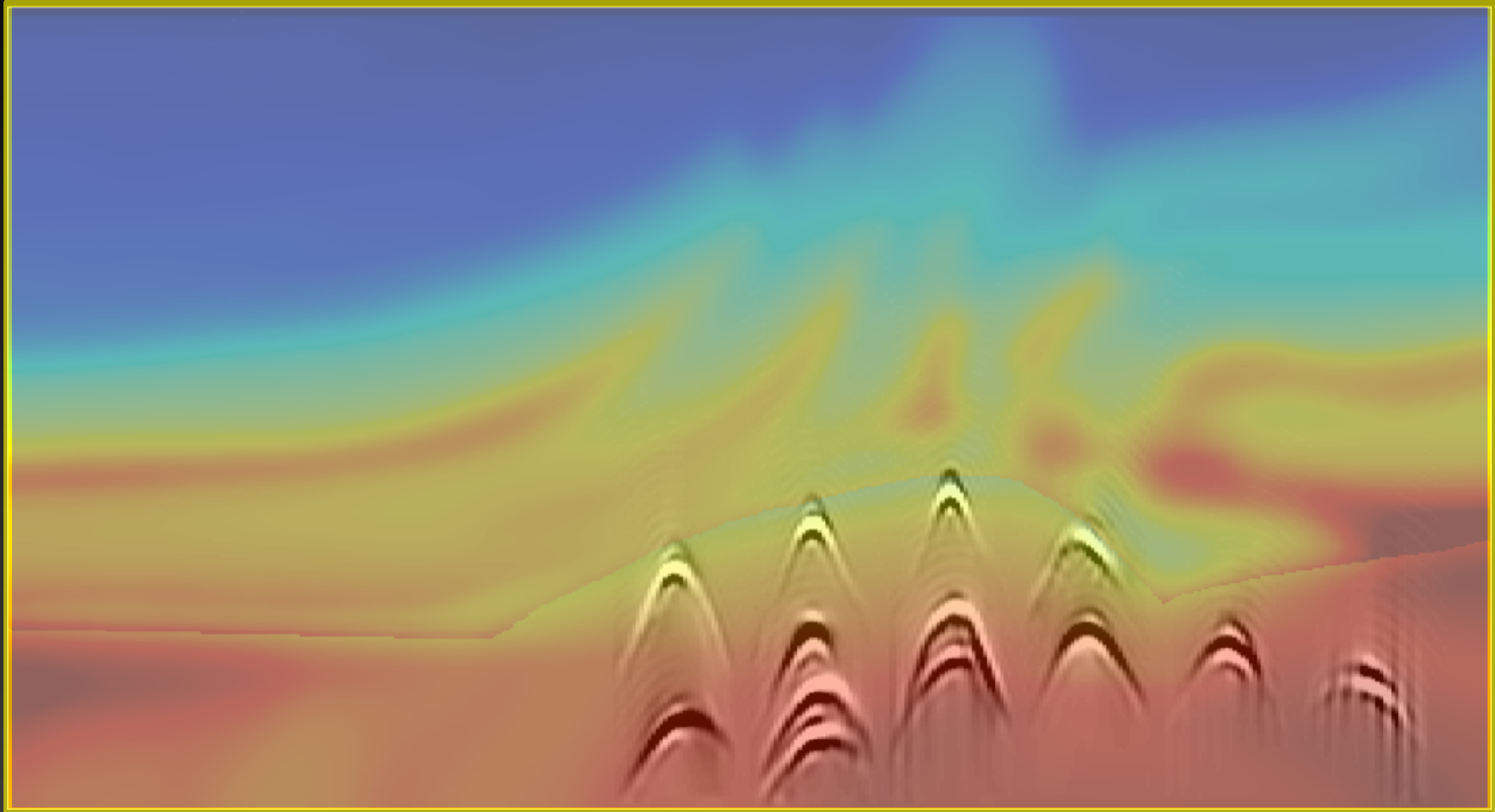


Modeling receiver wavefield

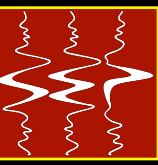


distance

depth

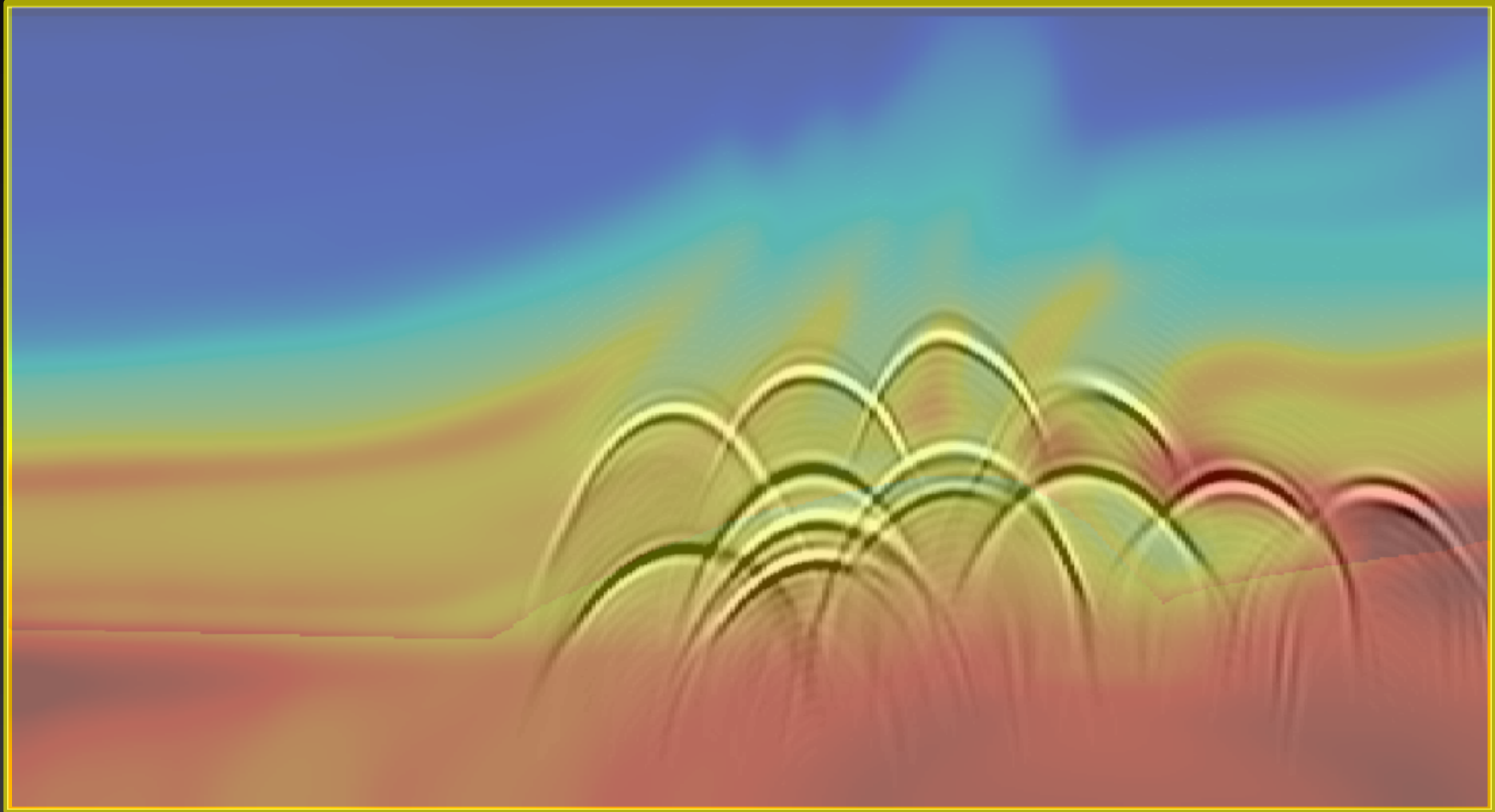


Modeling receiver wavefield

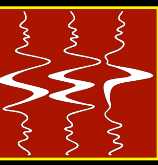


distance

depth

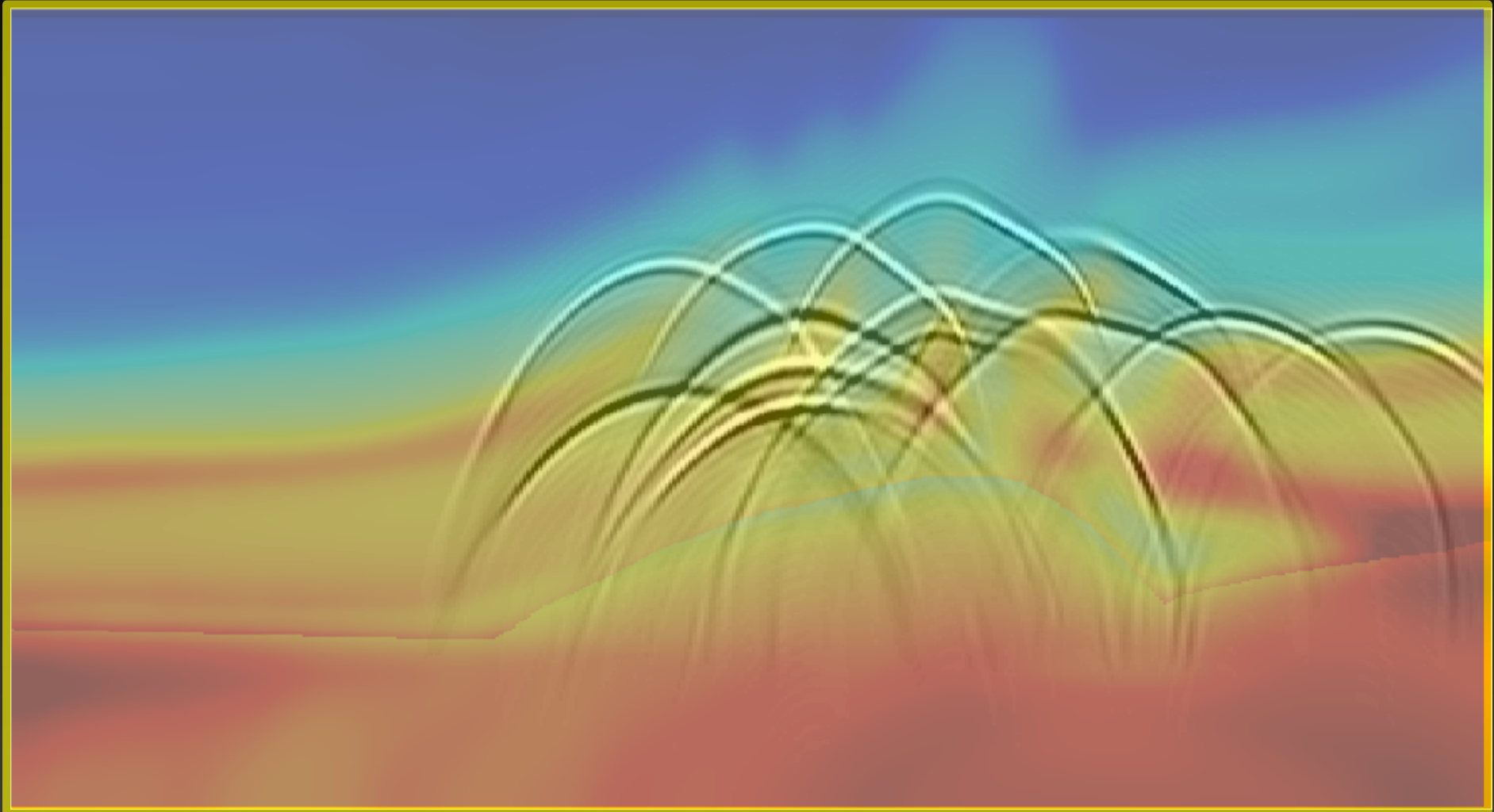


Modeling receiver wavefield

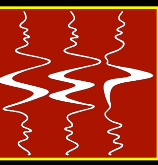


distance

depth

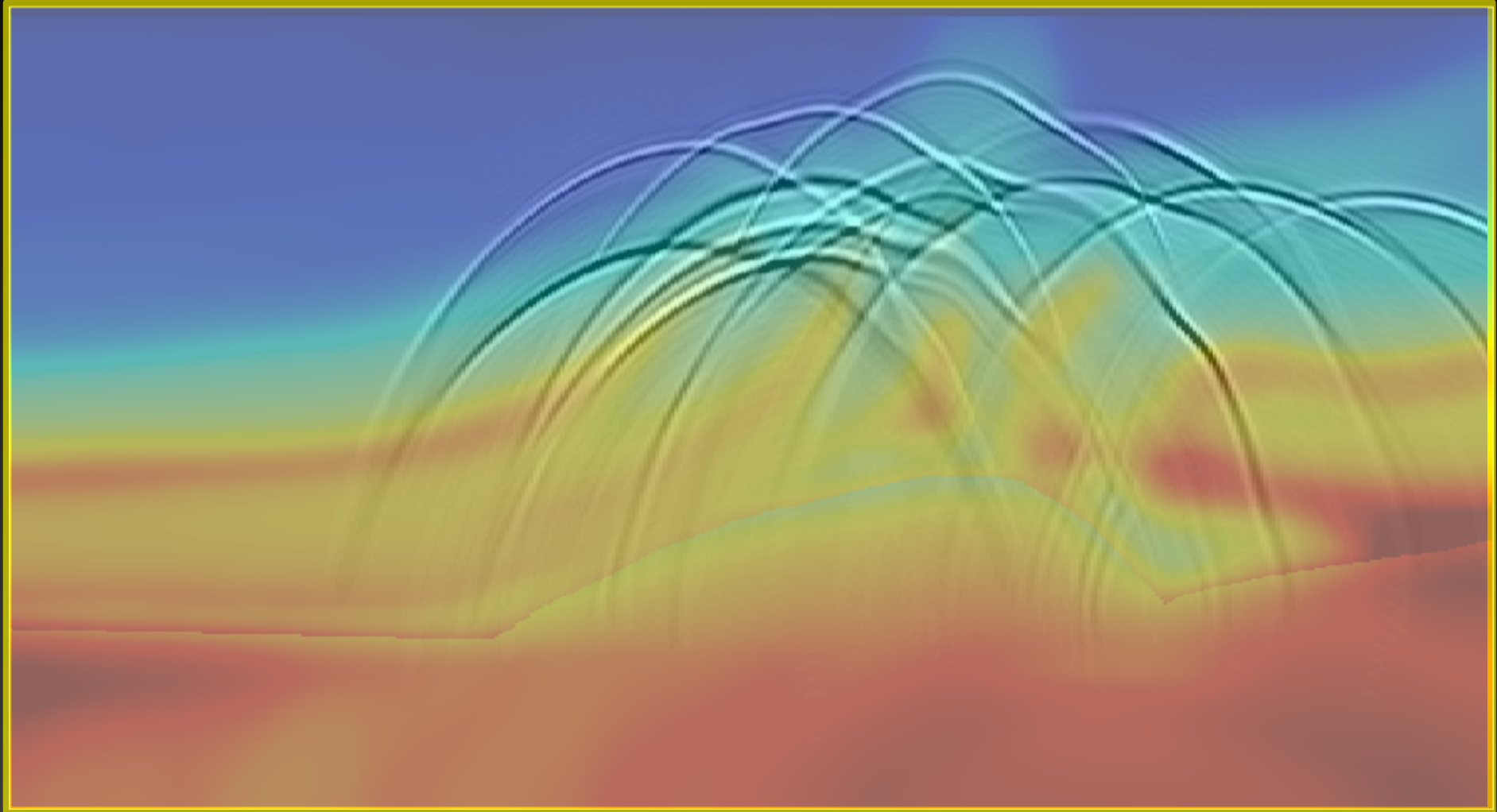


Modeling receiver wavefield

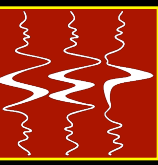


distance

depth

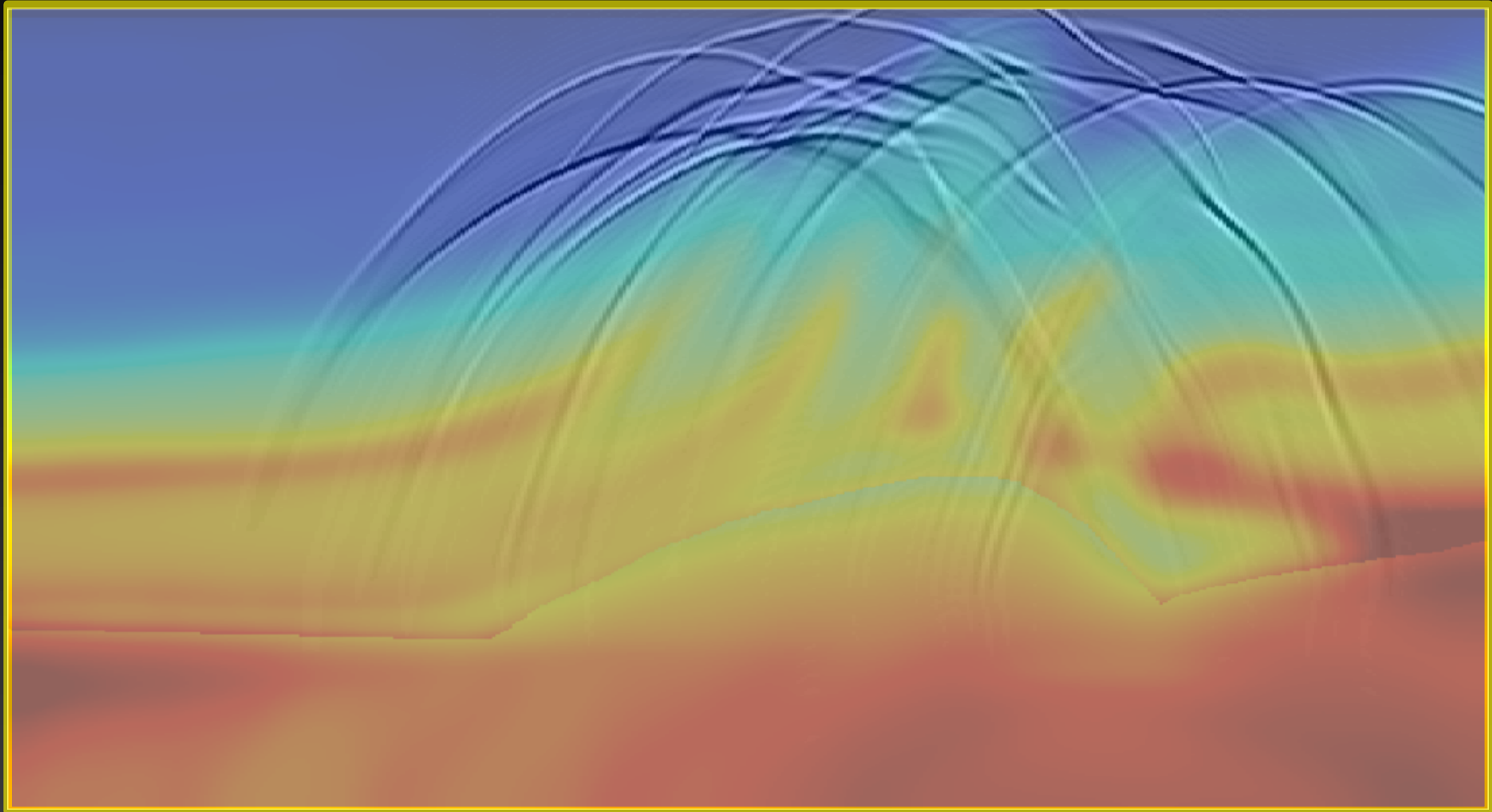


Modeling receiver wavefield

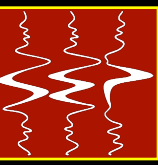


distance

depth

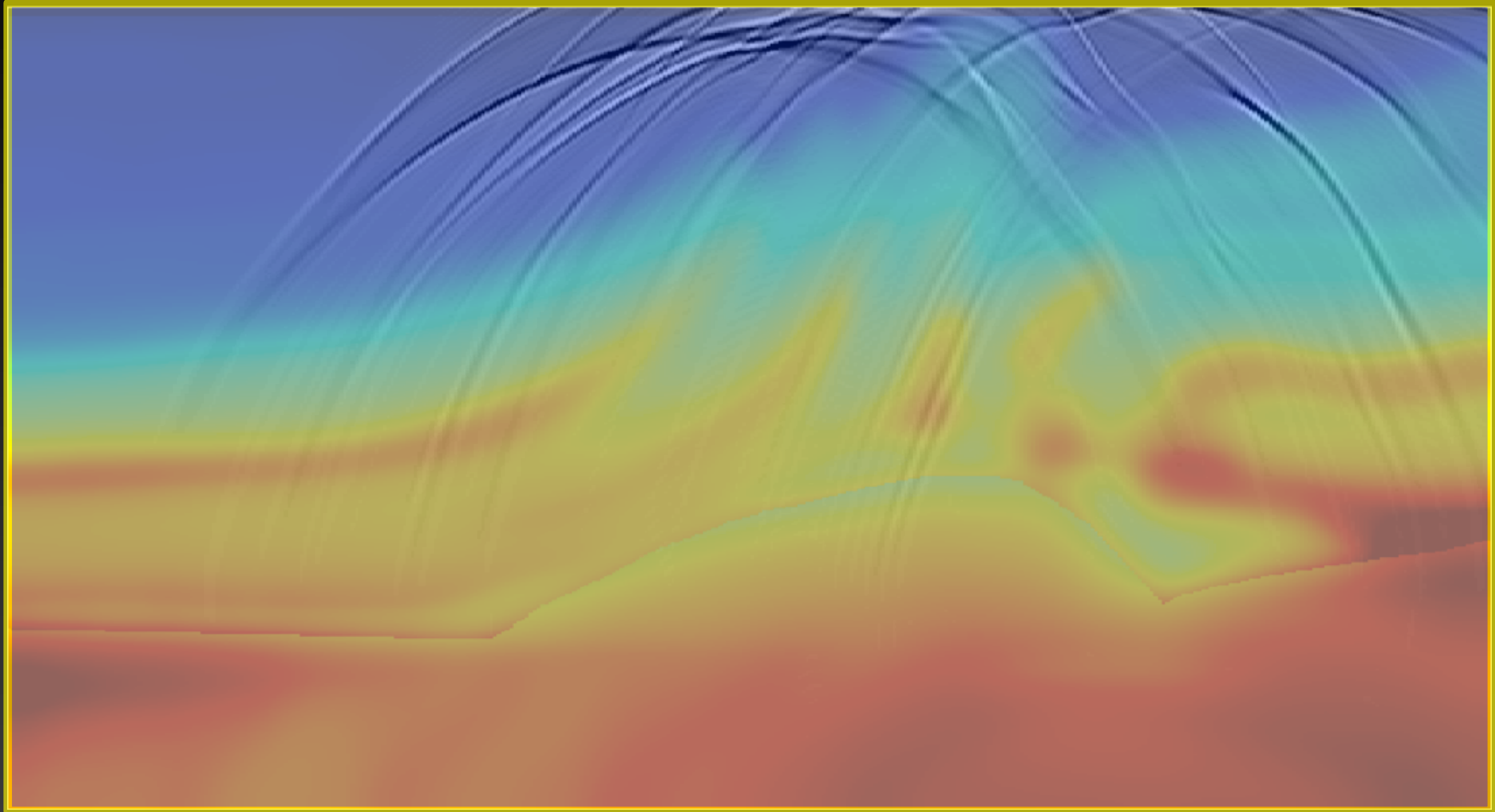


Modeling receiver wavefield

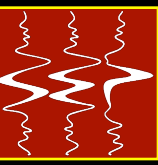


distance

depth

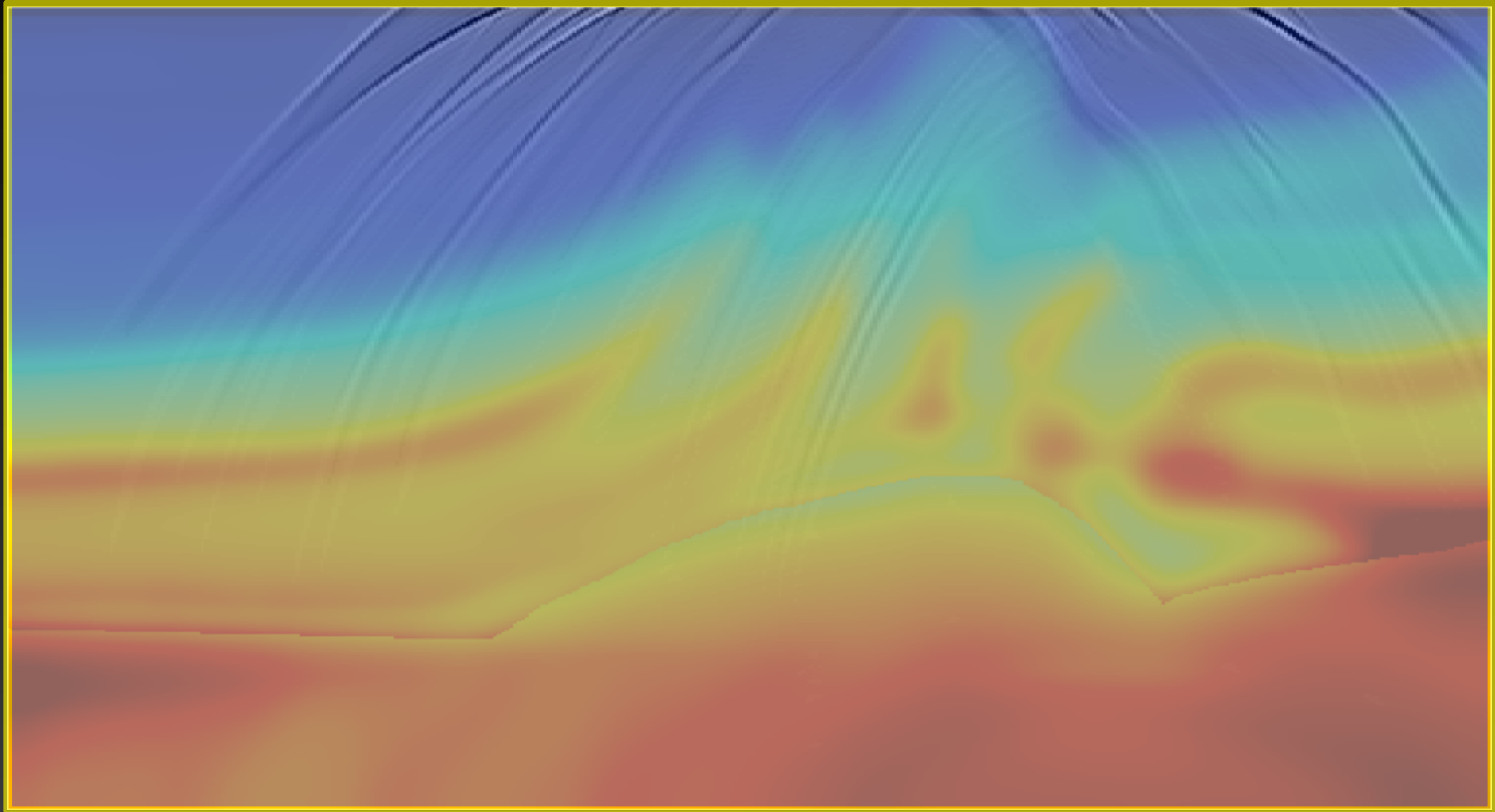


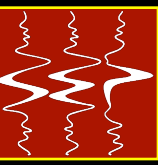
Modeling receiver wavefield



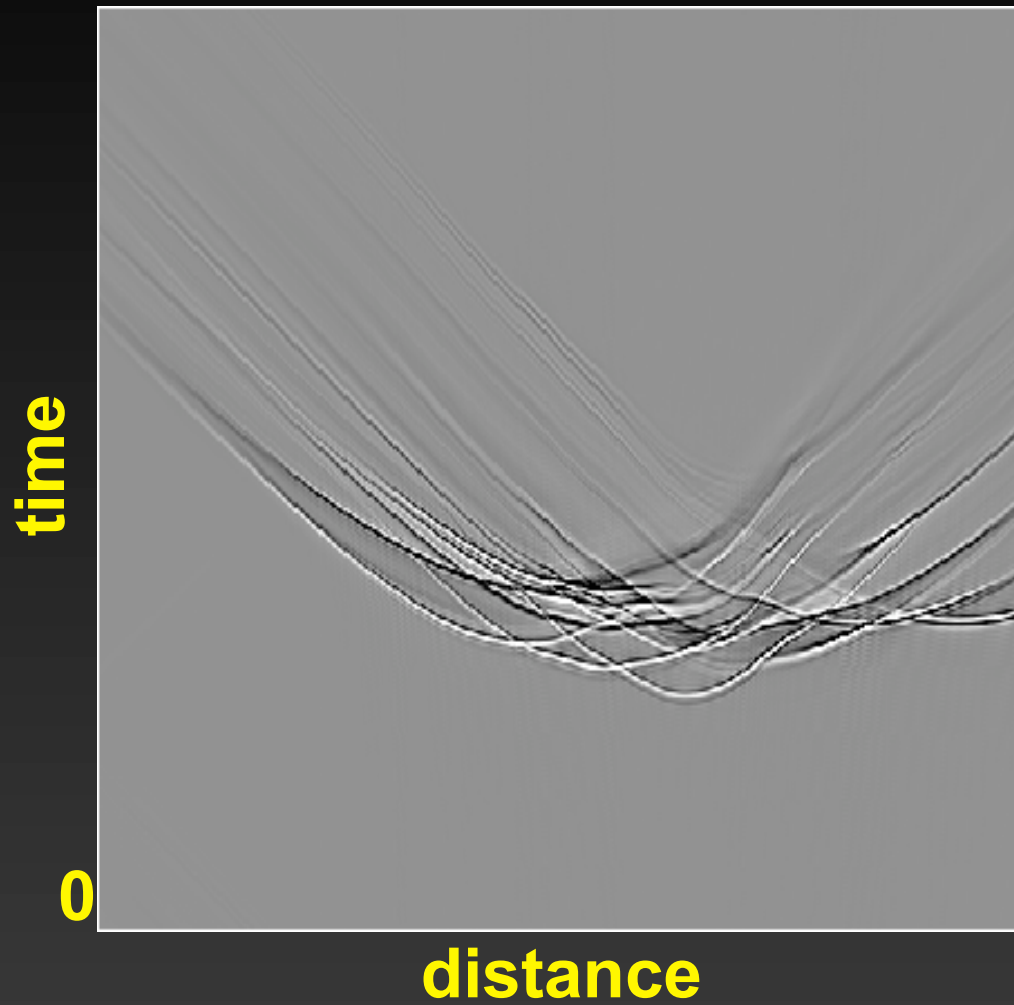
distance

depth

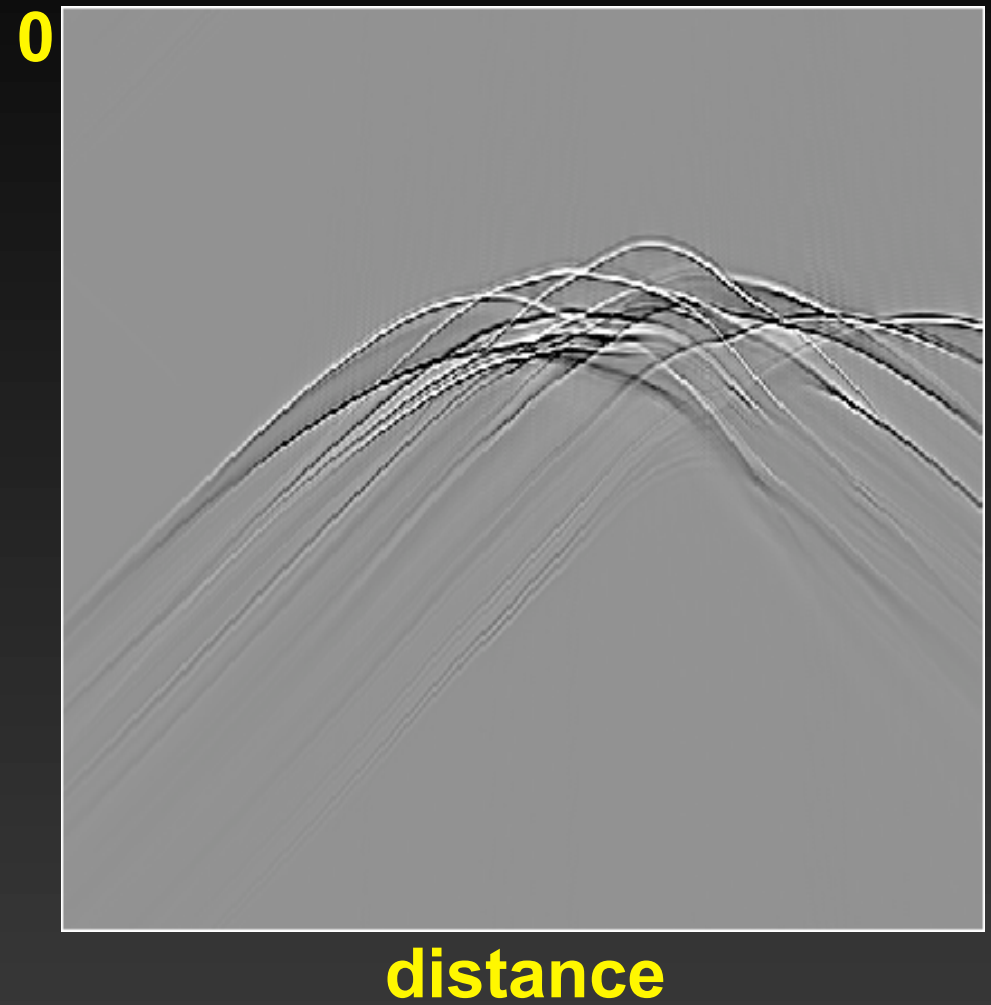


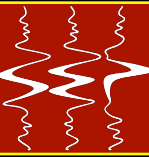


Source



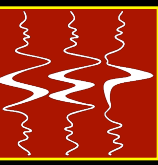
Receiver





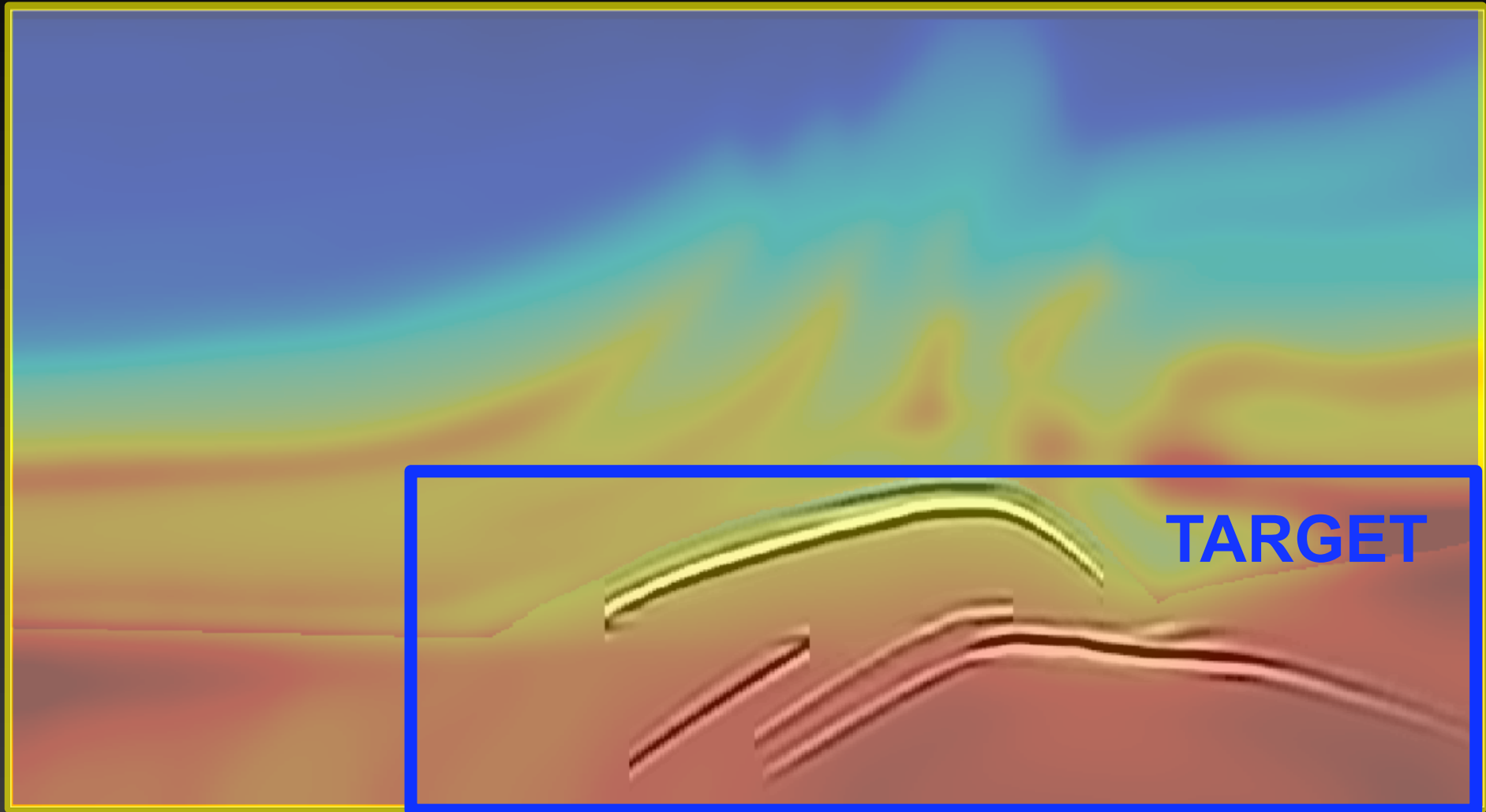
- **Generalizes the exploding-reflector model**
- **Uses selected reflectors as the initial conditions**
- **Uses a decorrelation distance to avoid crosstalk**
 - **Number of wavefields depends on the separation of SODCIGs**

Target-oriented strategy



distance

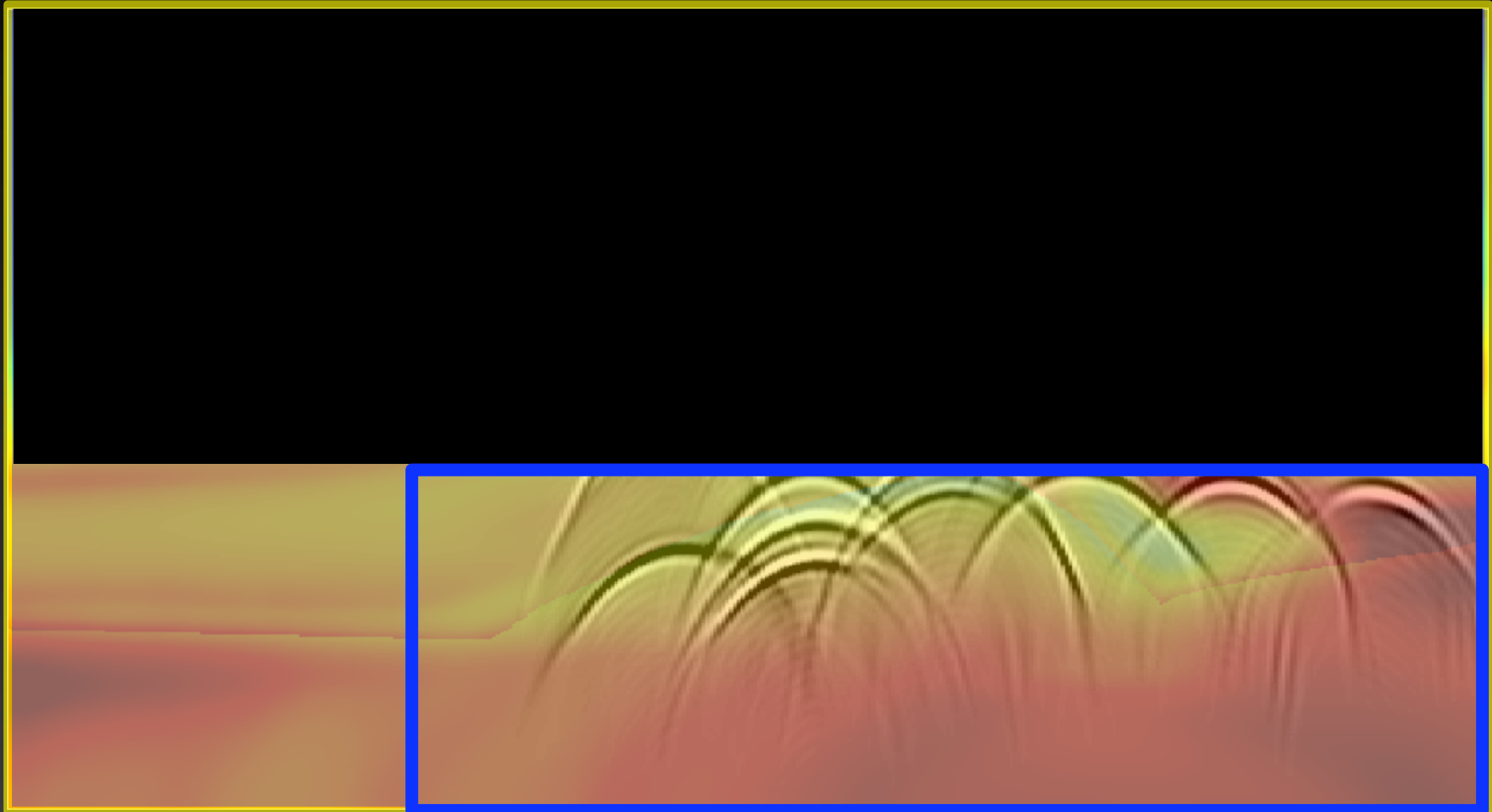
depth

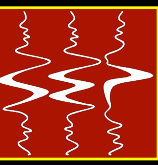




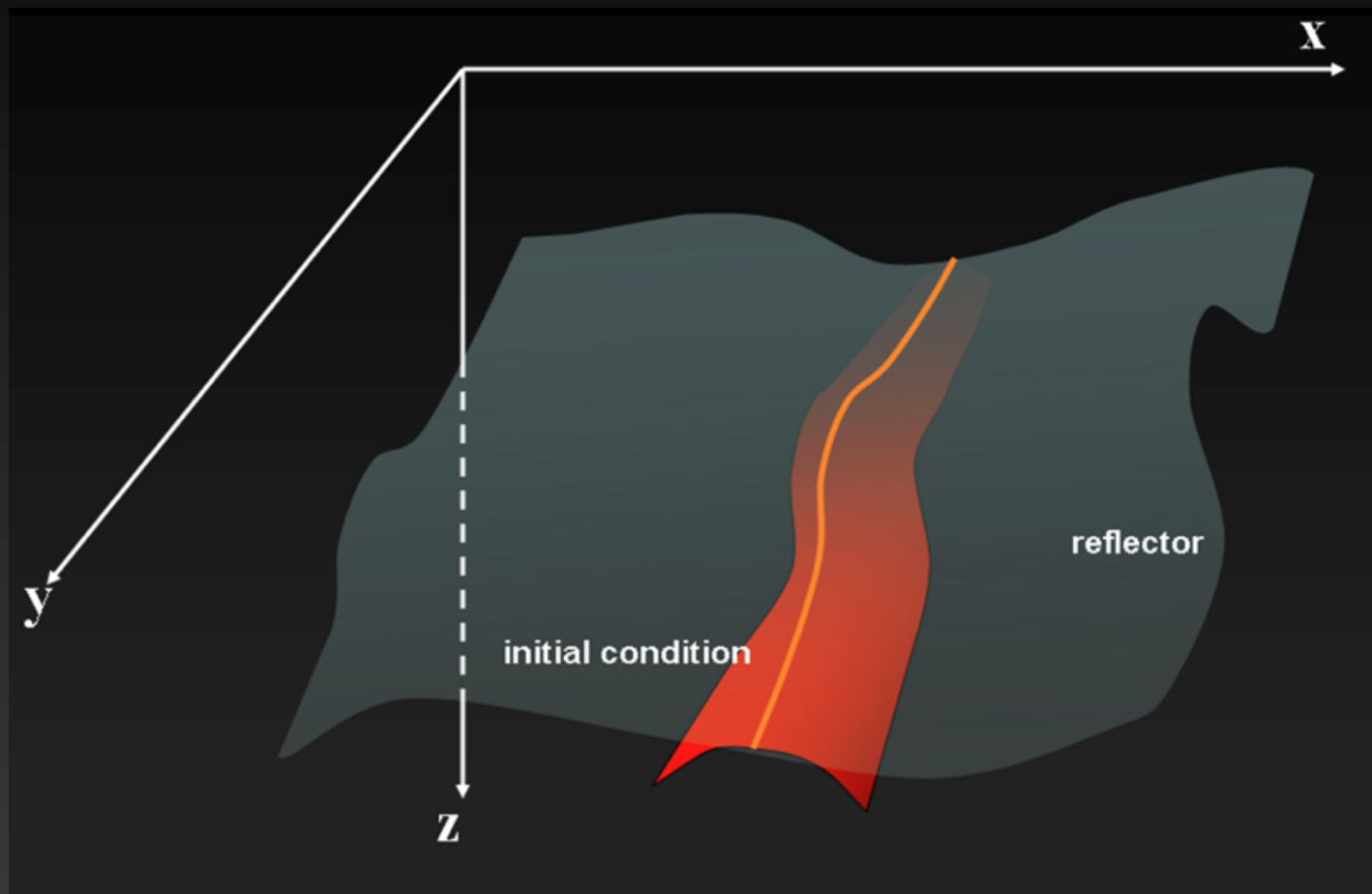
Wavefields collected at the top of the target distance

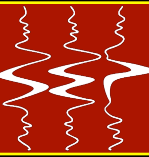
depth



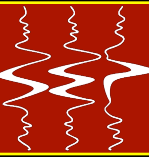


- **Data reduction can be of some orders of magnitude**





- ✓ **Chapter 2: Pre-stack exploding-reflector model**
- **Chapter 3: Image-space phase-encoded wavefields**
- **Chapter 4: MVA using image-space generalized sources**
- **Chapter 5: 3D-field data example**



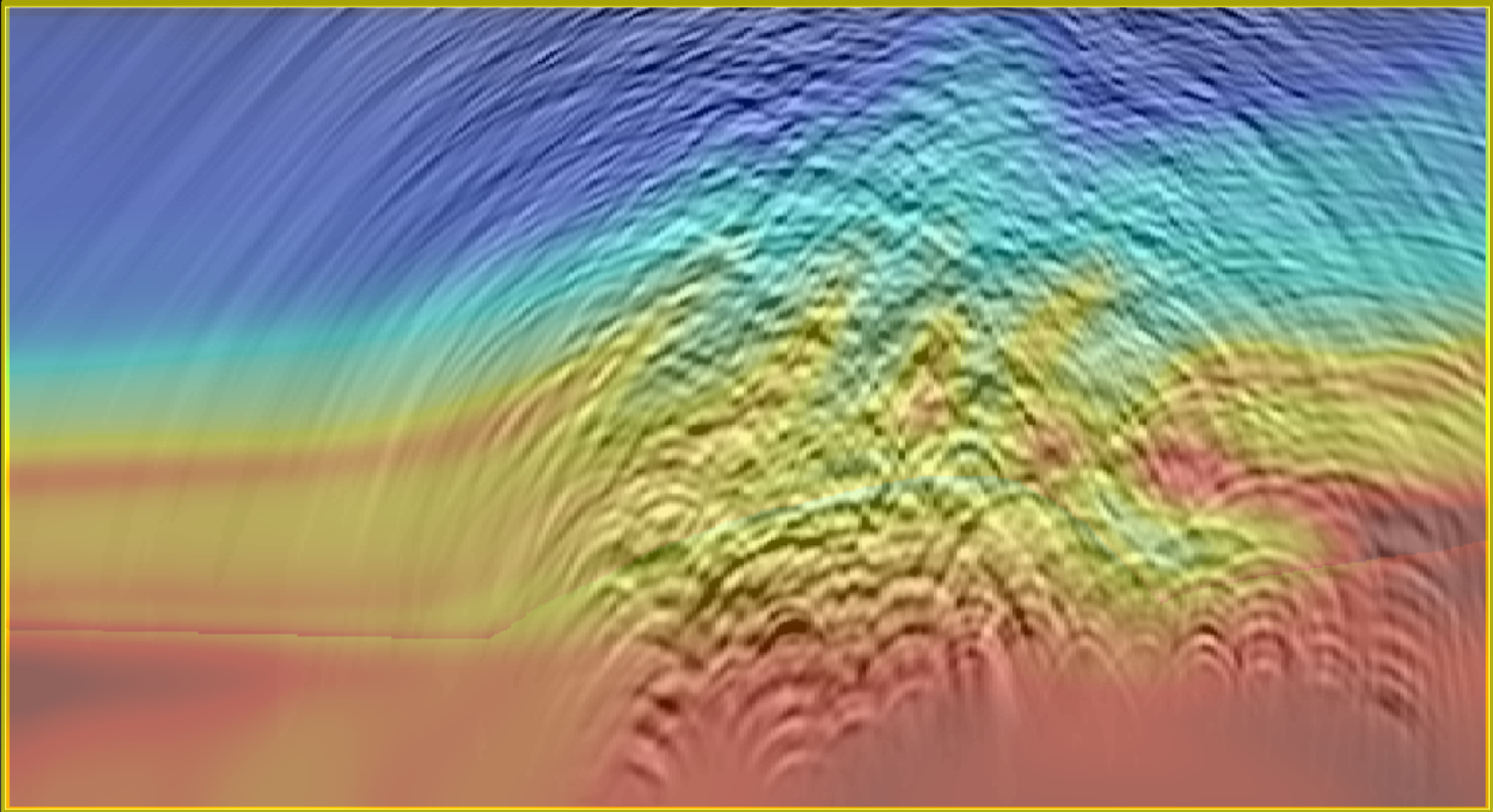
**Further data reduction
by phase-encoding the modeling
experiments**

Phase-encoded receiver wavefield

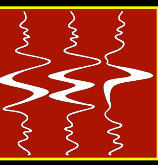


distance

depth

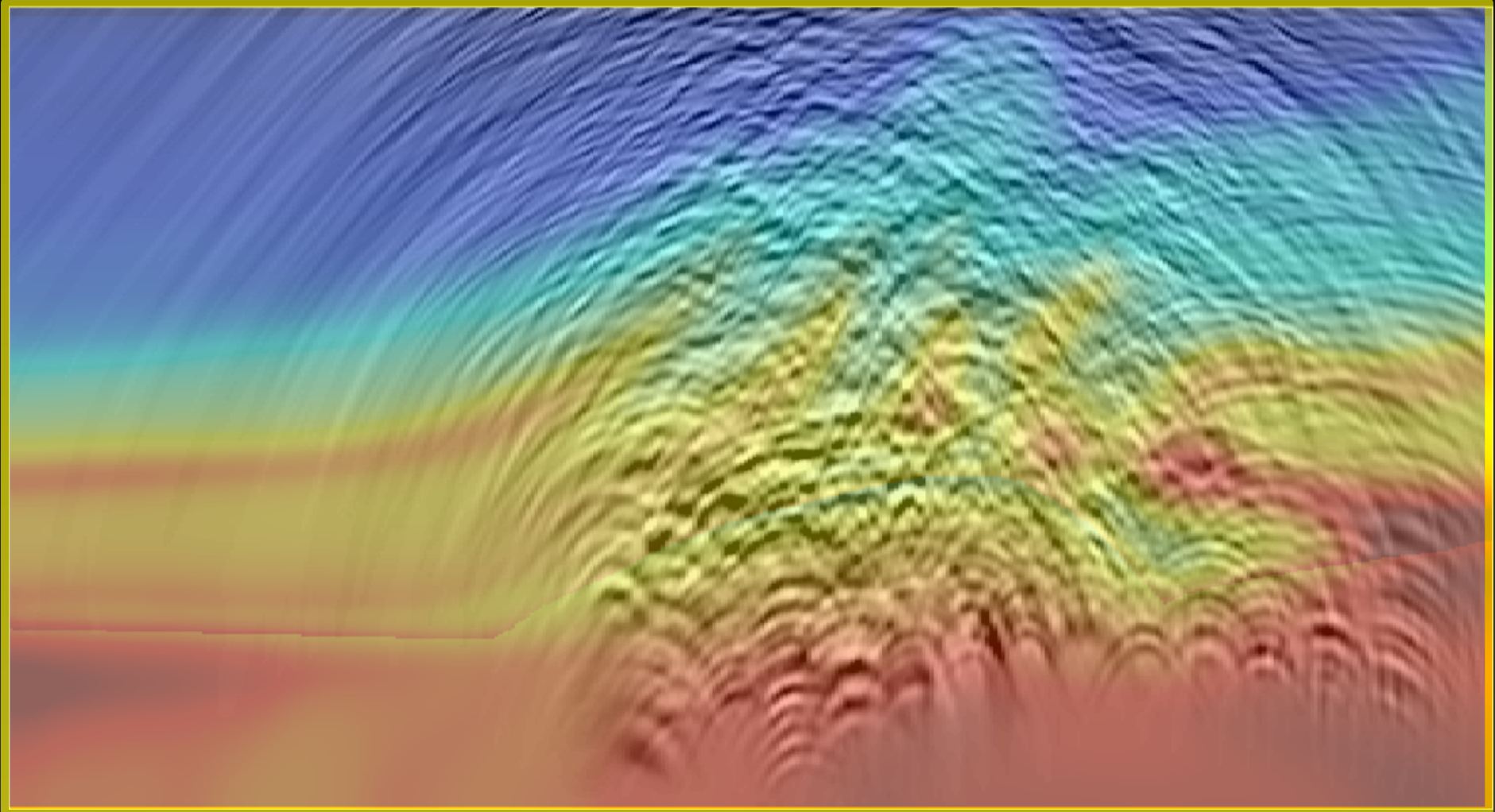


Phase-encoded receiver wavefield

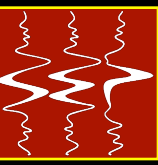


distance

depth

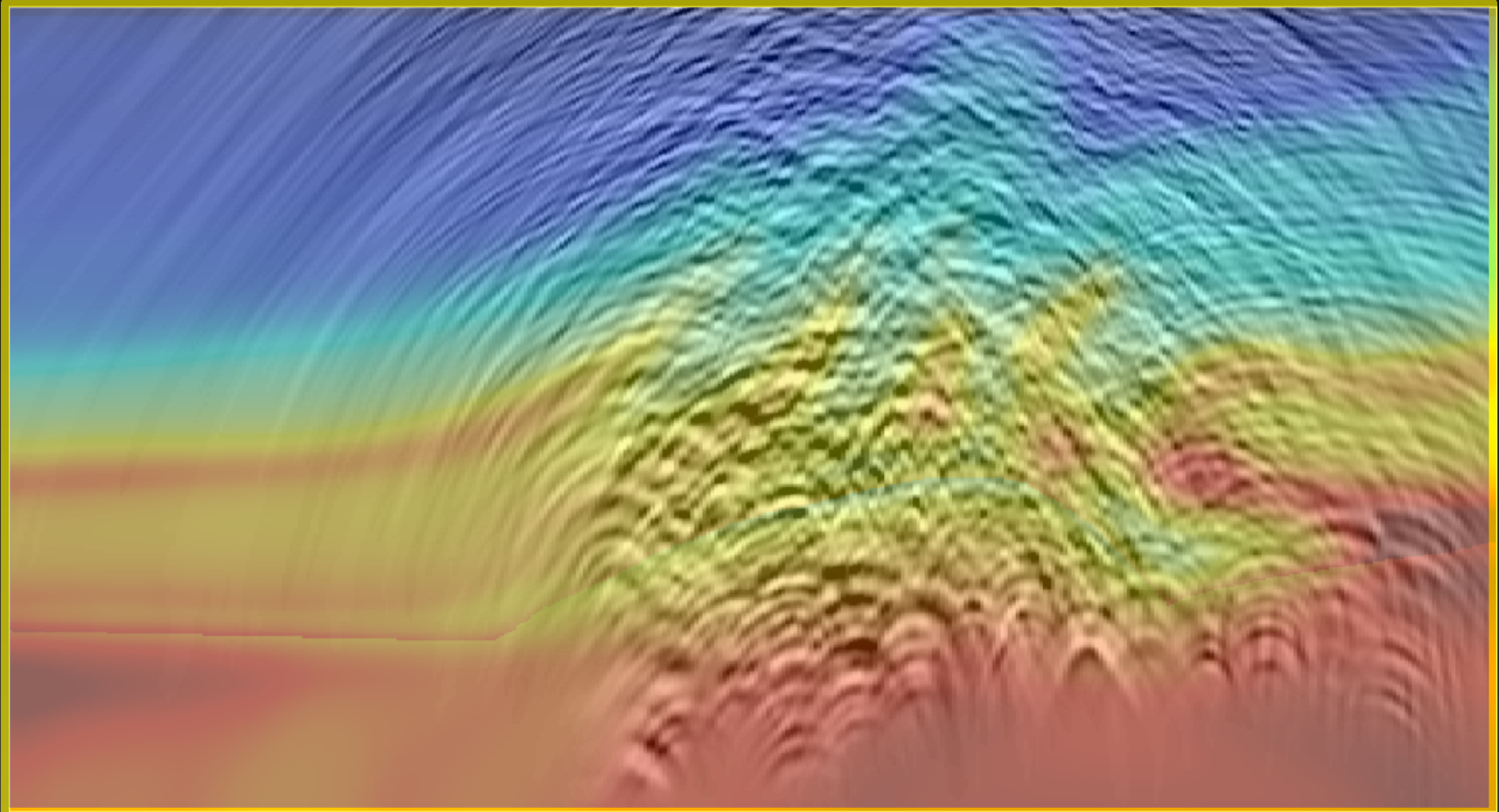


Phase-encoded receiver wavefield

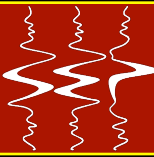


distance

depth

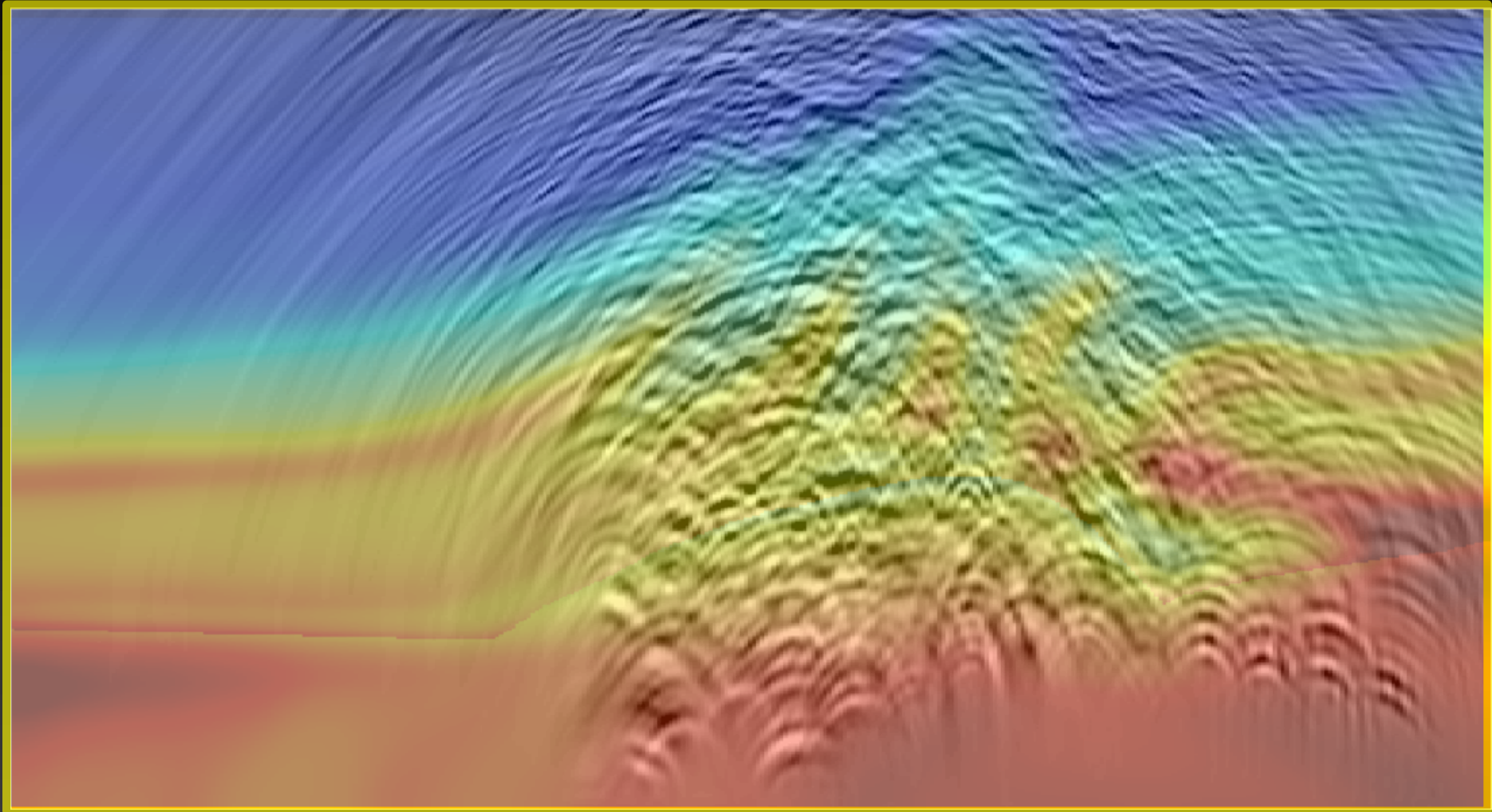


Phase-encoded receiver wavefield

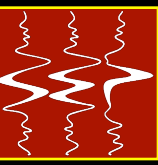


distance

depth

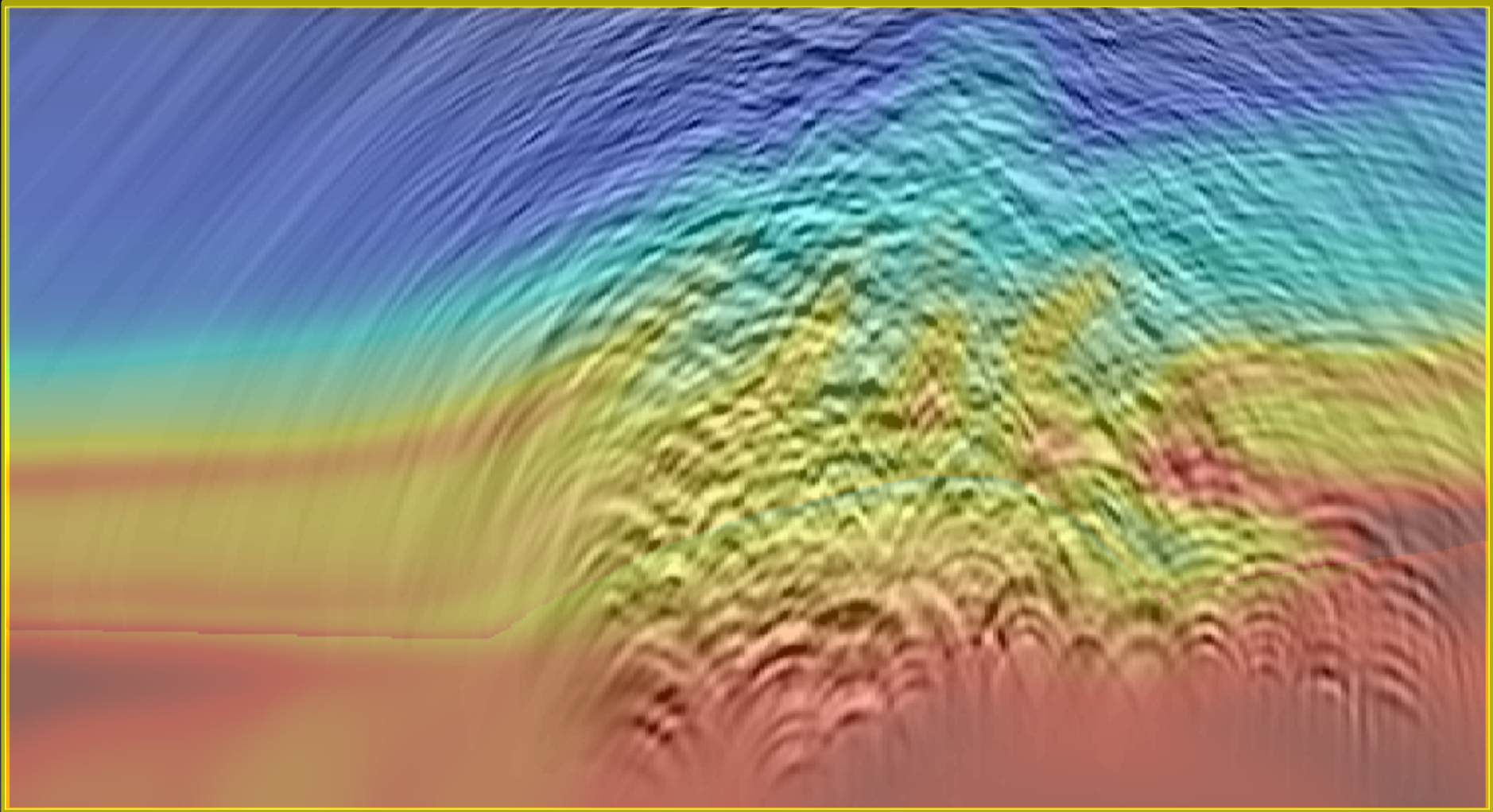


Phase-encoded receiver wavefield

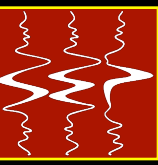


distance

depth

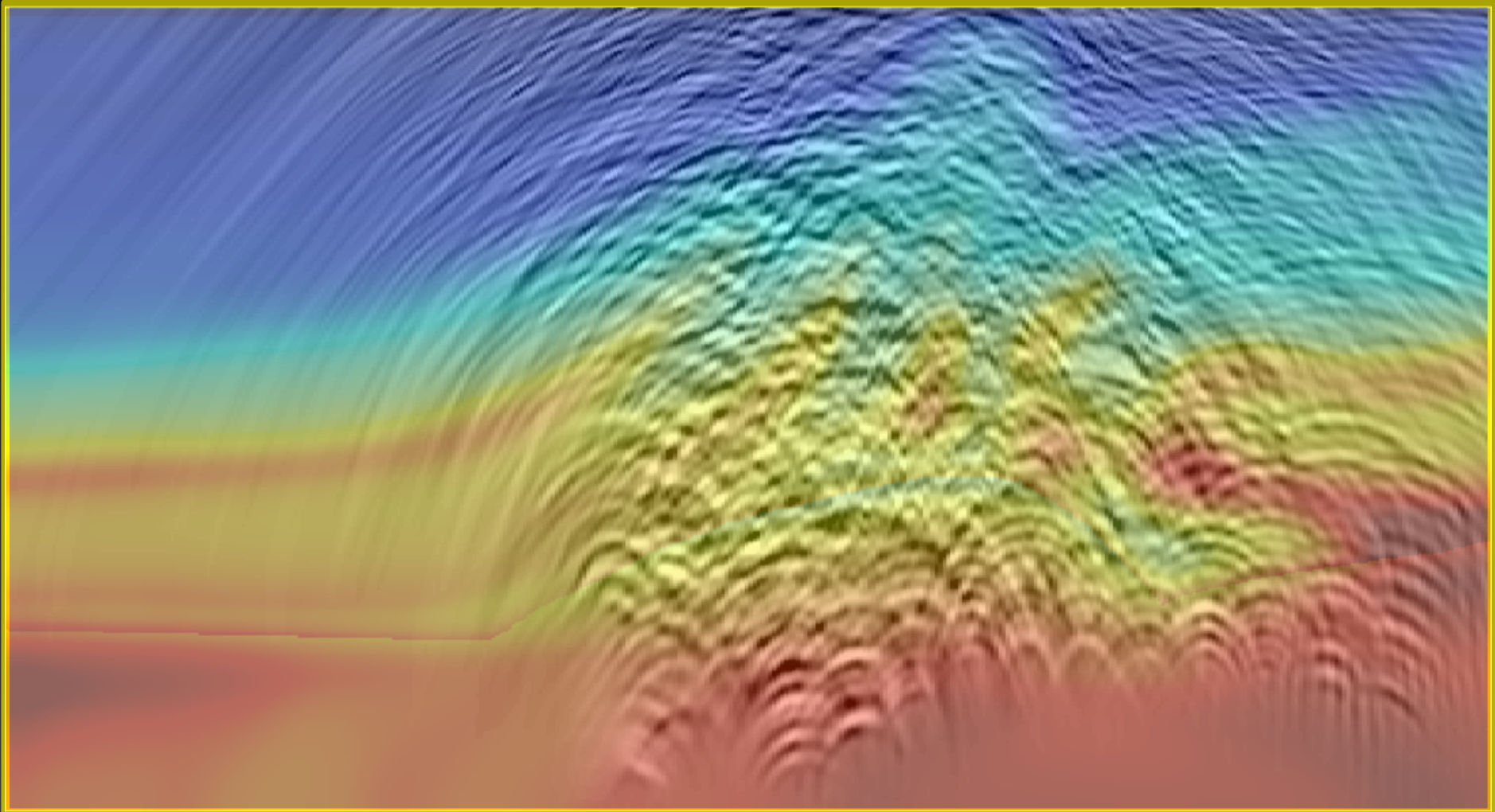


Phase-encoded receiver wavefield

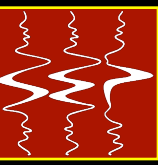


distance

depth

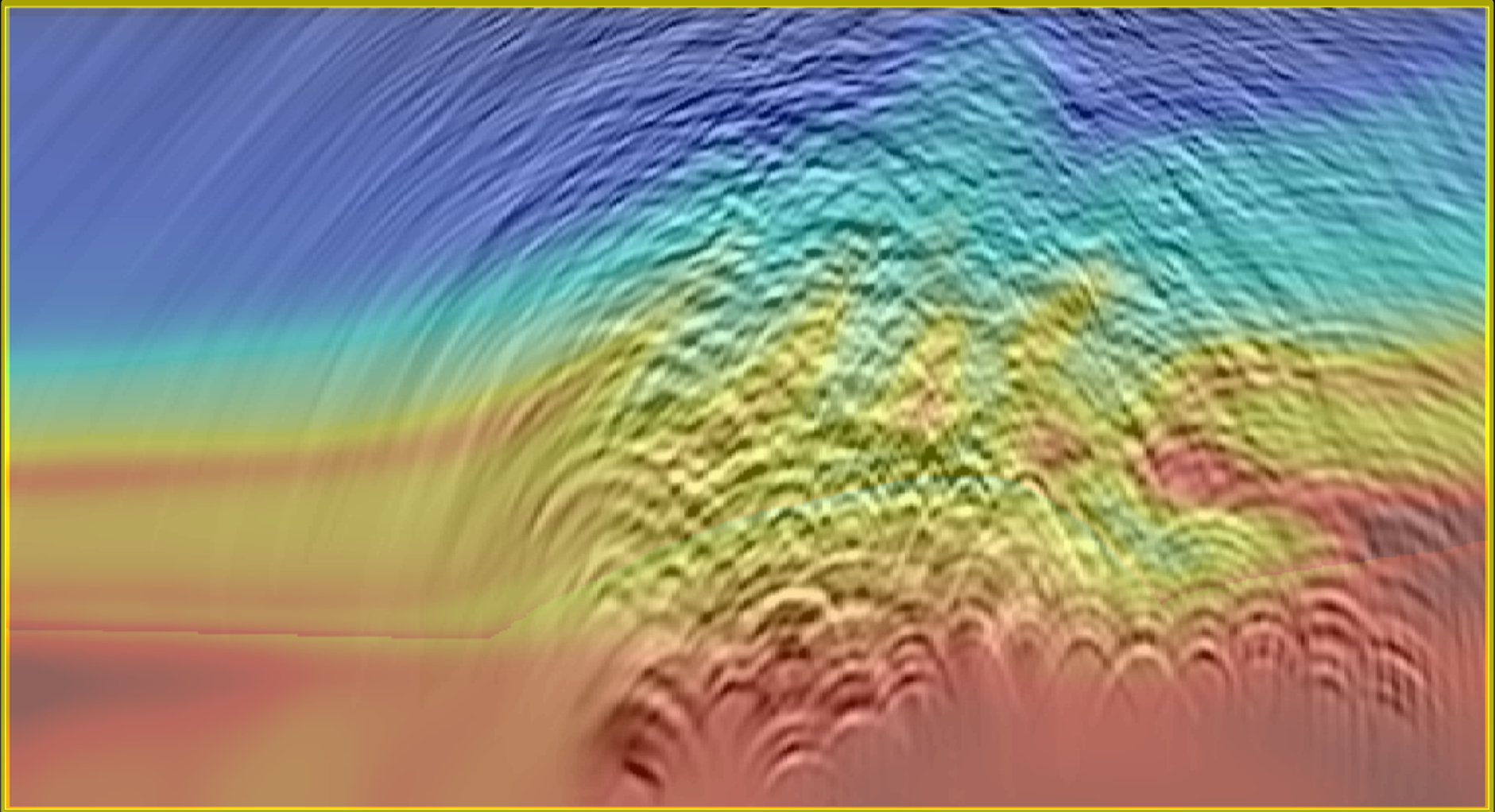


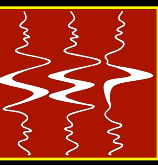
Phase-encoded receiver wavefield



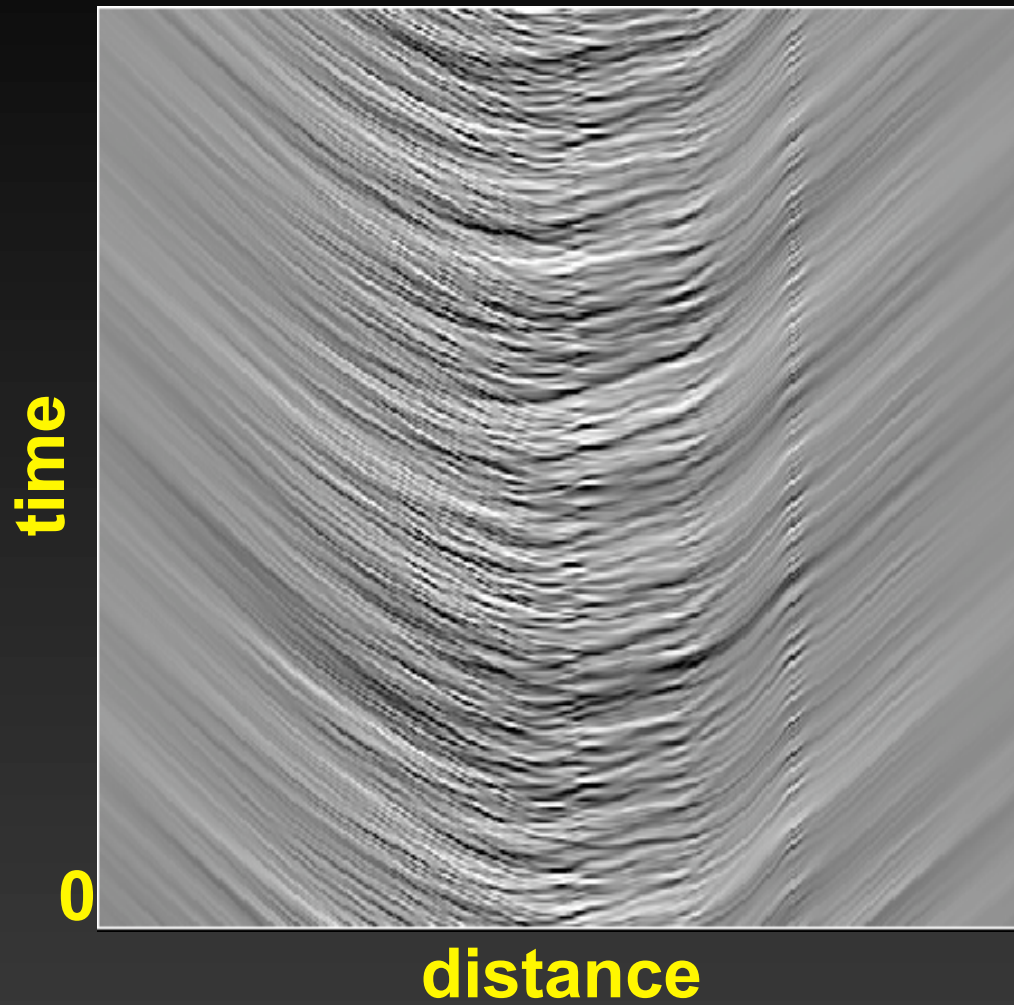
distance

depth





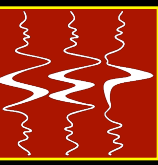
Source



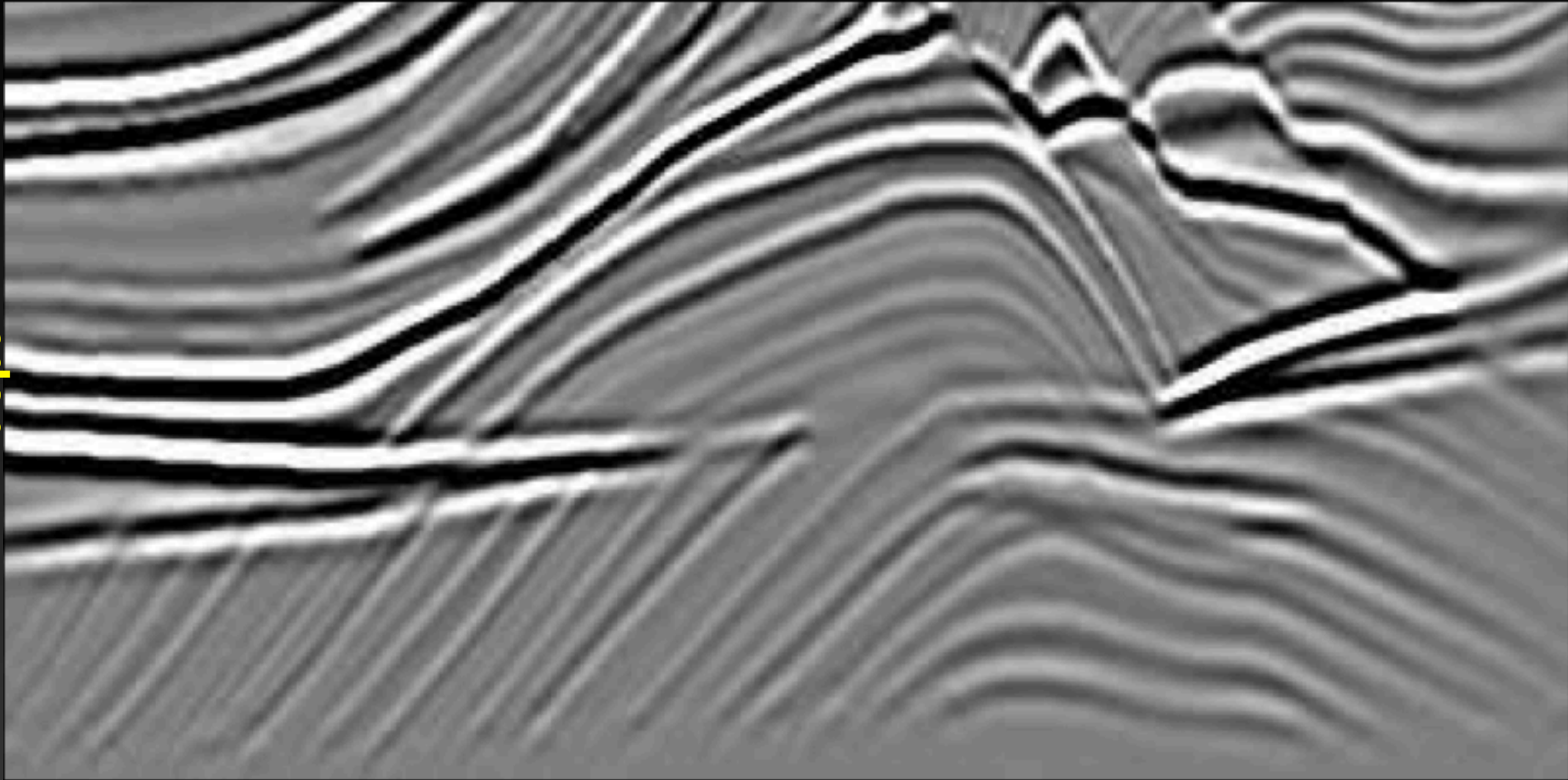
Receiver



Migration of 375 shot profiles

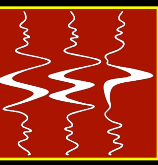


distance



depth

Selected reflectors

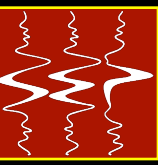


distance

depth



35 PERM migrated image

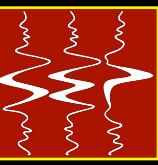


distance

depth

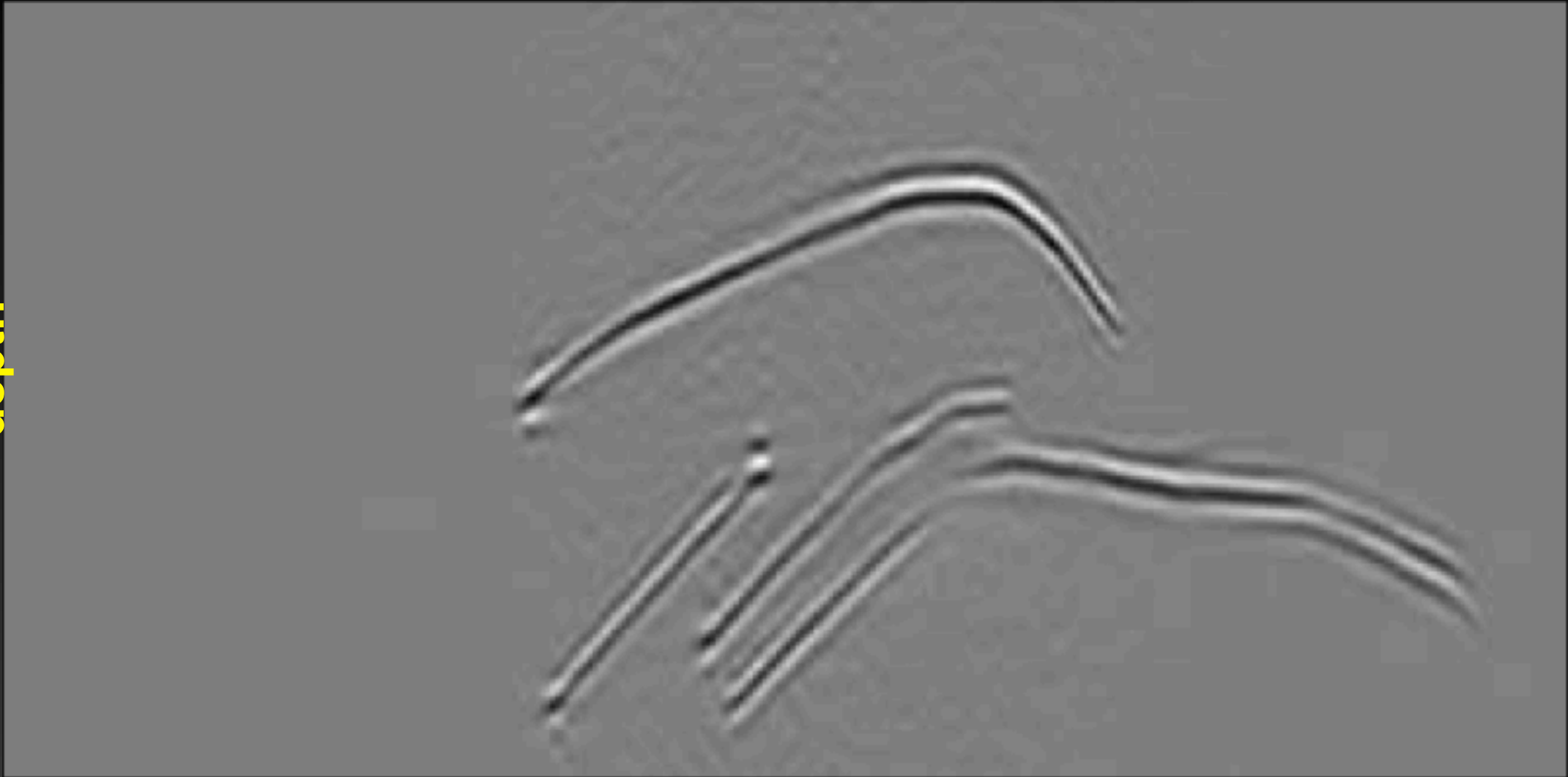


11 ISPEW migrated image

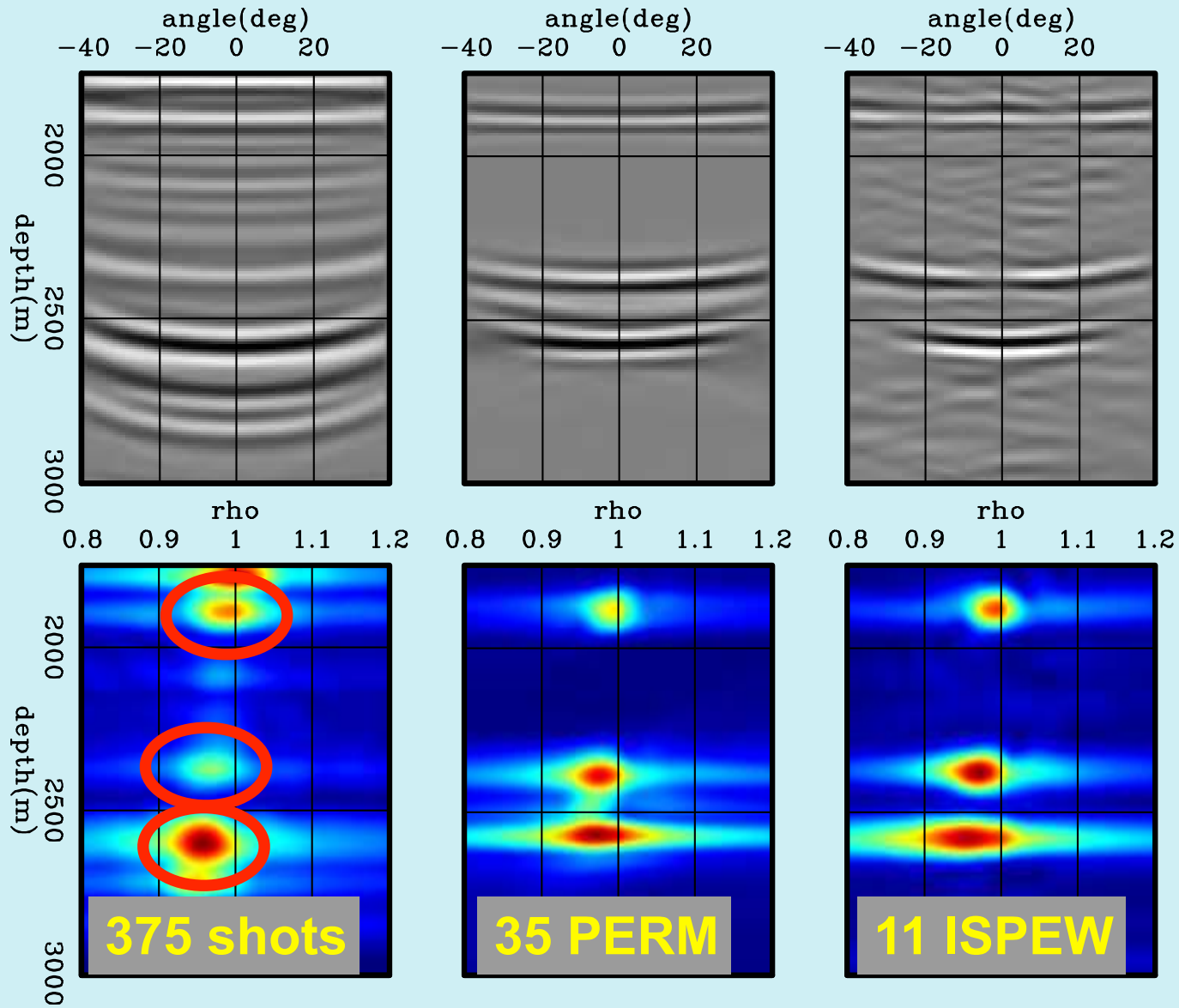


distance

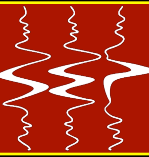
depth



Velocity information



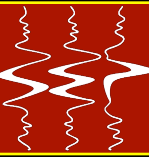
**rho - curvature
parameter**



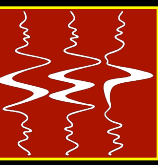
- ✓ **Chapter 2: Pre-stack exploding-reflector model**
- ✓ **Chapter 3: Image-space phase-encoded wavefields**
- **Chapter 4: MVA using image-space generalized sources**
- **Chapter 5: 3D-field data example**



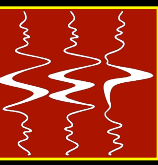
- **ISWET extended from shot-profile to the generalized source domain (Tang et al., 2009 - SEP136)**



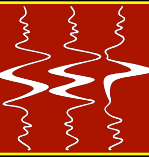
- **ISWET extended from shot-profile to the generalized source domain (Tang et al., 2009 - SEP136)**
- **Small number of wavefields**



- **Wavefields initiated at selected reflectors**



- **Wavefields initiated at selected reflectors**
 - **Horizon-based ISWET**



- **Wavefields initiated at selected reflectors**
 - Horizon-based ISWET
- **Easily solved in a target-oriented way**

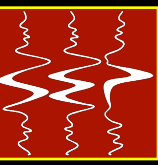


$$J(\mathbf{s}) = \frac{1}{2} \left\| \mathbf{h} \tilde{I}(\mathbf{s}) \right\|_2$$

DSO operator (Symes and Carazzone, 1991)

$J(\mathbf{s})$ = objective function $\Delta \tilde{I}(\mathbf{s})$ = perturbed image
 \mathbf{h} = DSO operator $\tilde{I}(\mathbf{s})$ = current image

DSO operator = $|h|$

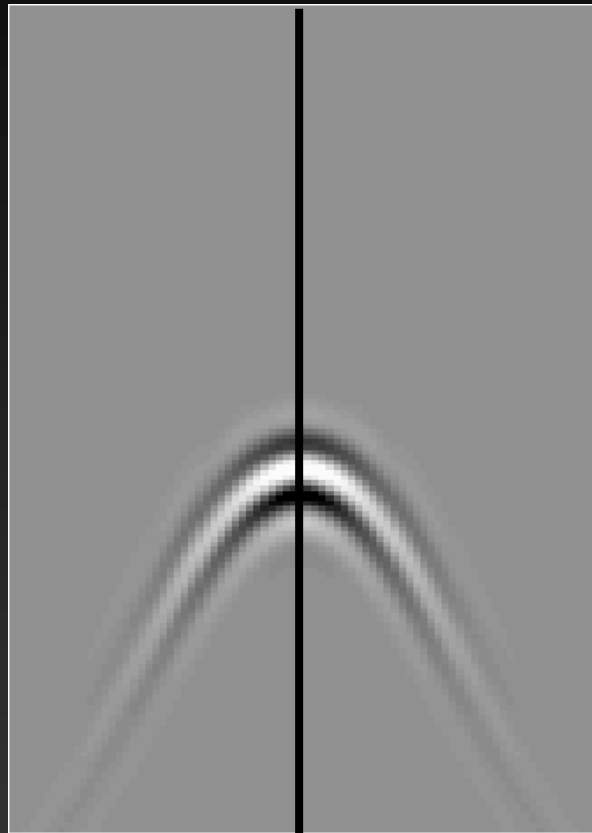


**SLOWER
VELOCITY**

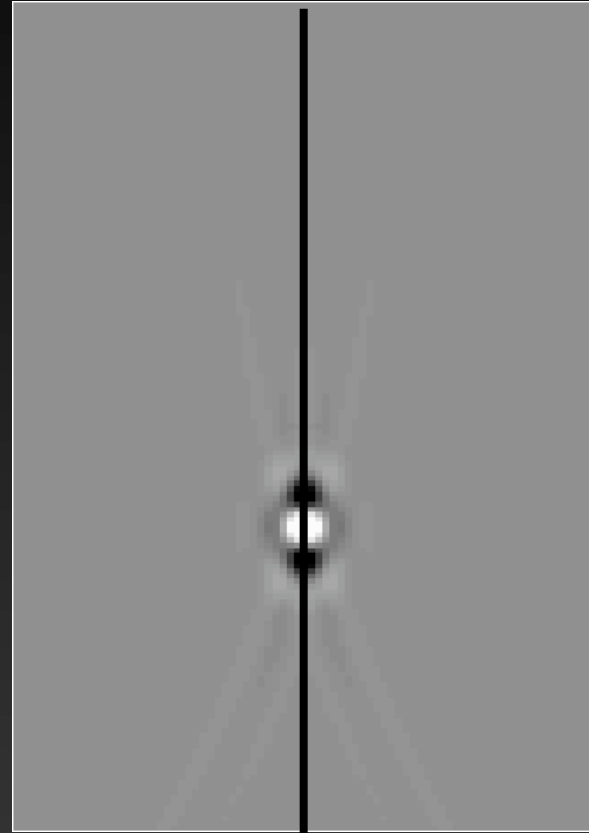
**CORRECT
VELOCITY**

**FASTER
VELOCITY**

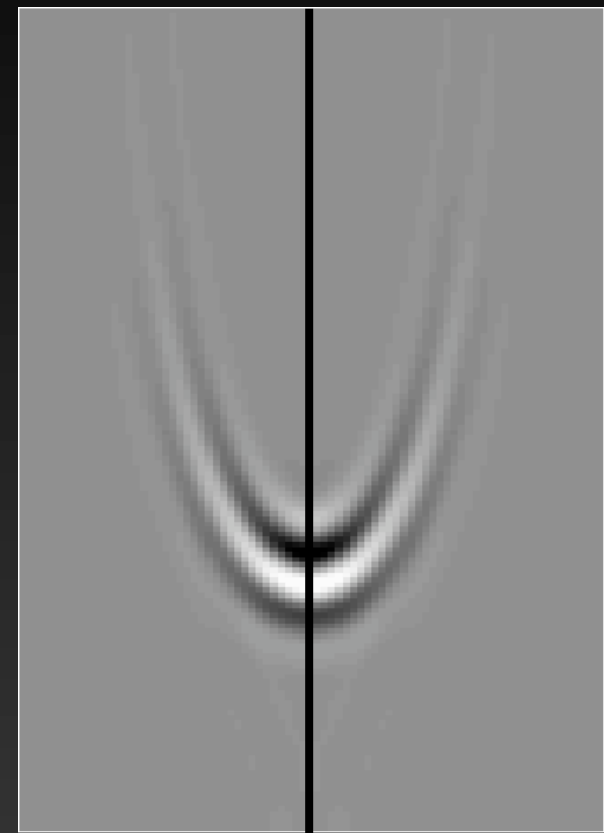
depth



offset

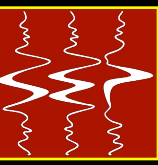


offset



offset

DSO operator = $|h|$

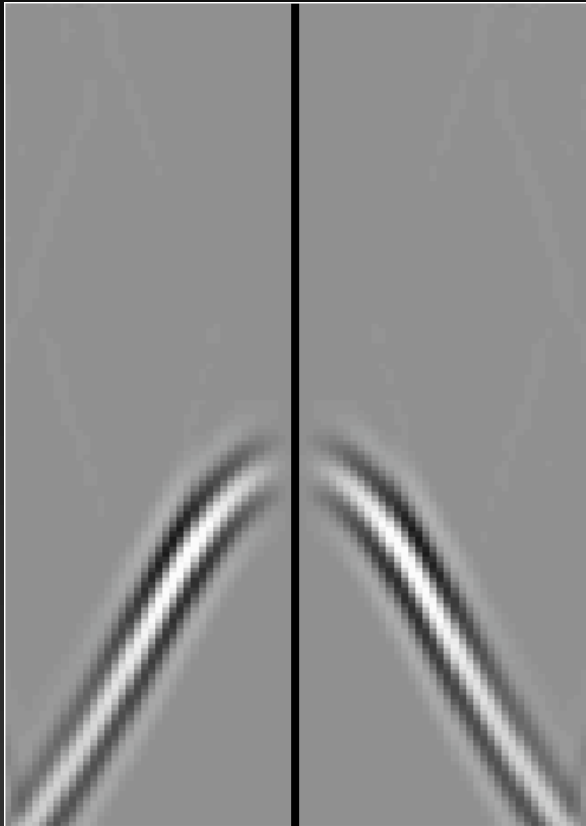


**SLOWER
VELOCITY**

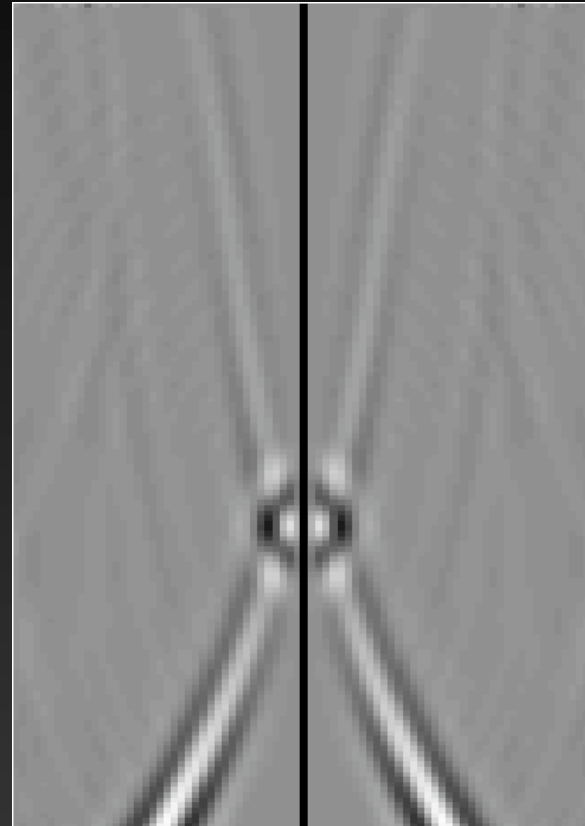
**CORRECT
VELOCITY**

**FASTER
VELOCITY**

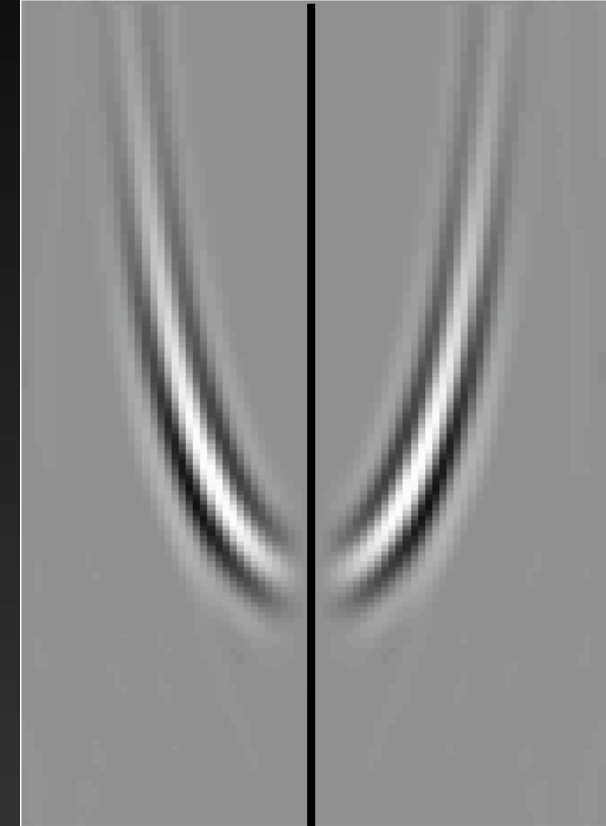
depth



offset



offset



offset



$$J(\mathbf{s}) = \frac{1}{2} \left\| \mathbf{h} \tilde{I}(\mathbf{s}) \right\|_2$$

$$\nabla J(\mathbf{s}) = \left(\frac{\partial \tilde{I}}{\partial \mathbf{s}} \right)' \mathbf{h}^2 \tilde{I} \Big|_{\mathbf{s}=\mathbf{s}_0}$$

$J(\mathbf{s})$ = objective function

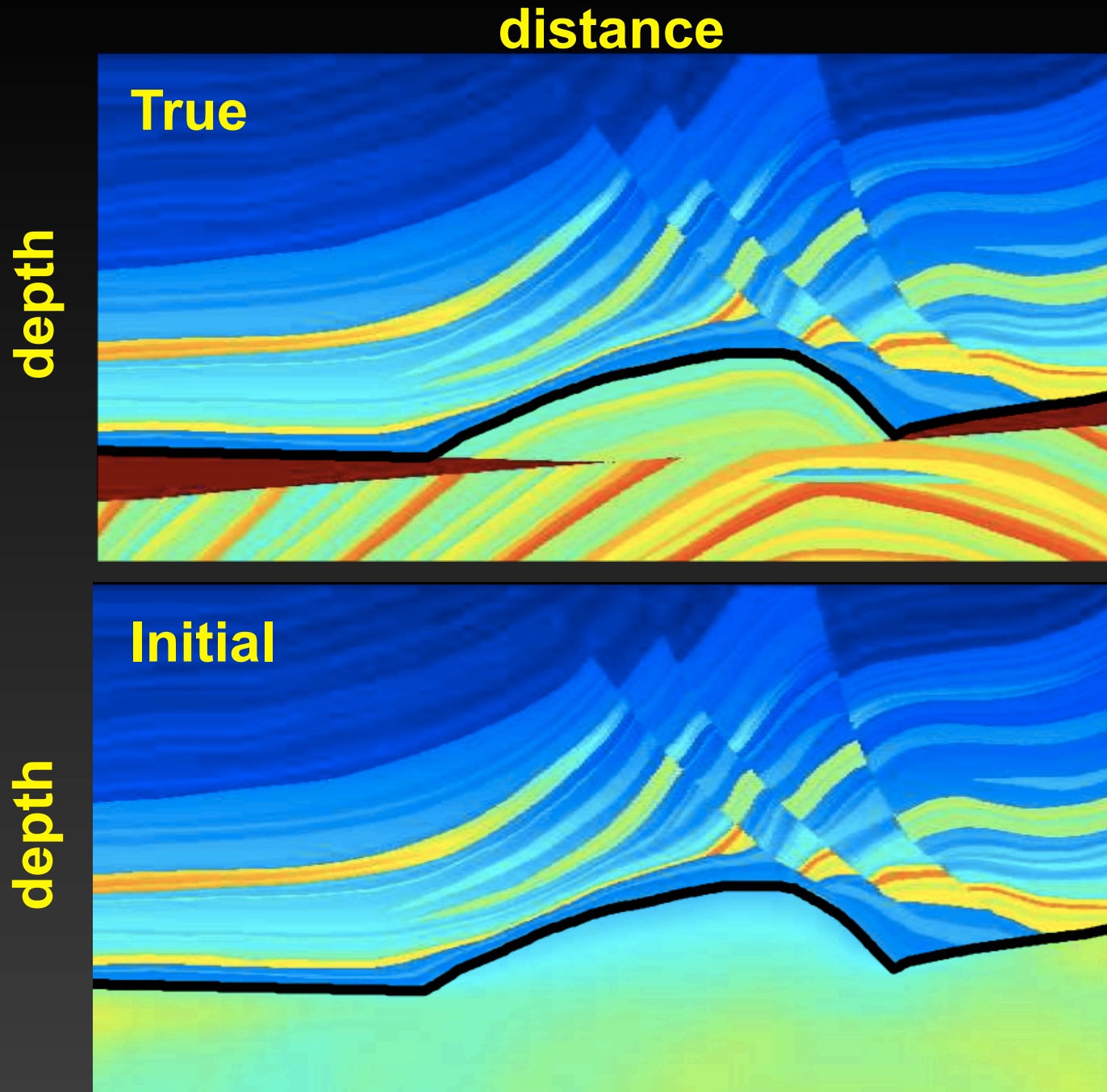
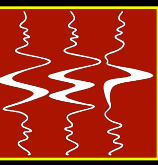
\mathbf{h} = DSO operator

\mathbf{s}_0 = current velocity

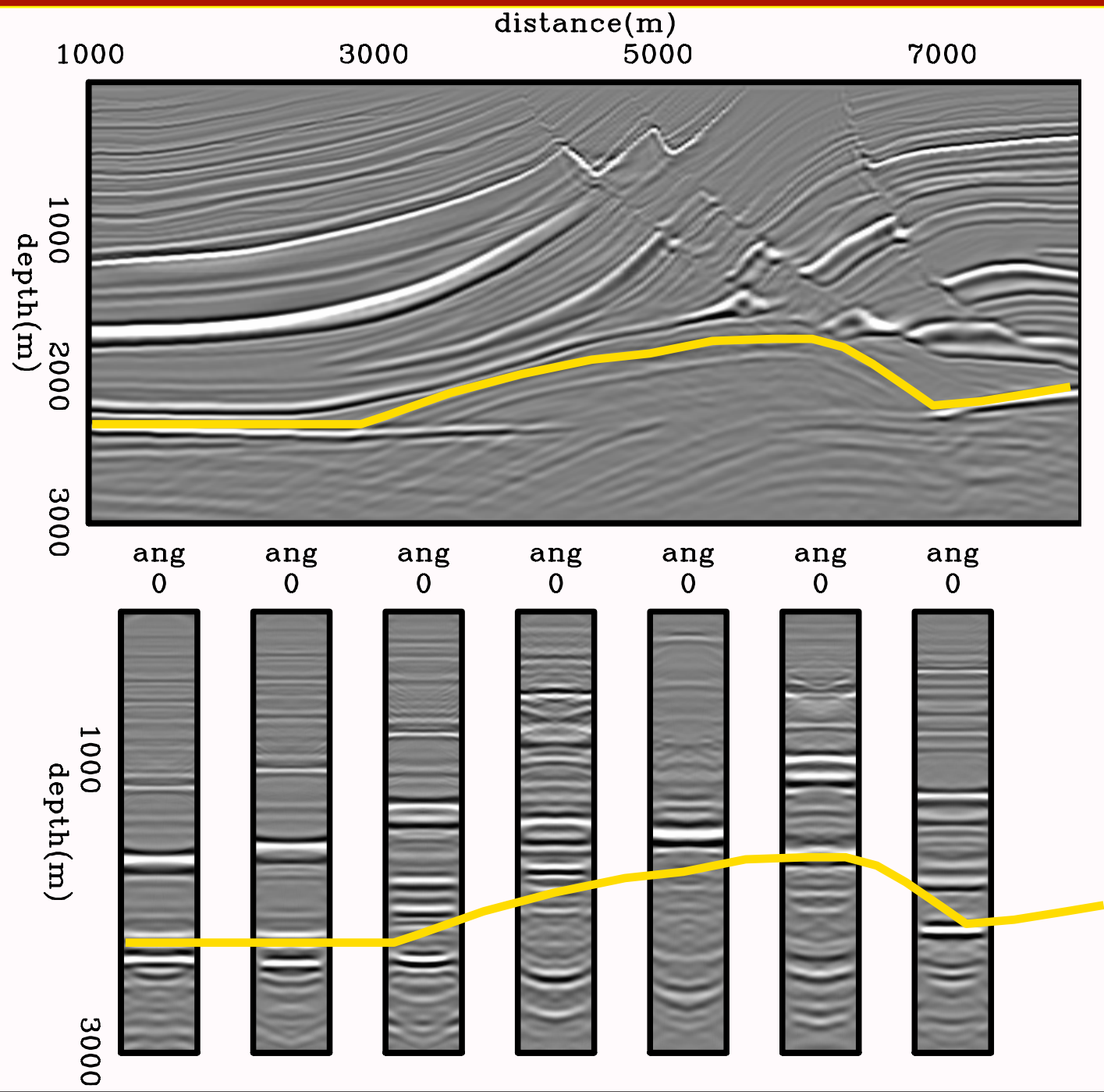
$\Delta \tilde{I}(\mathbf{s})$ = perturbed image

$\tilde{I}(\mathbf{s})$ = current image

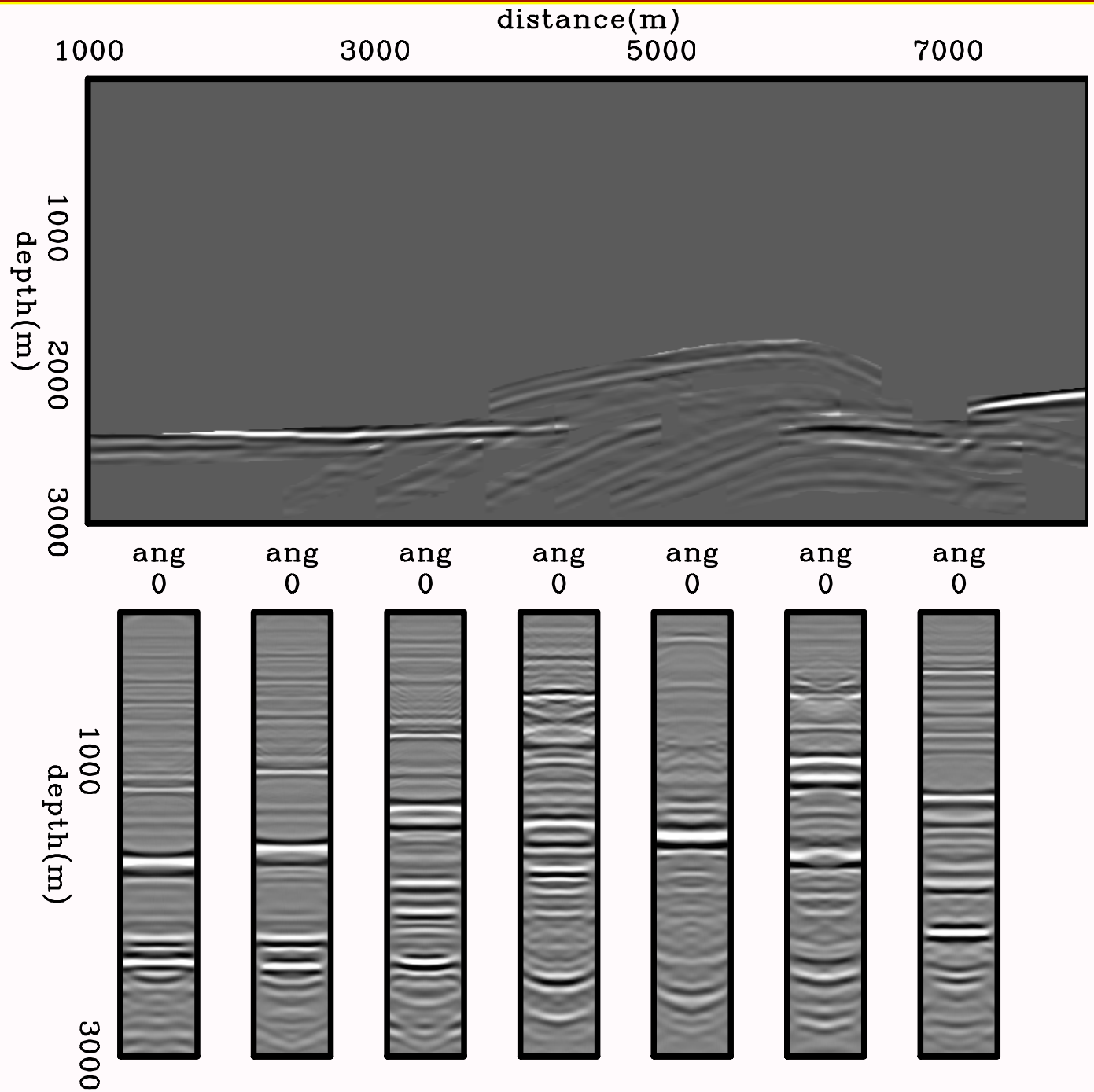
2D synthetic example



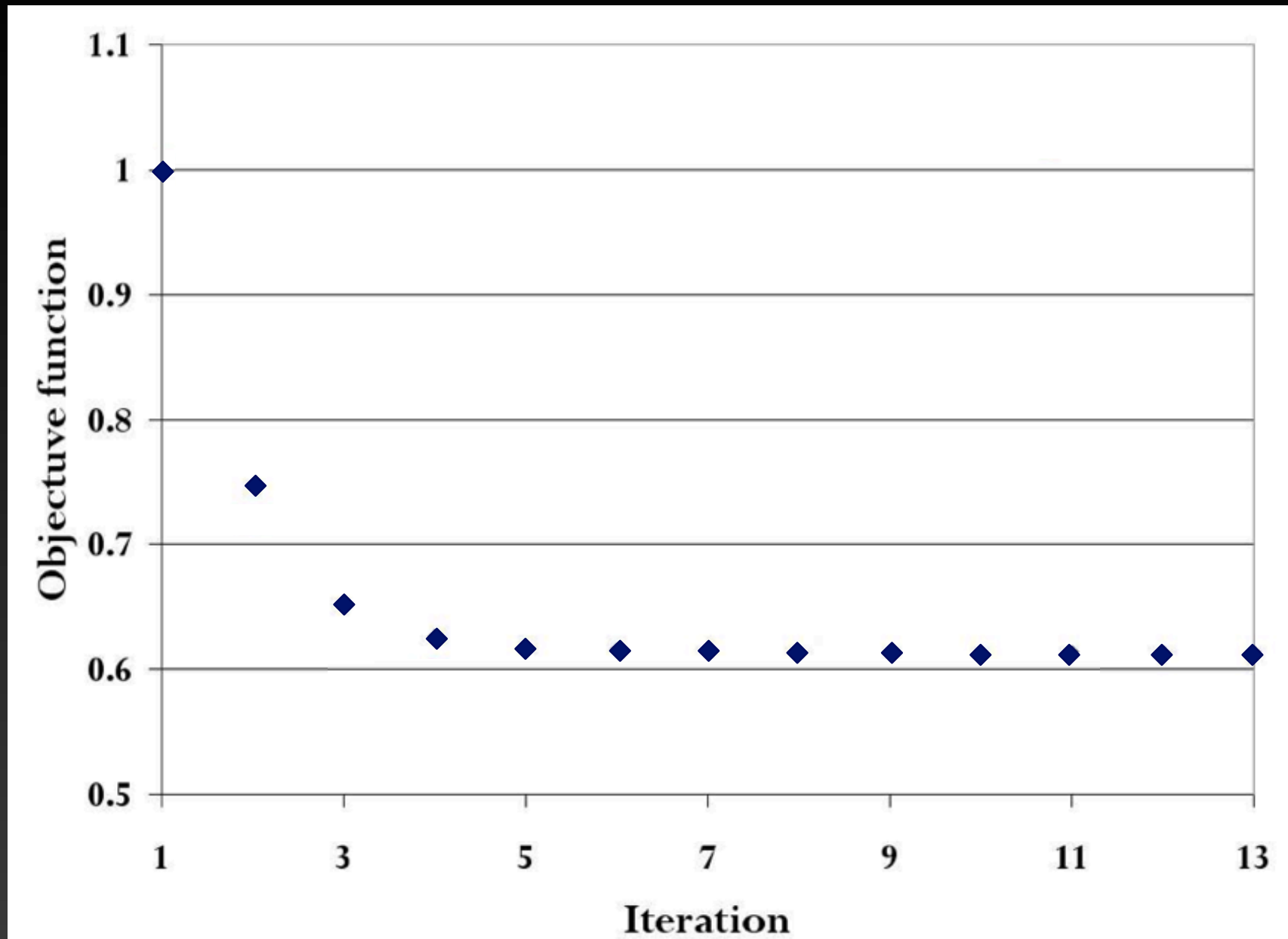
Initial image



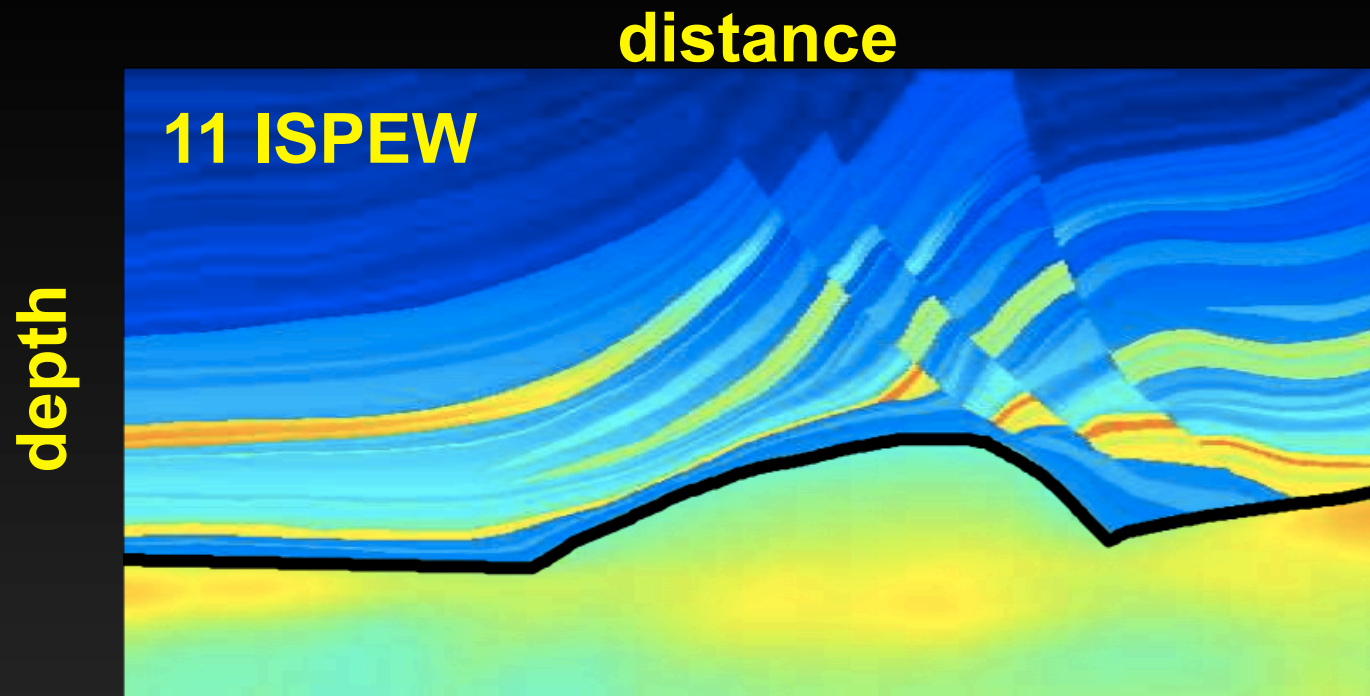
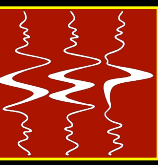
12 selected reflectors



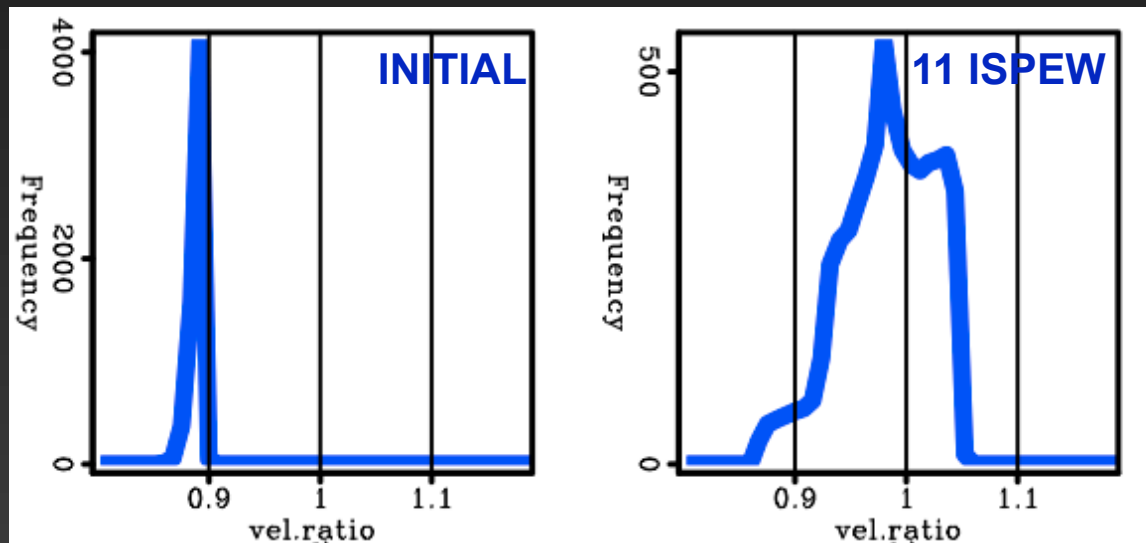
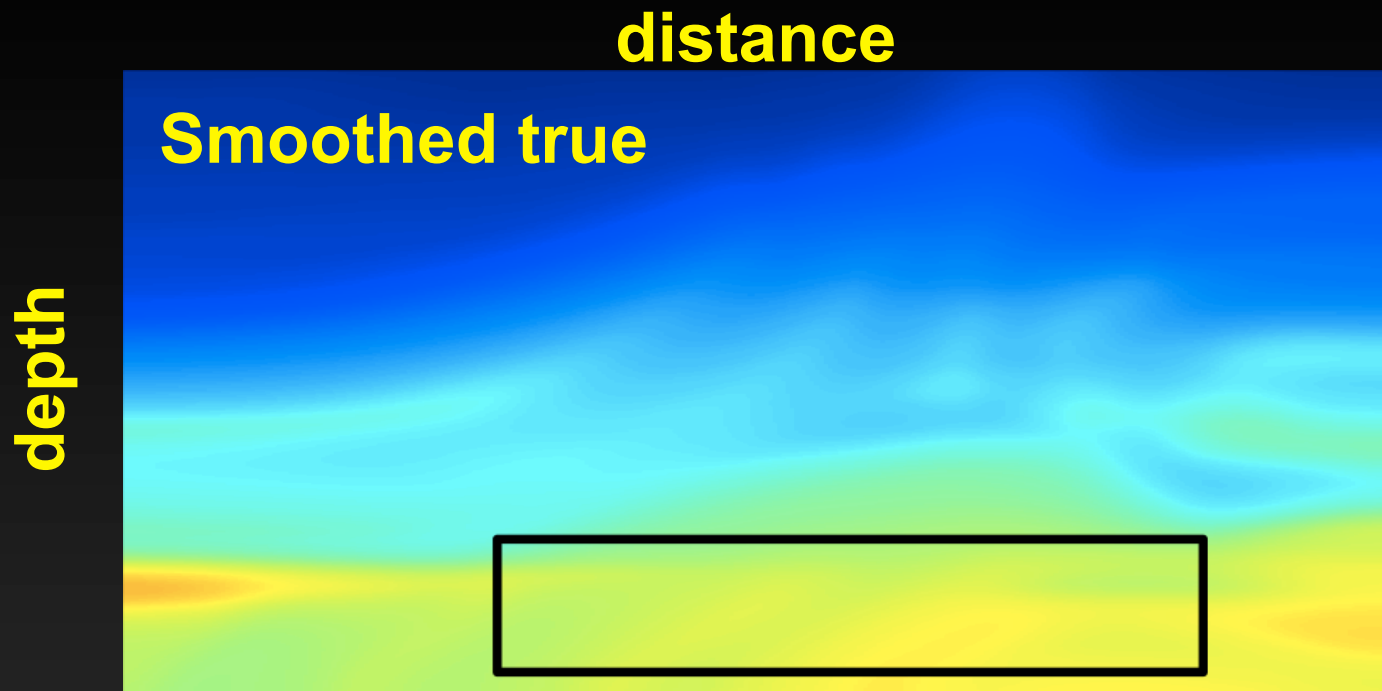
Evolution of the objective function



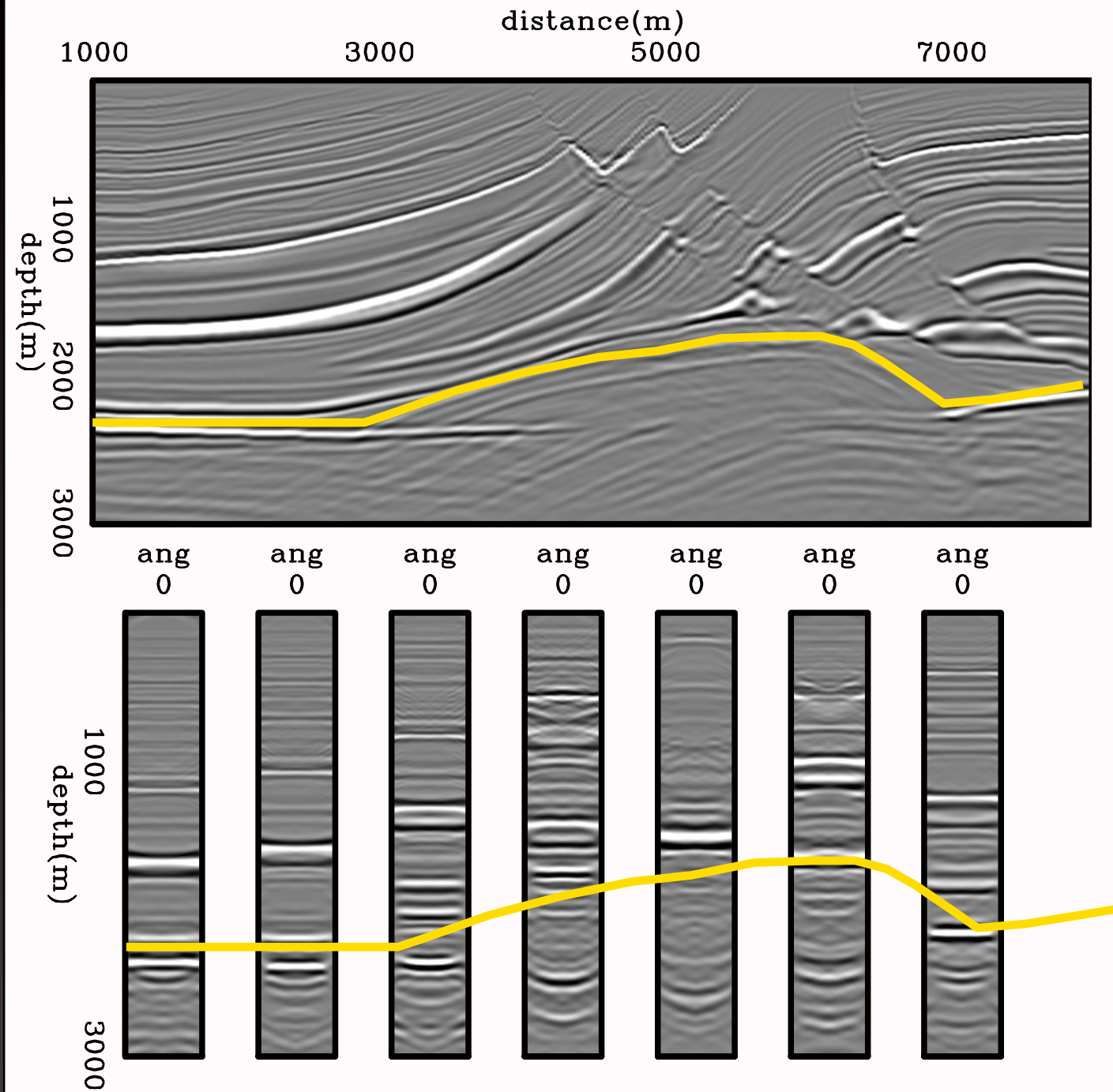
Optimized velocities



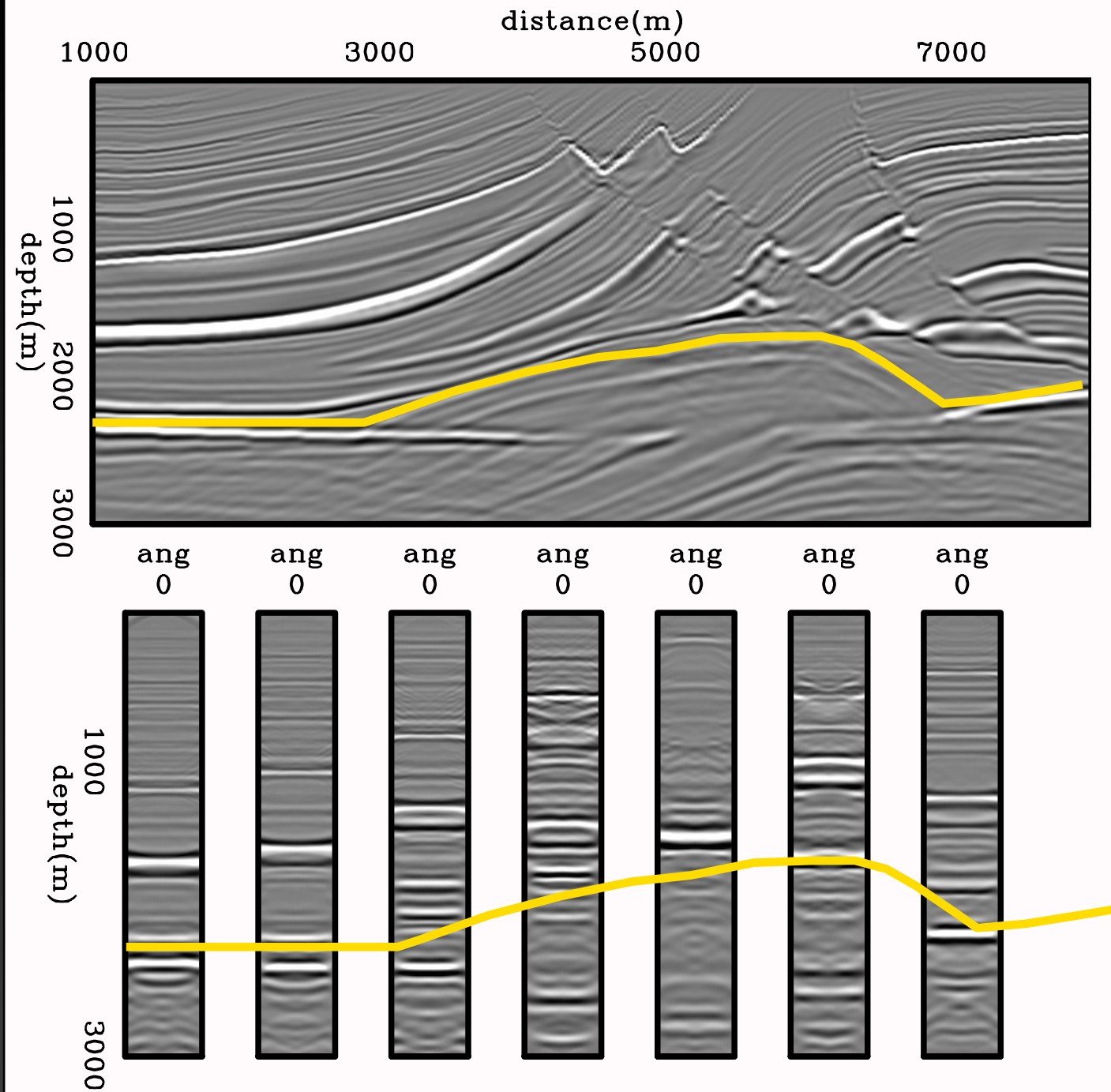
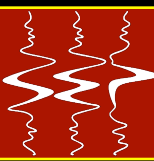
Velocity accuracy



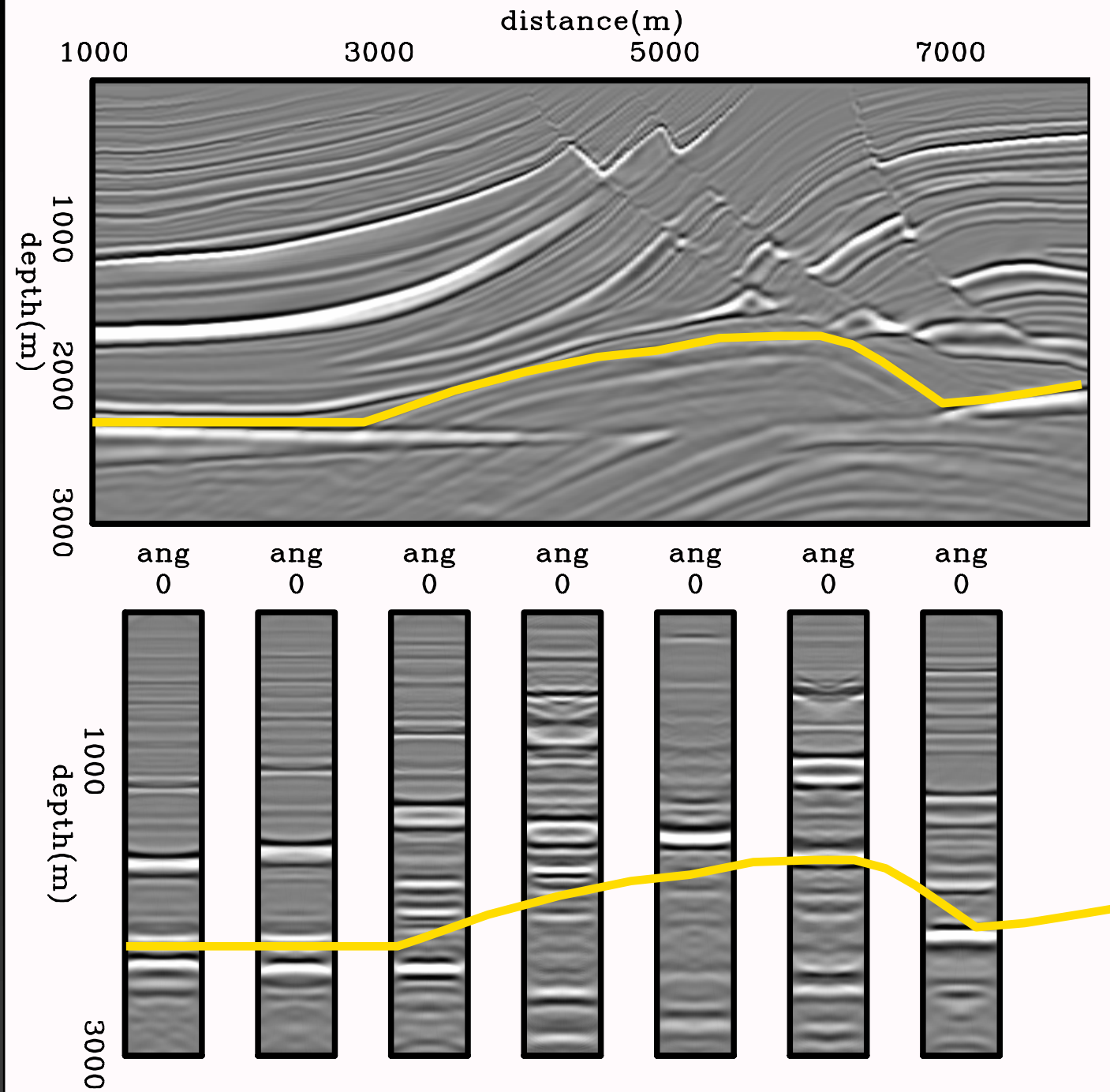
Initial image



Migration with optimized velocity



Migration with true velocity

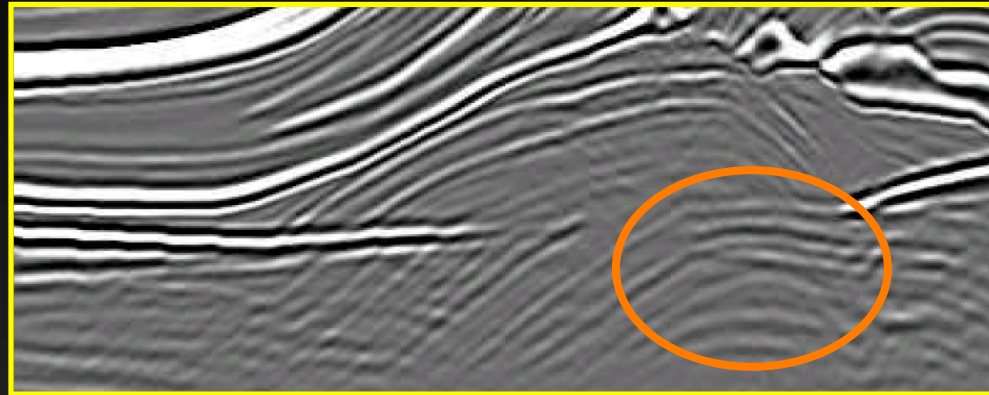


Computational gain



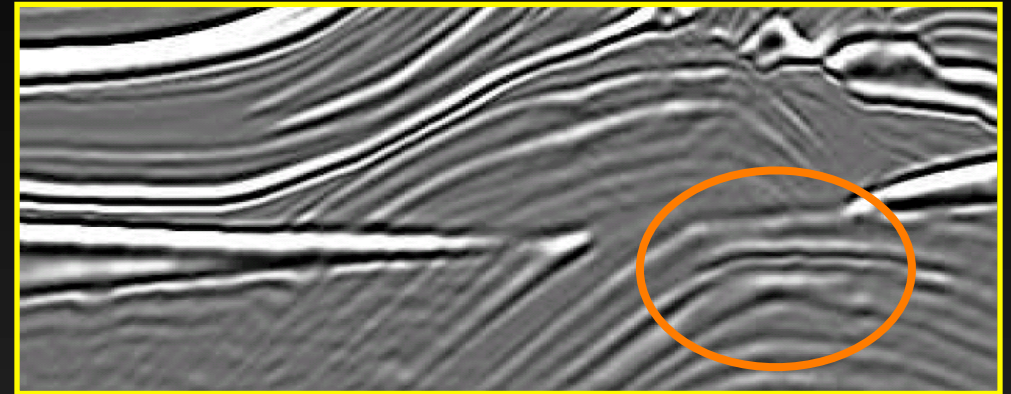
Initial

x



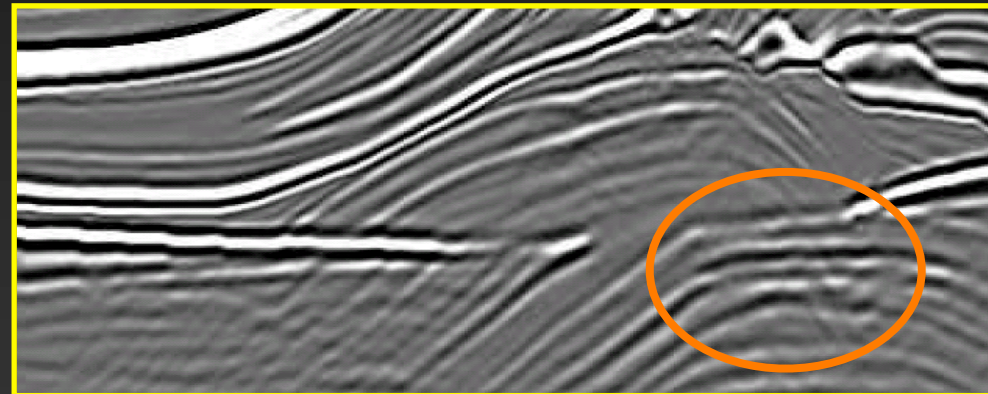
True

x

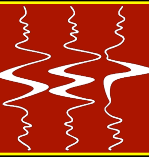


Optimized

z

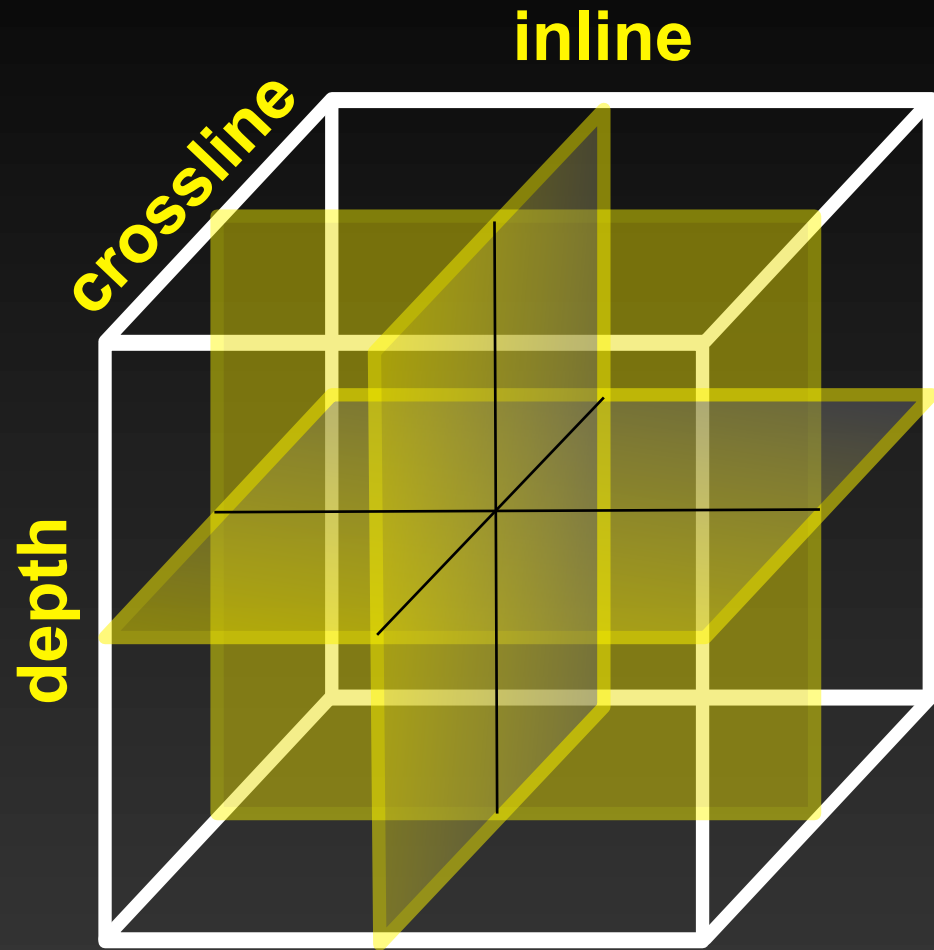
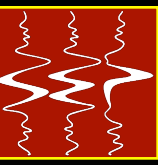


30x faster

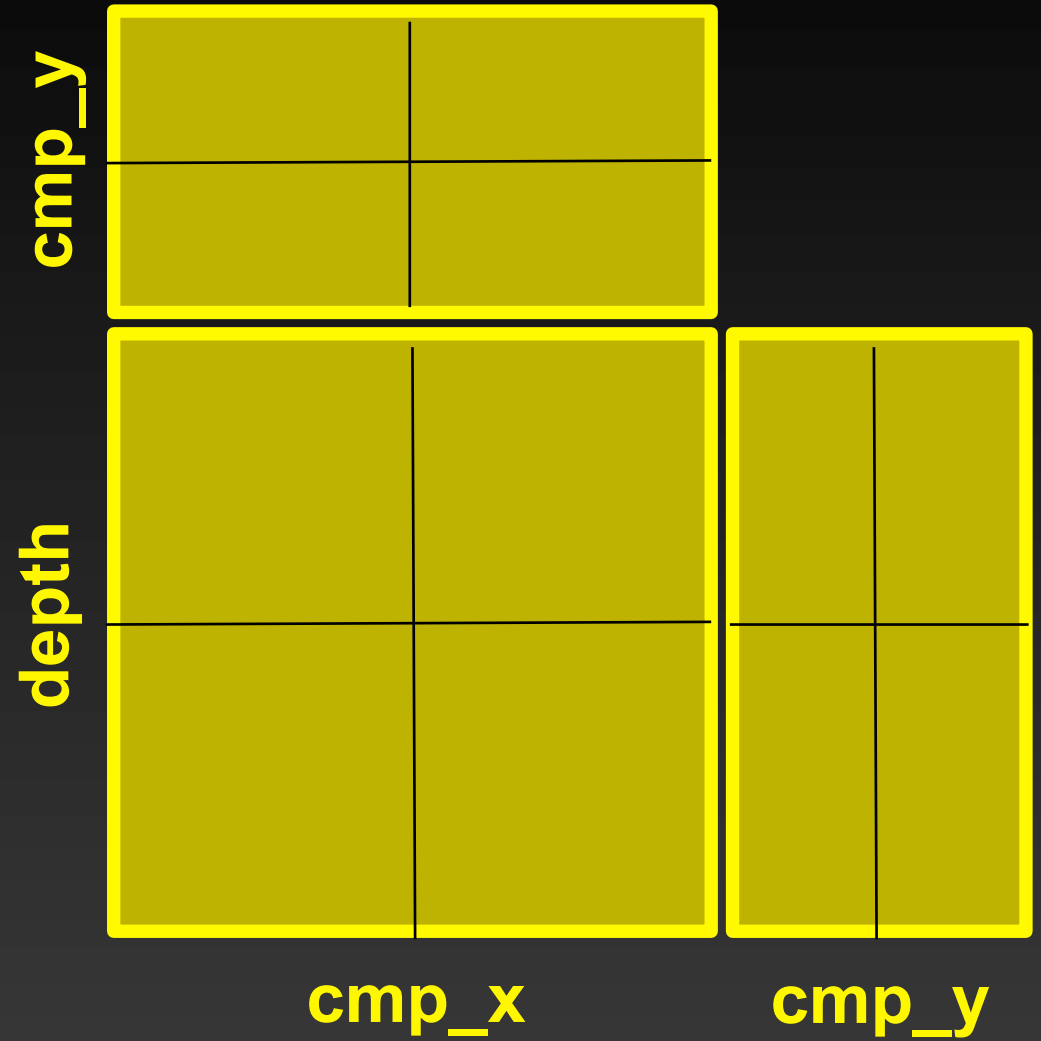
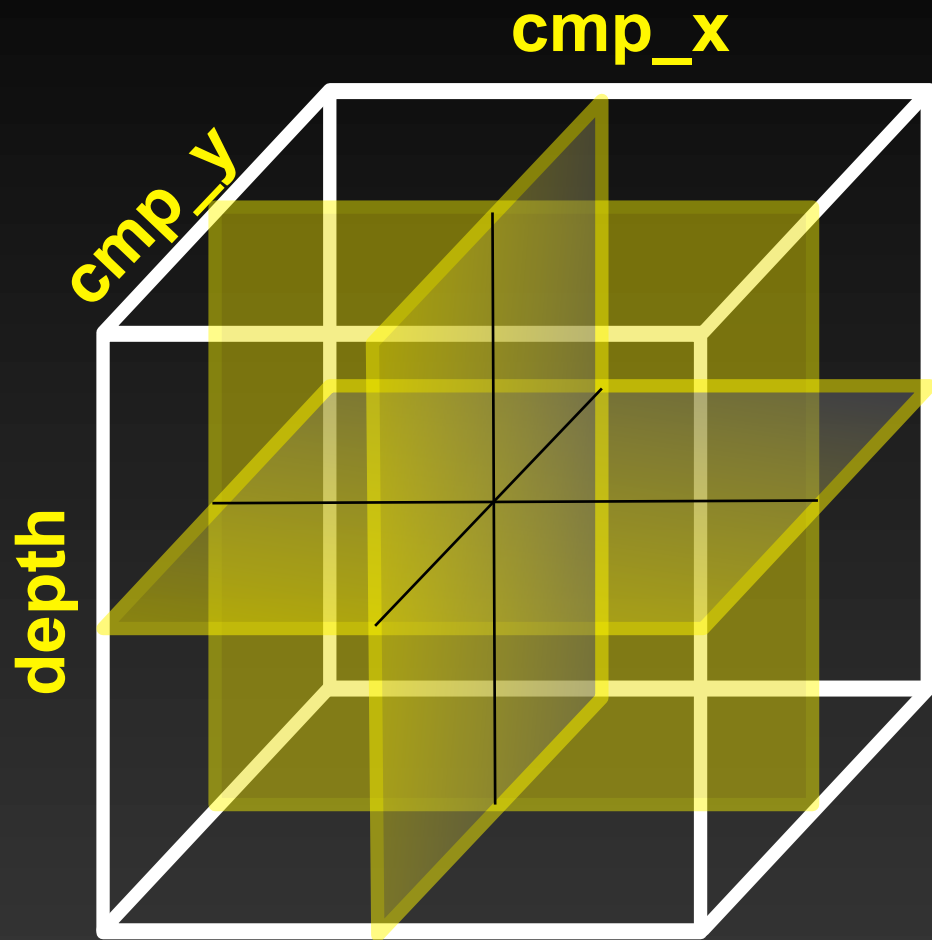
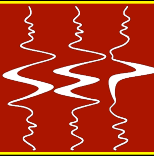


- ✓ **Chapter 2: Pre-stack exploding-reflector model**
- ✓ **Chapter 3: Image-space phase-encoded wavefields**
- ✓ **Chapter 4: MVA using image-space generalized sources**
- **Chapter 5: 3D-field data example**

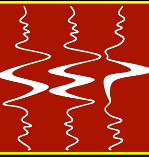
3D views



3D views



3D-North Sea data example



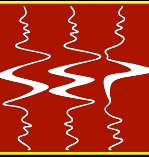
- **Dimensions: 12 x 4 km**

3D-North Sea data example

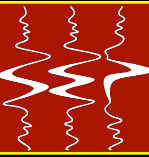


- **Dimensions: 12 x 4 km**
- **Maximum offset: 3.6 km**

3D-North Sea data example



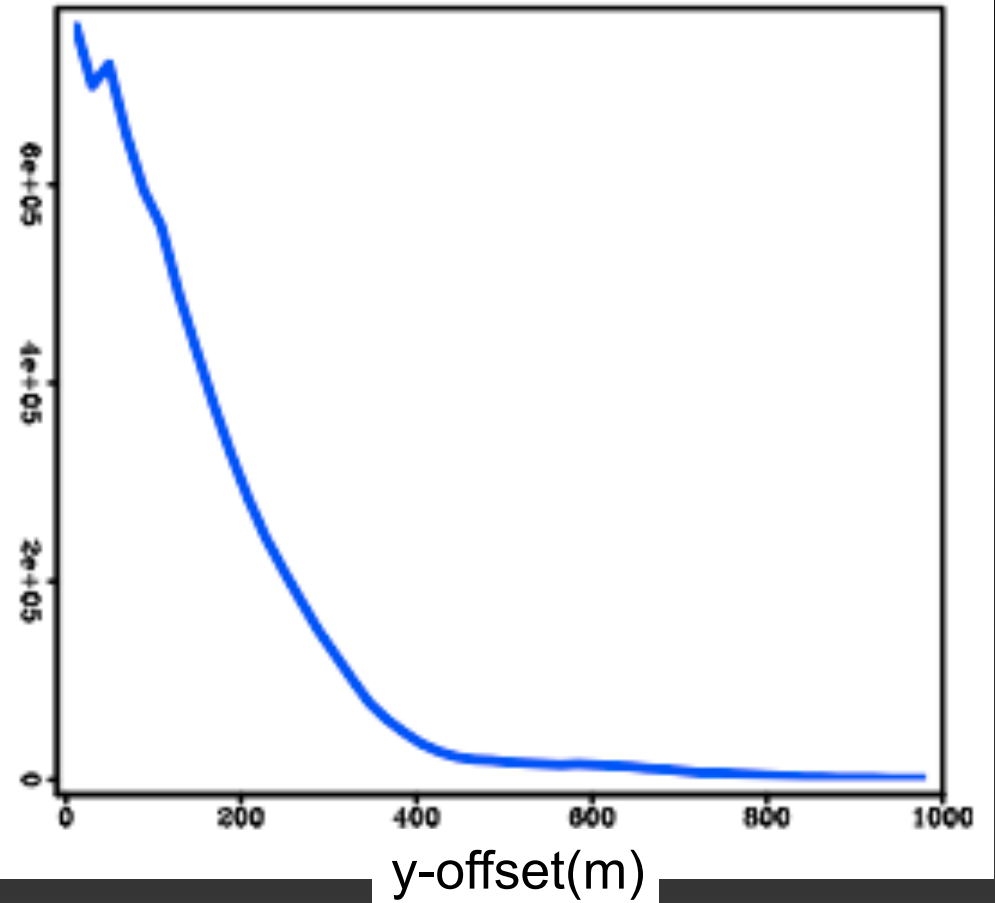
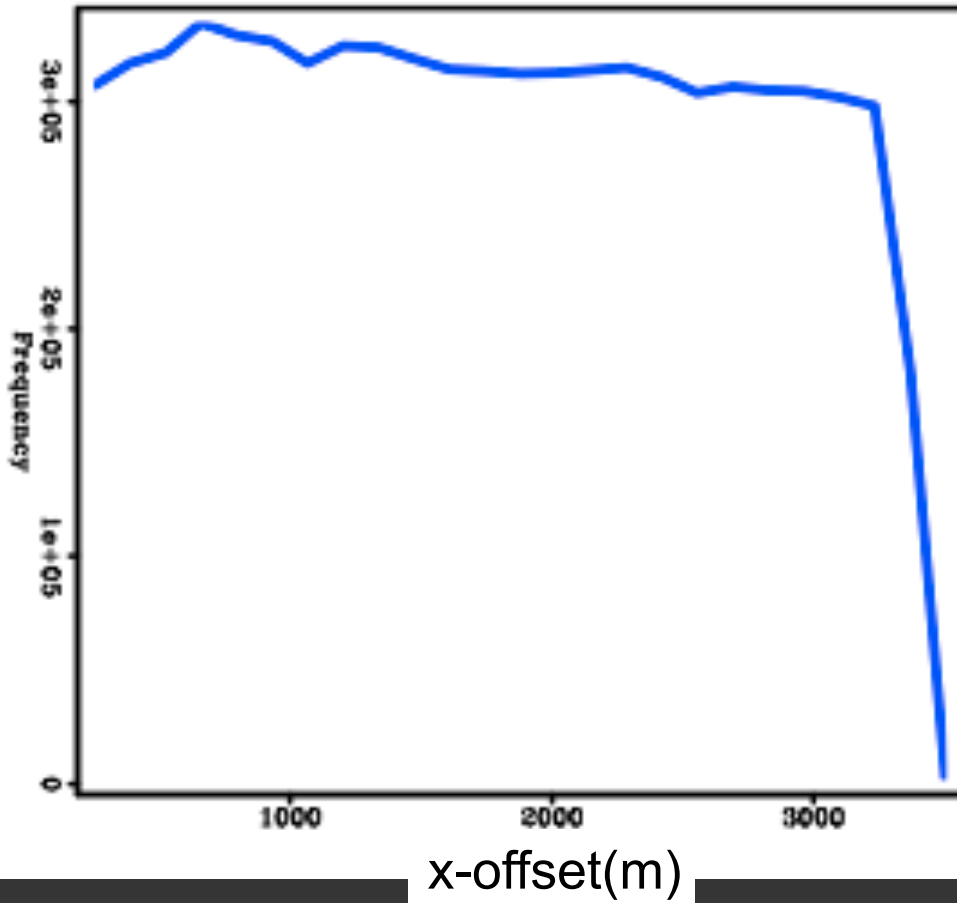
- **Dimensions: 12 x 4 km**
- **Maximum offset: 3.6 km**
- **30 ISPEW**

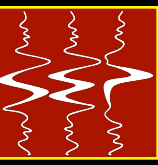


- **Intense faulting, irregular salt body**
 - **interpretation inaccuracy**

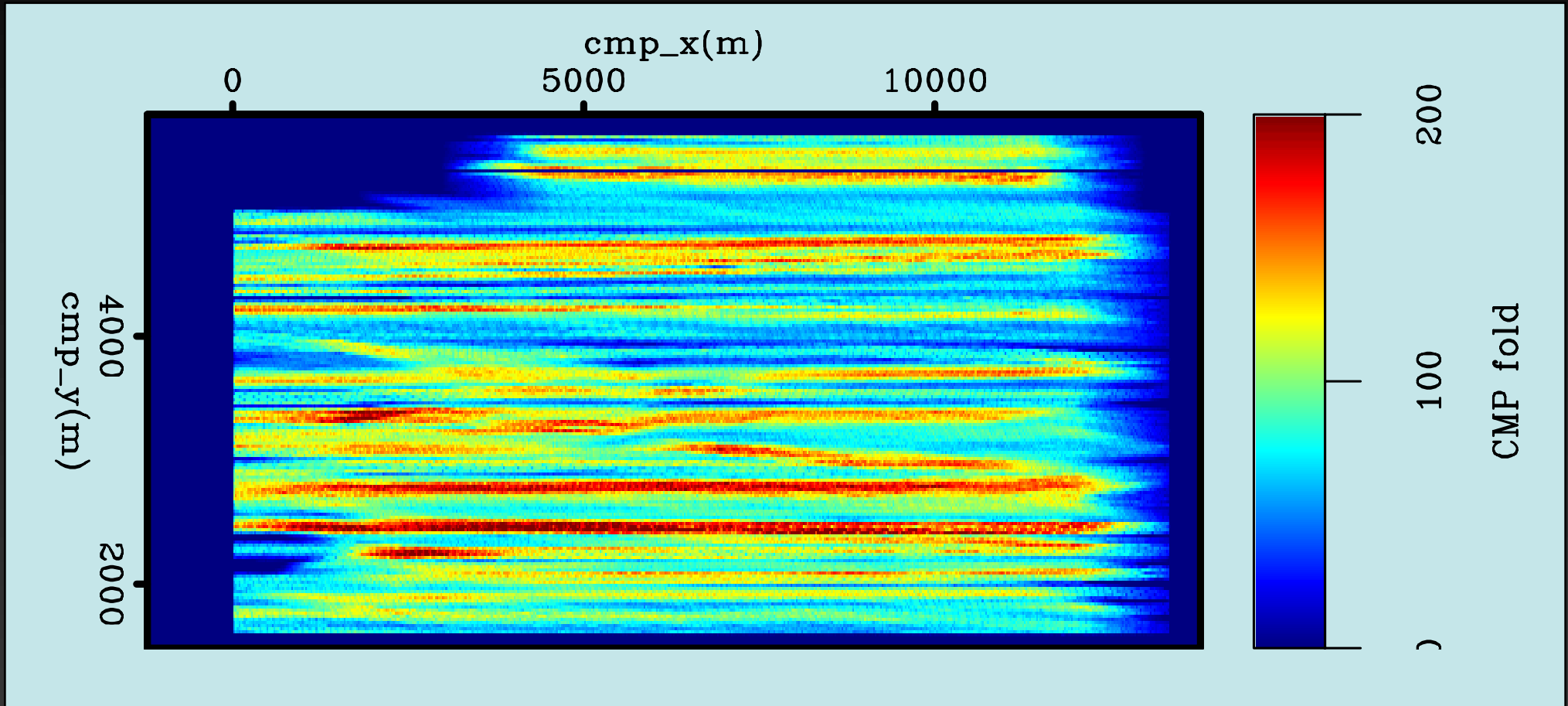


- **Limited angular coverage and offsets**

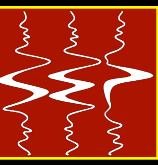




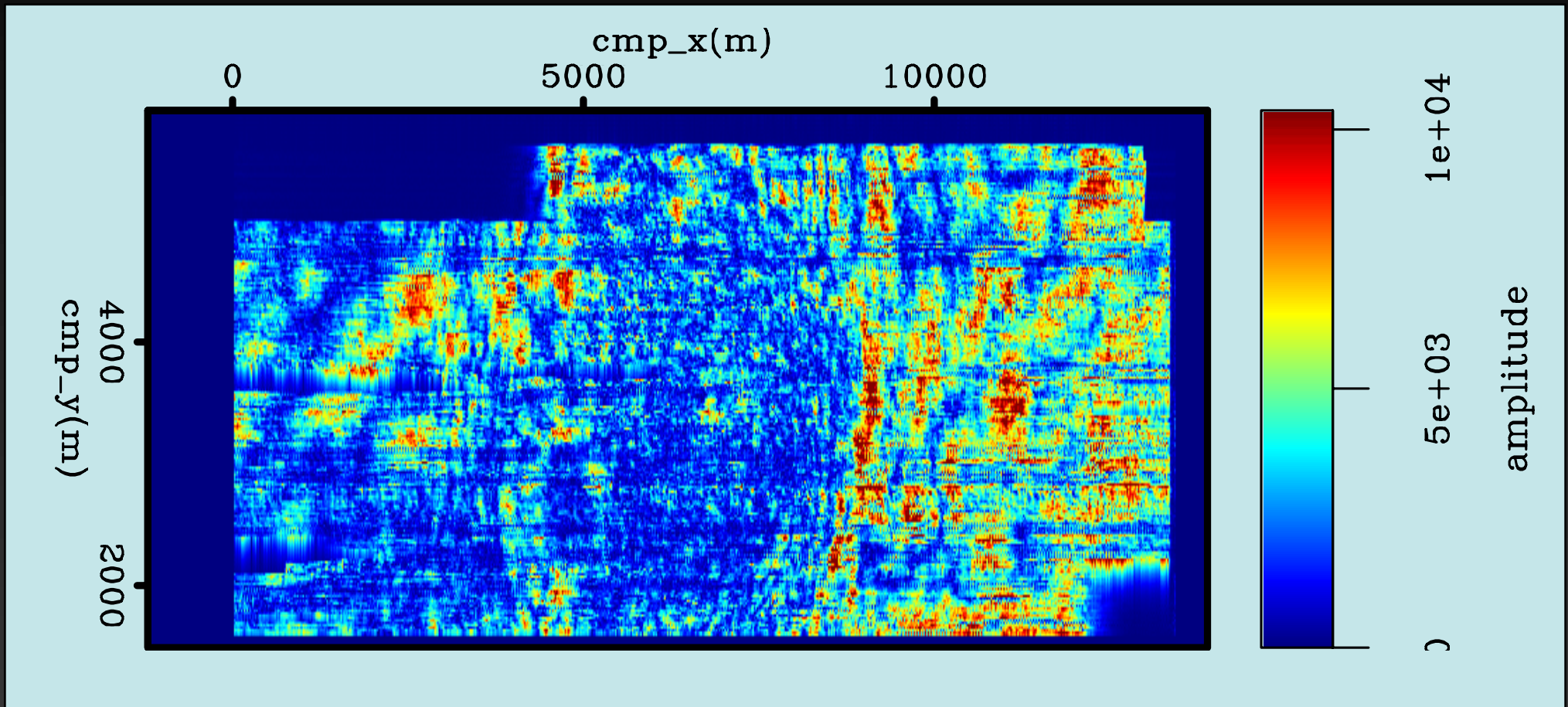
- **Acquisition footprint**
 - **CMP fold**



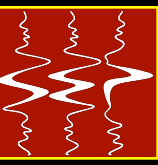
Challenges



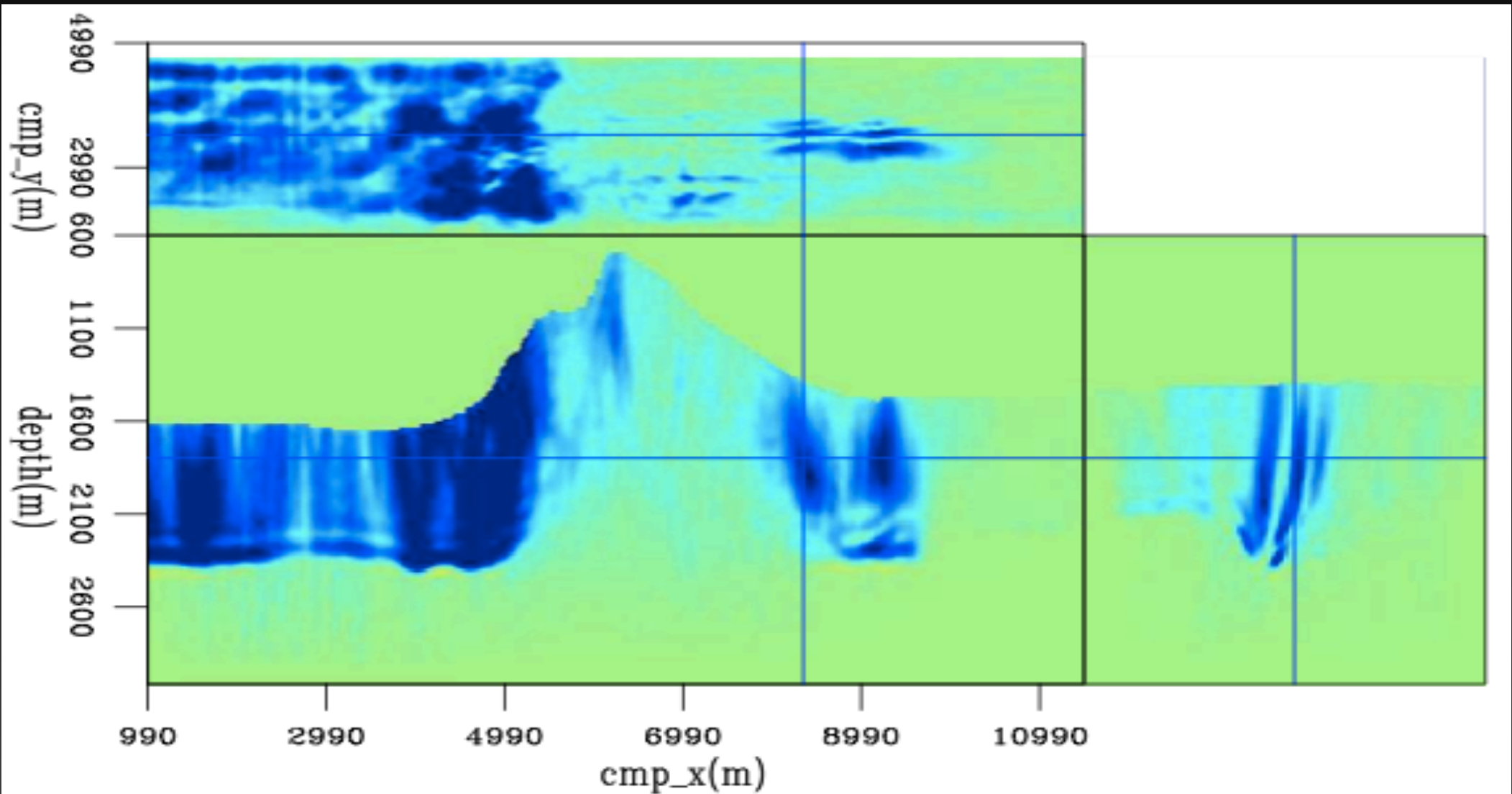
- Acquisition footprint
- RMS amplitude map



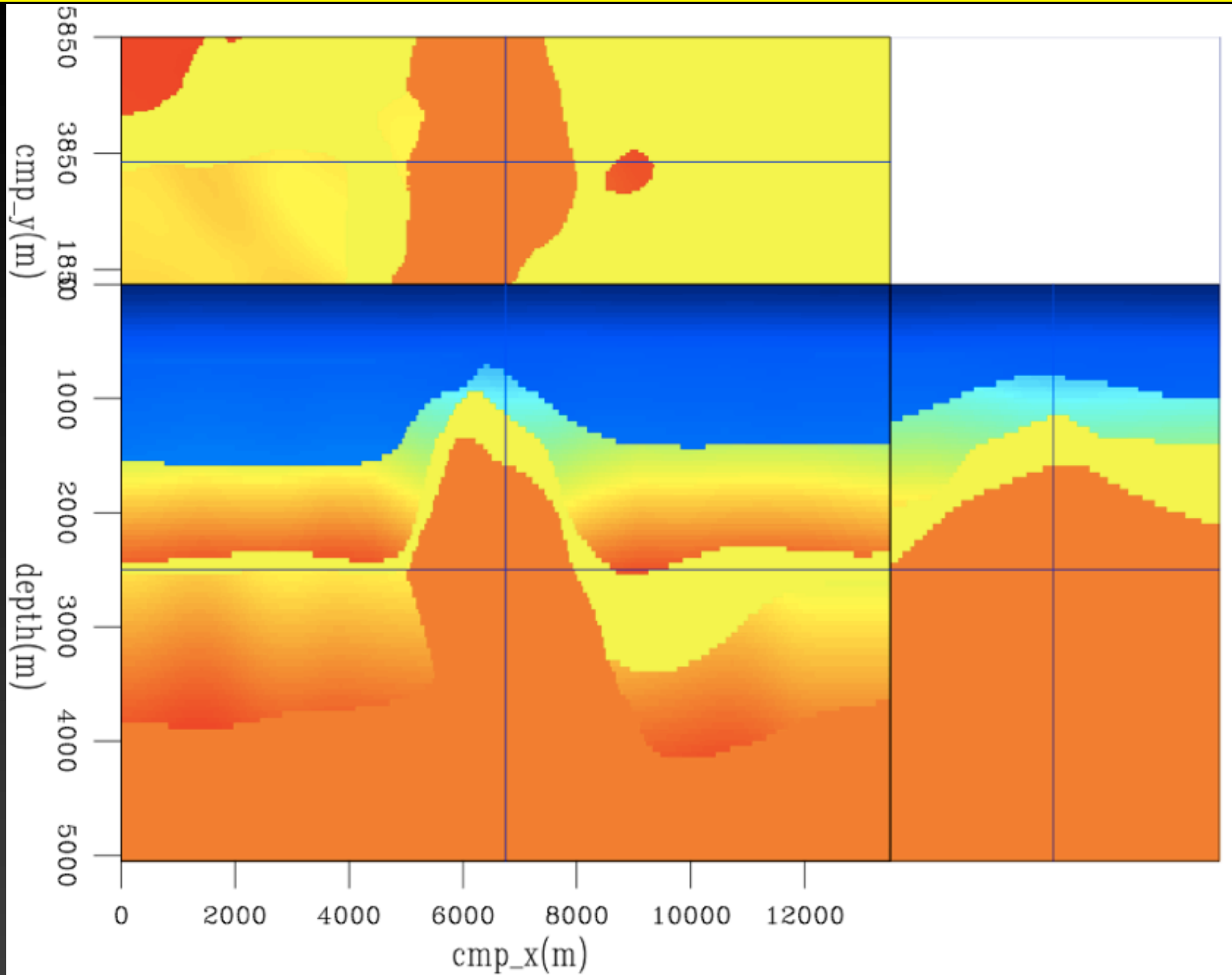
Challenges



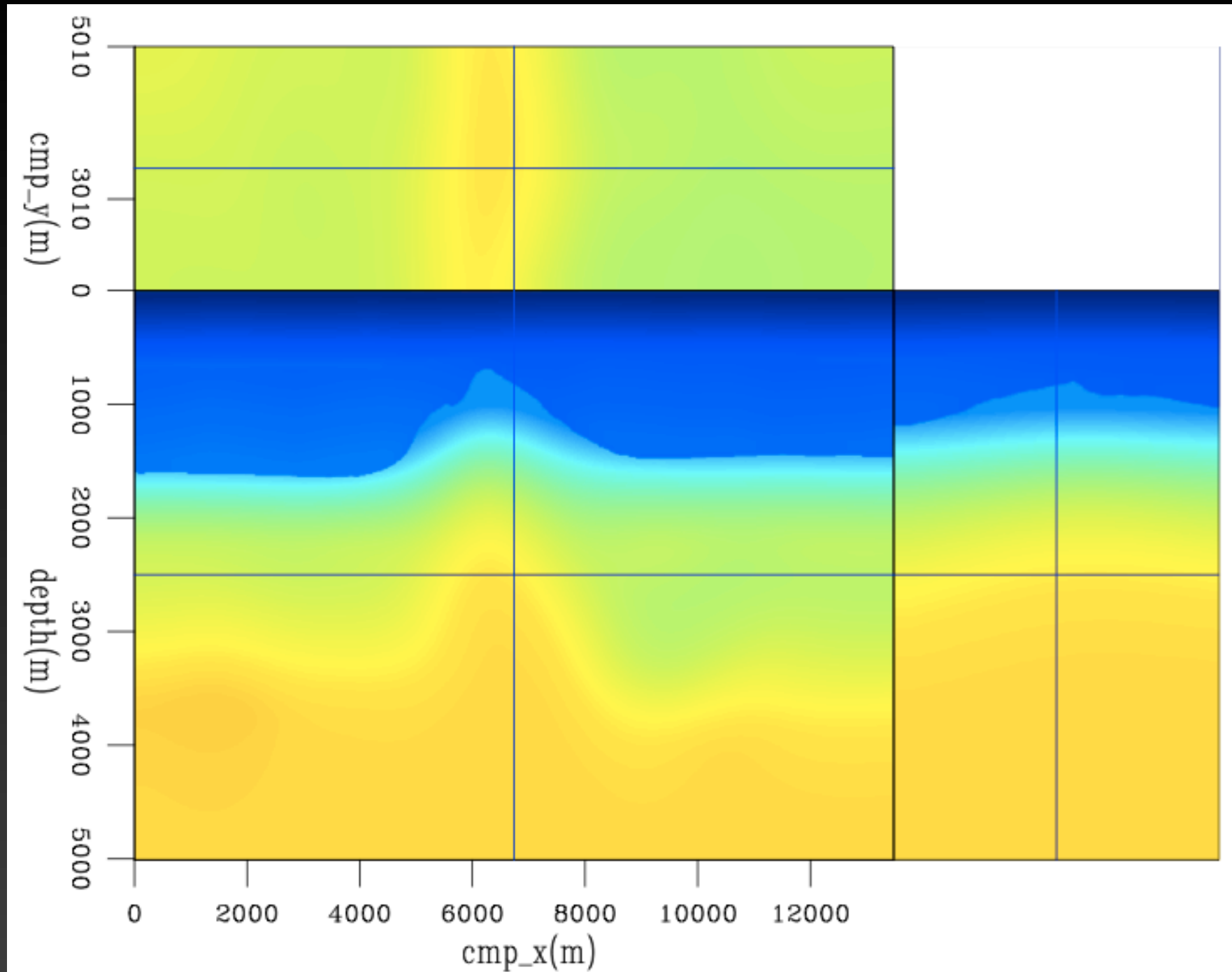
- **Acquisition footprint**
 - deteriorates the gradient



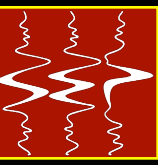
Original velocity model



Initial velocity model

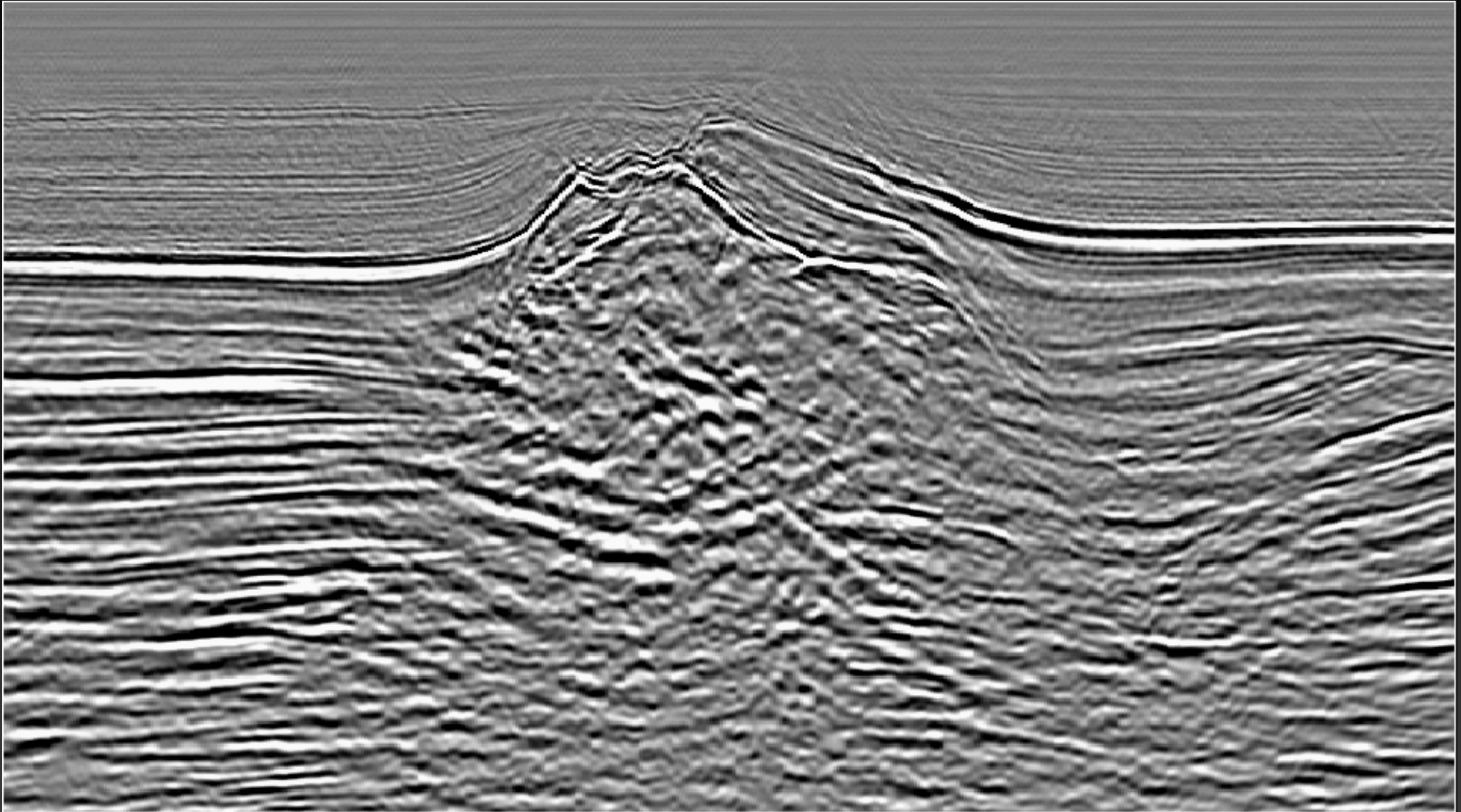


MVA strategy

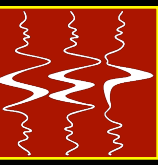


distance

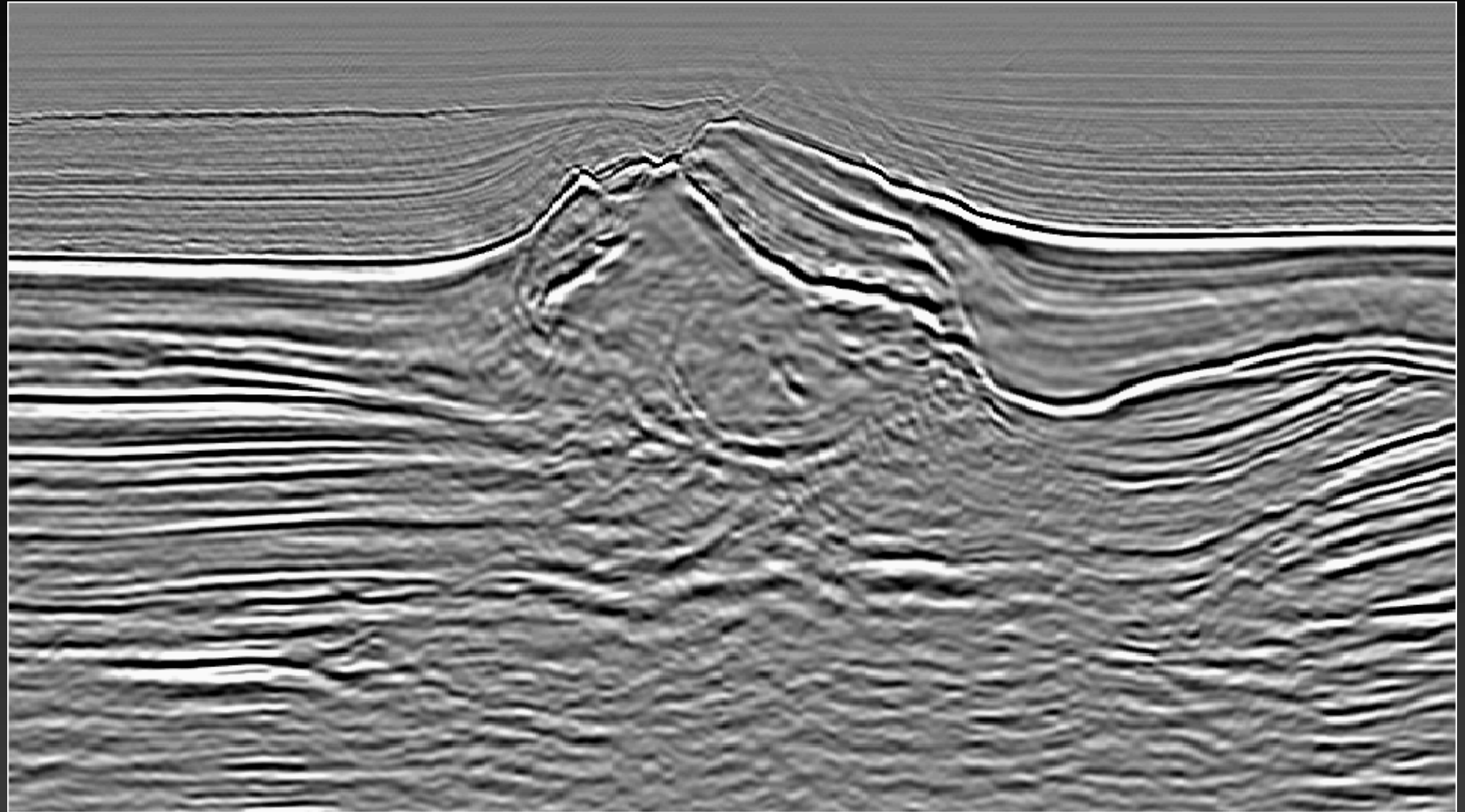
depth



MVA strategy

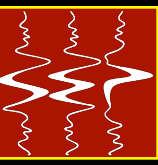


distance



depth

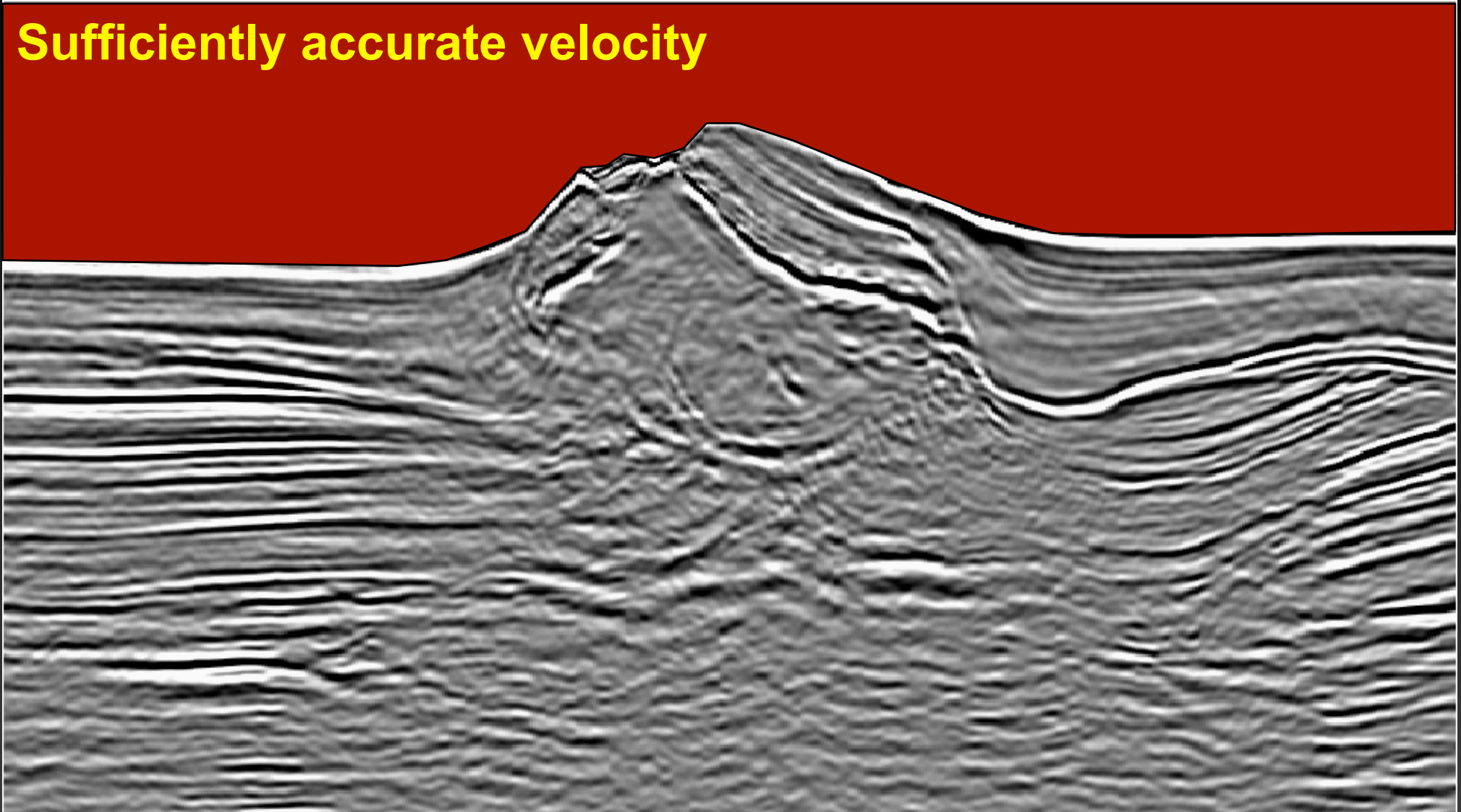
MVA strategy



distance

Sufficiently accurate velocity

depth



MVA strategy



distance

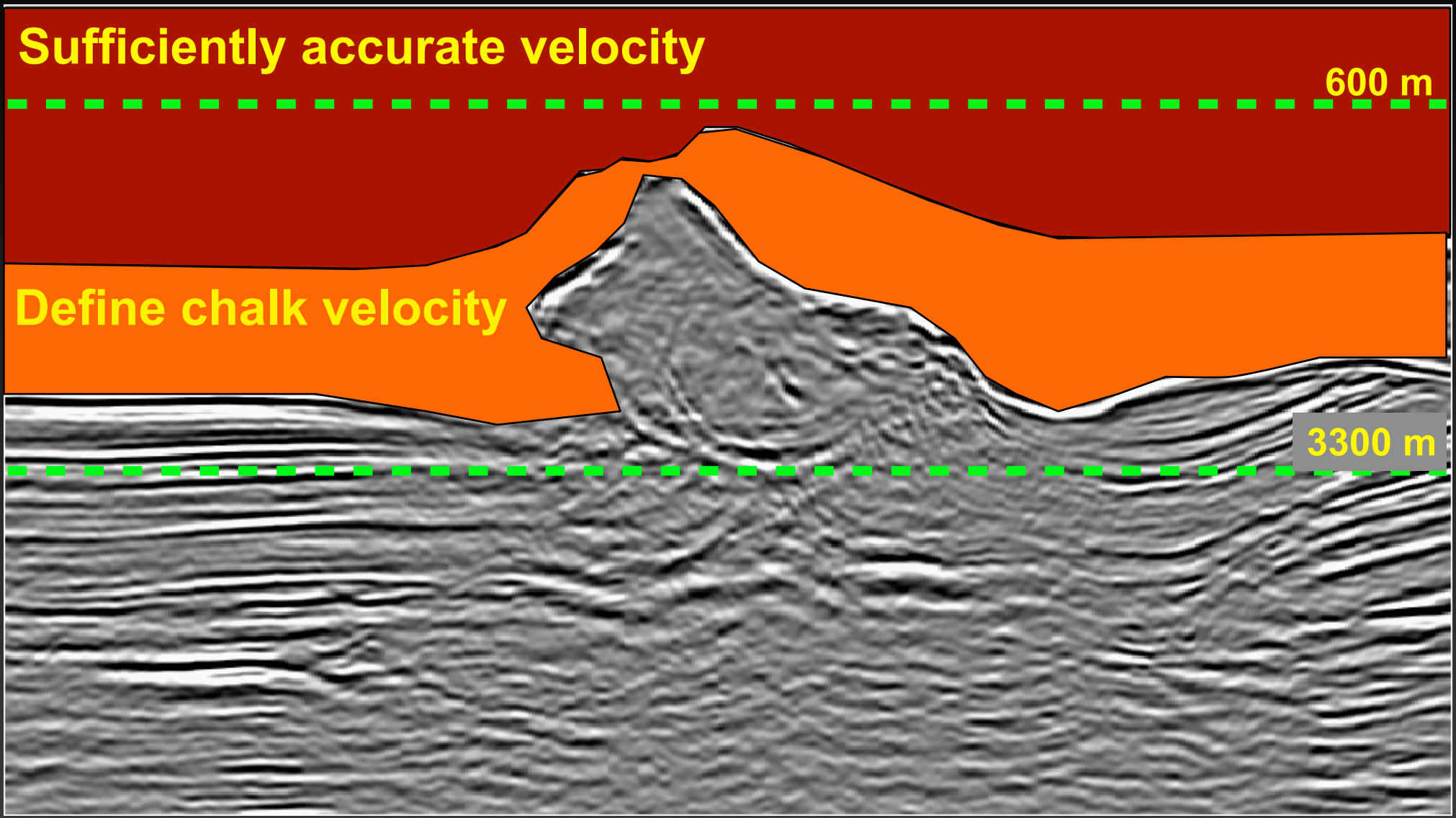
Sufficiently accurate velocity

600 m

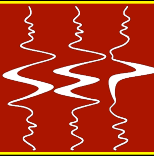
Define chalk velocity

3300 m

depth



MVA strategy



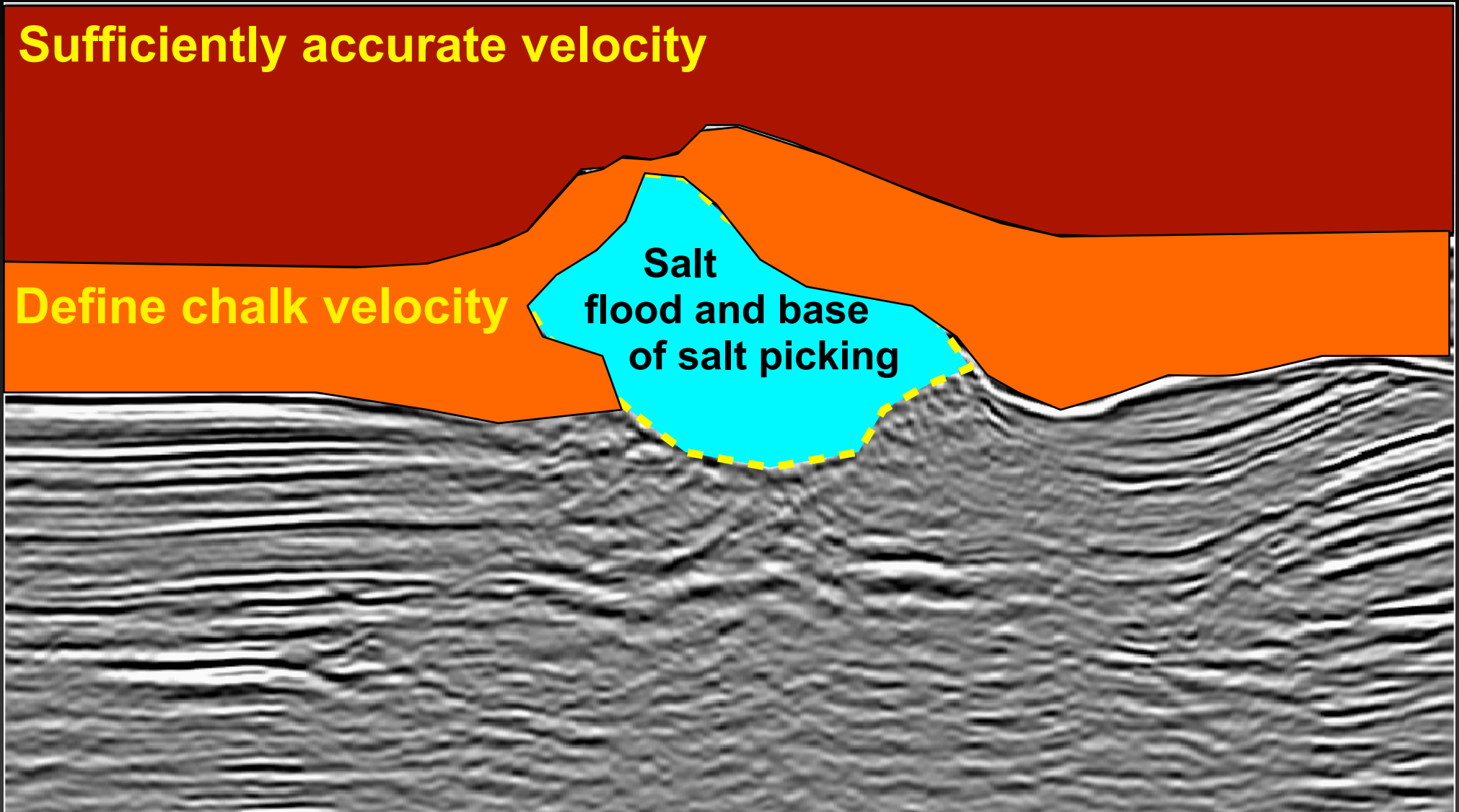
distance

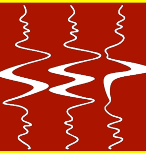
Sufficiently accurate velocity

Define chalk velocity

Salt
flood and base
of salt picking

depth





distance

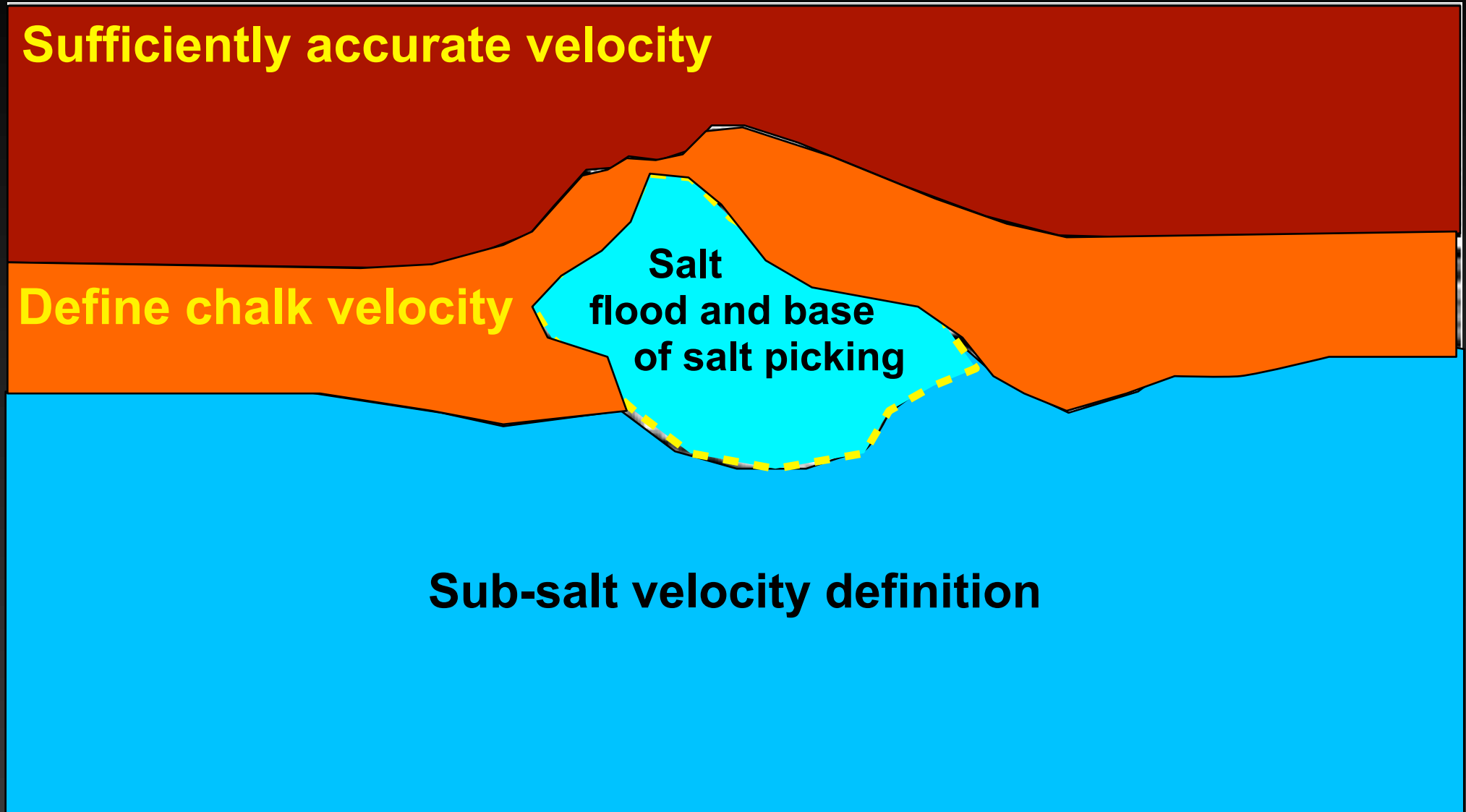
Sufficiently accurate velocity

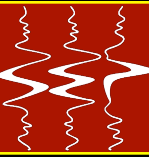
Define chalk velocity

**Salt
flood and base
of salt picking**

Sub-salt velocity definition

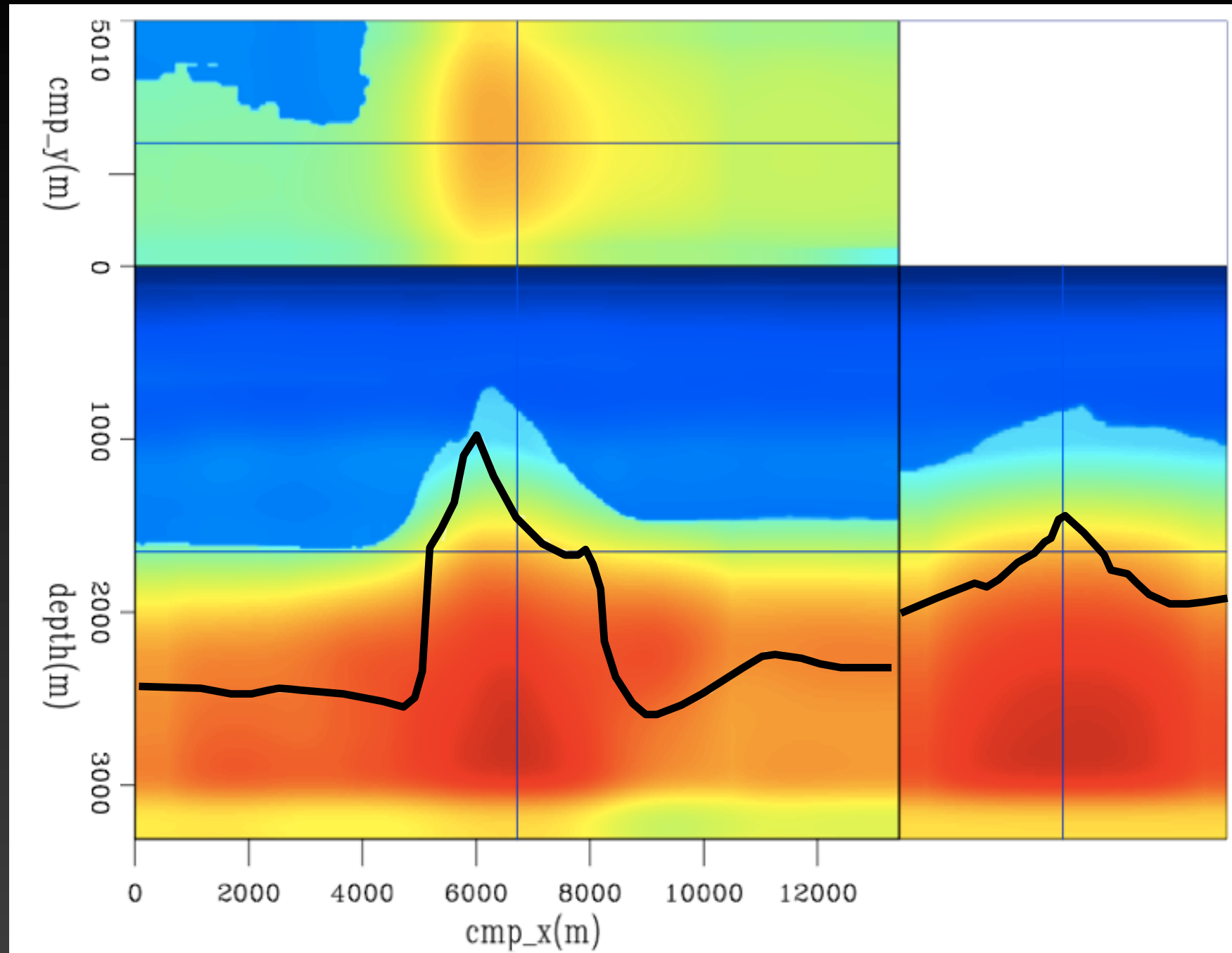
depth



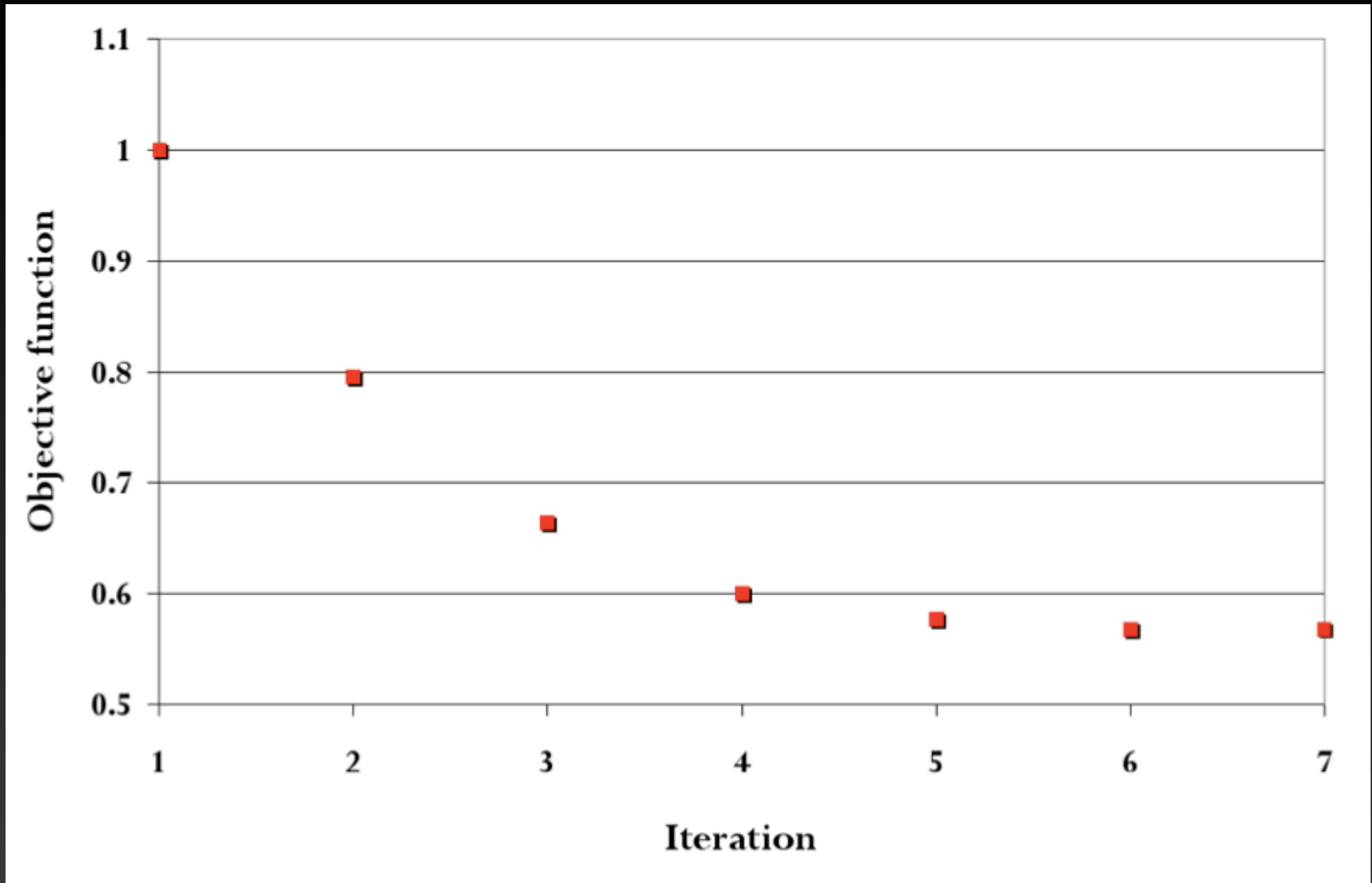


- **Non-linear conjugate gradient**
- **Maximum of 10% velocity variation between iterations**
- **Two function evaluations per iteration**
- **CEES: 30 Dual Nehalem 5520, 24Gb RAM**
 - **Objective function: 20 min**
 - **Gradient: 40 min**

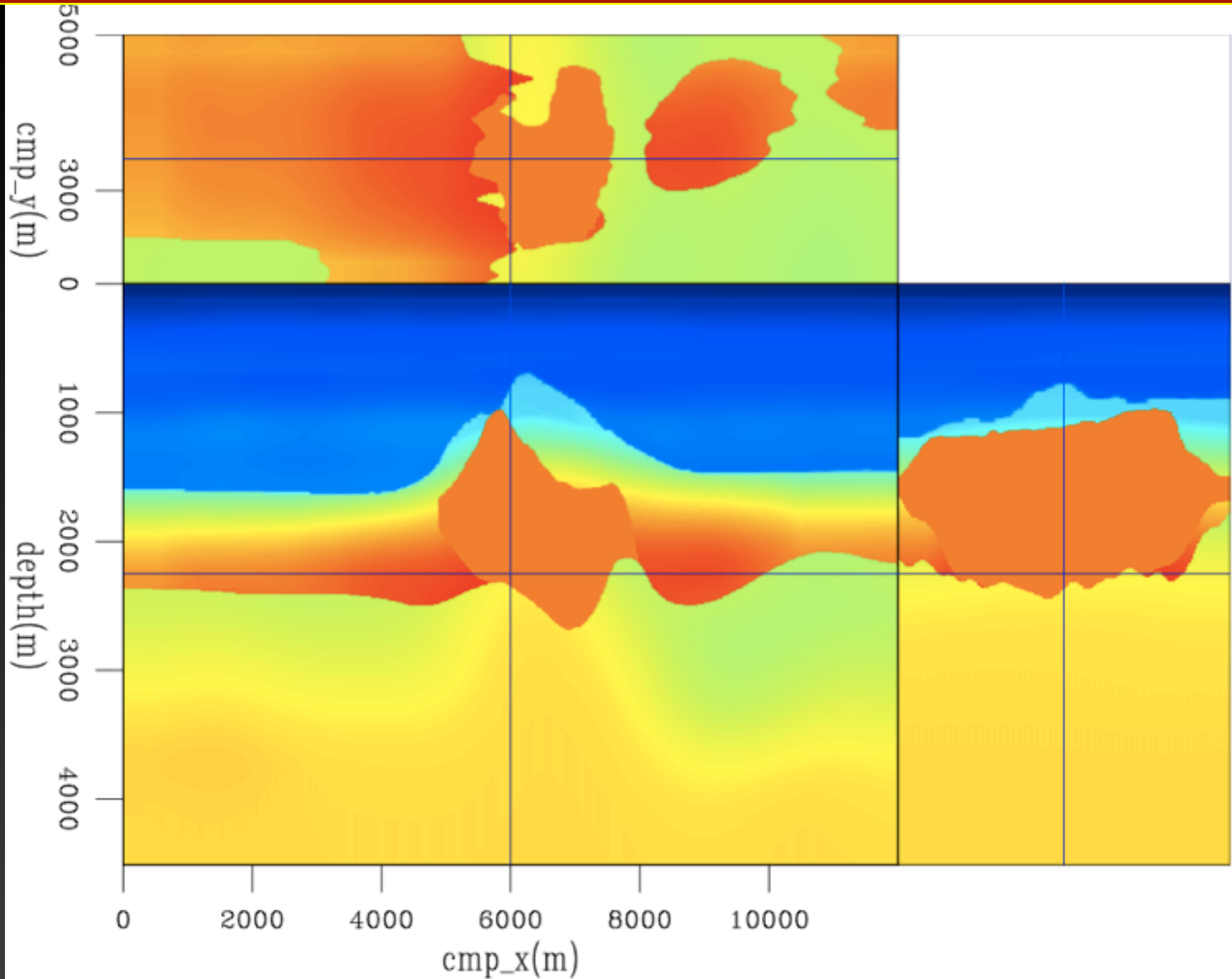
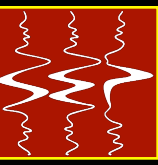
Optimized chalk velocity



Objective function



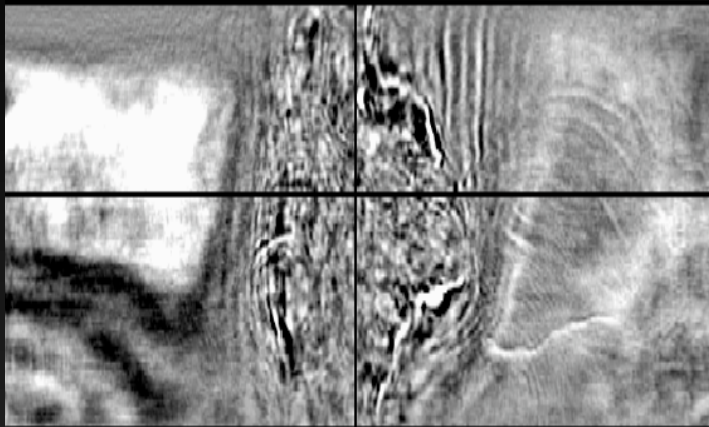
Velocity after salt body definition



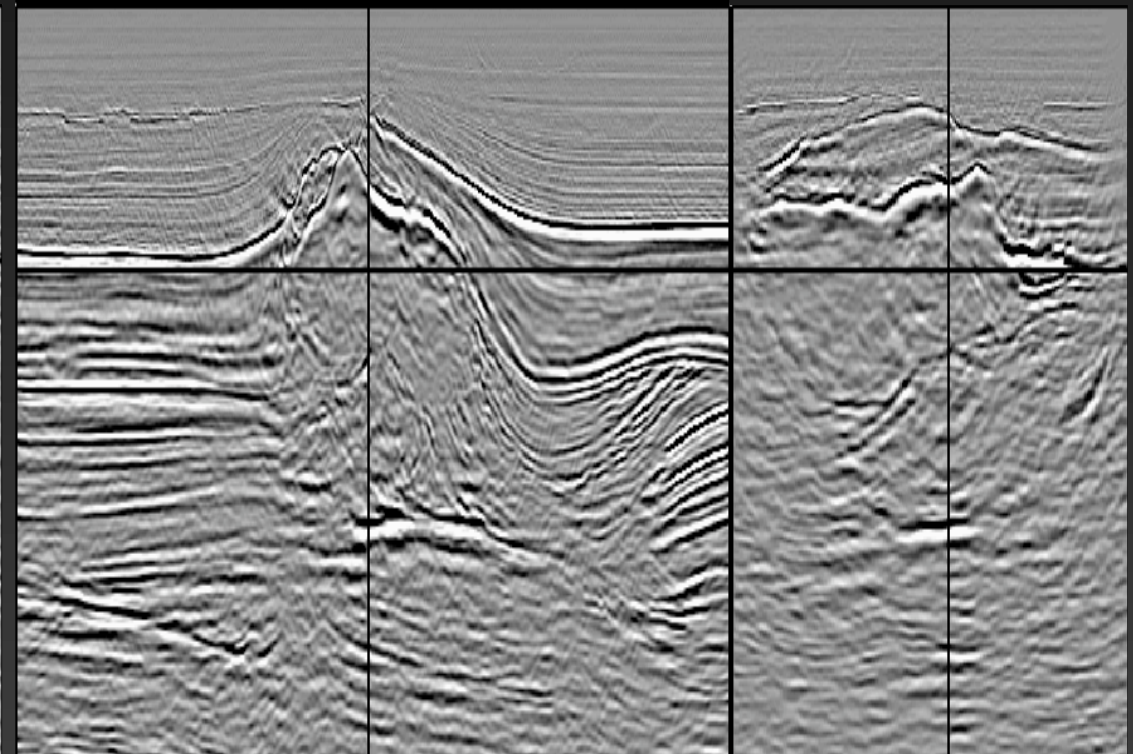
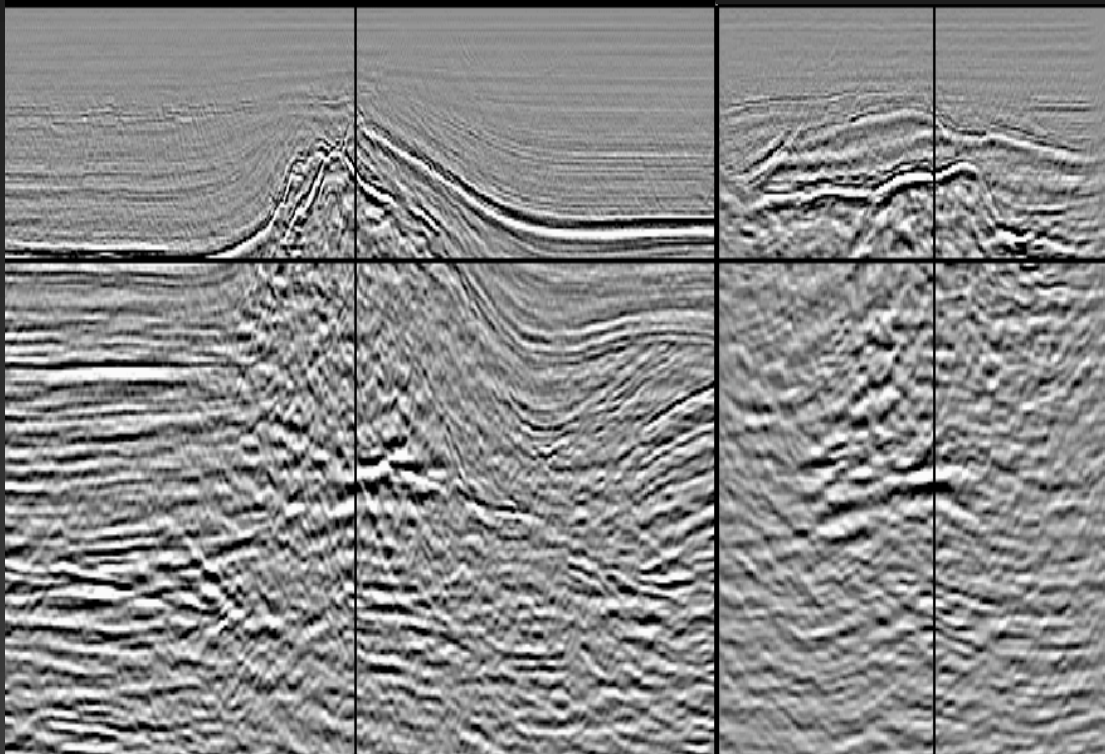
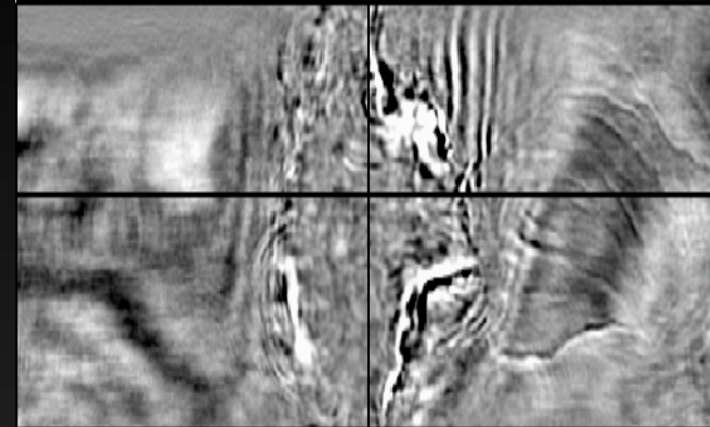
Better base of salt & focusing



Initial



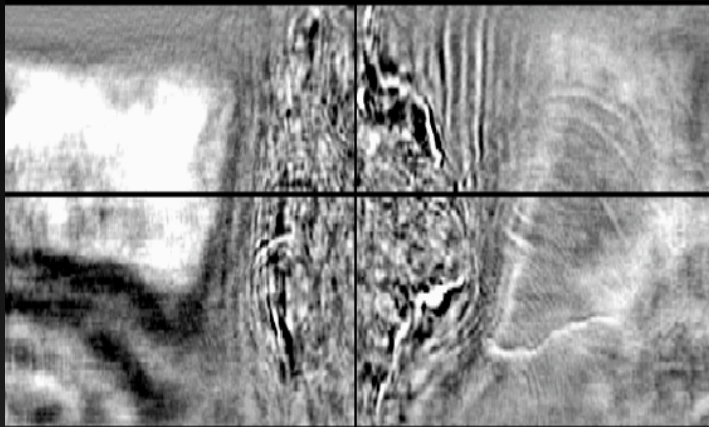
After salt body



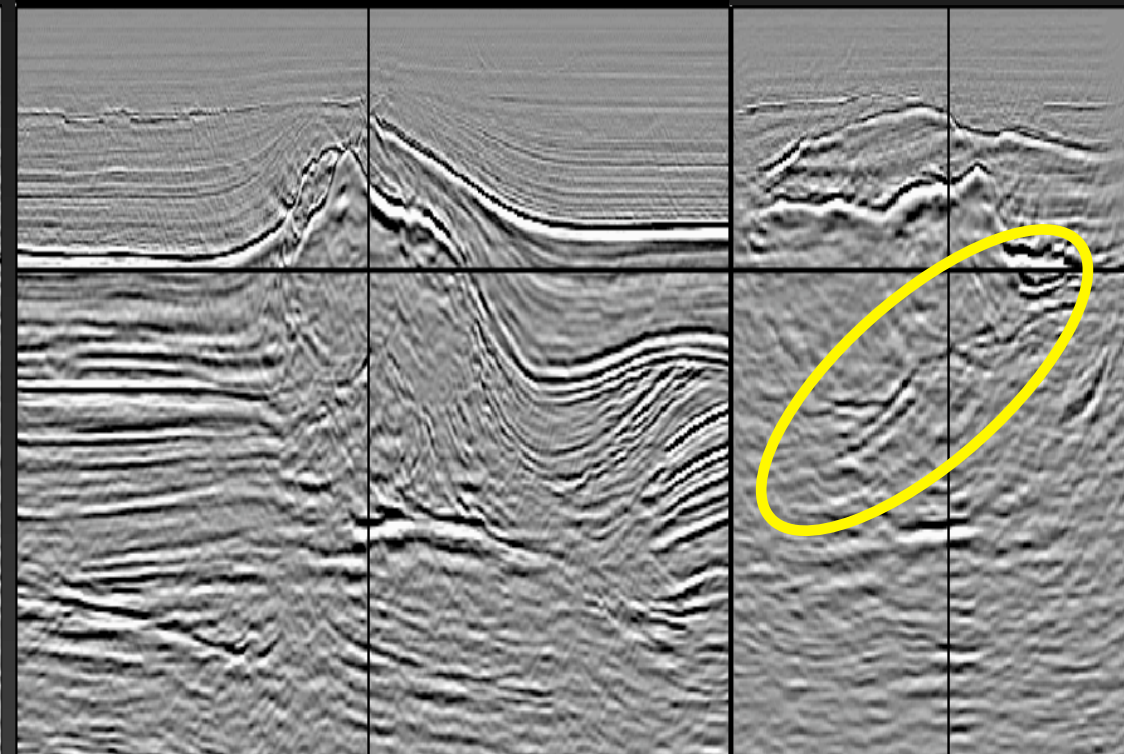
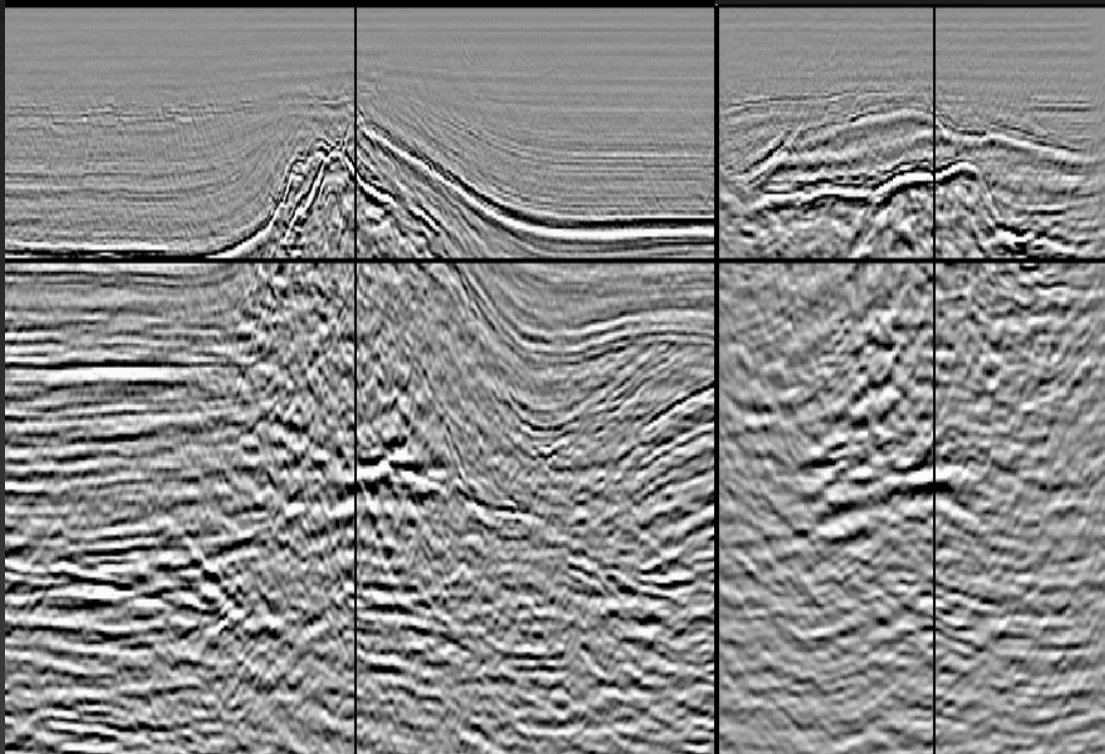
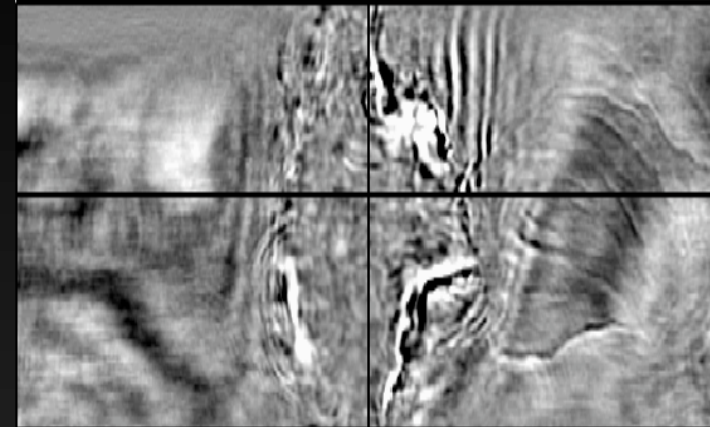
Better base of salt & focusing



Initial



After salt body

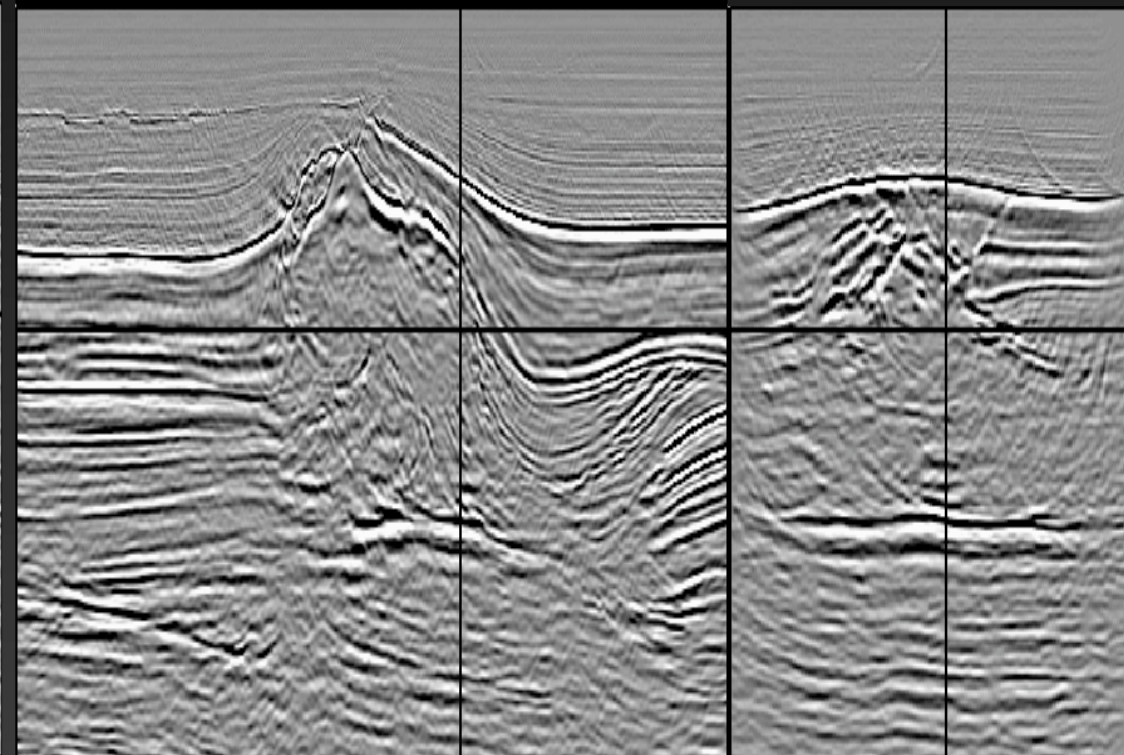
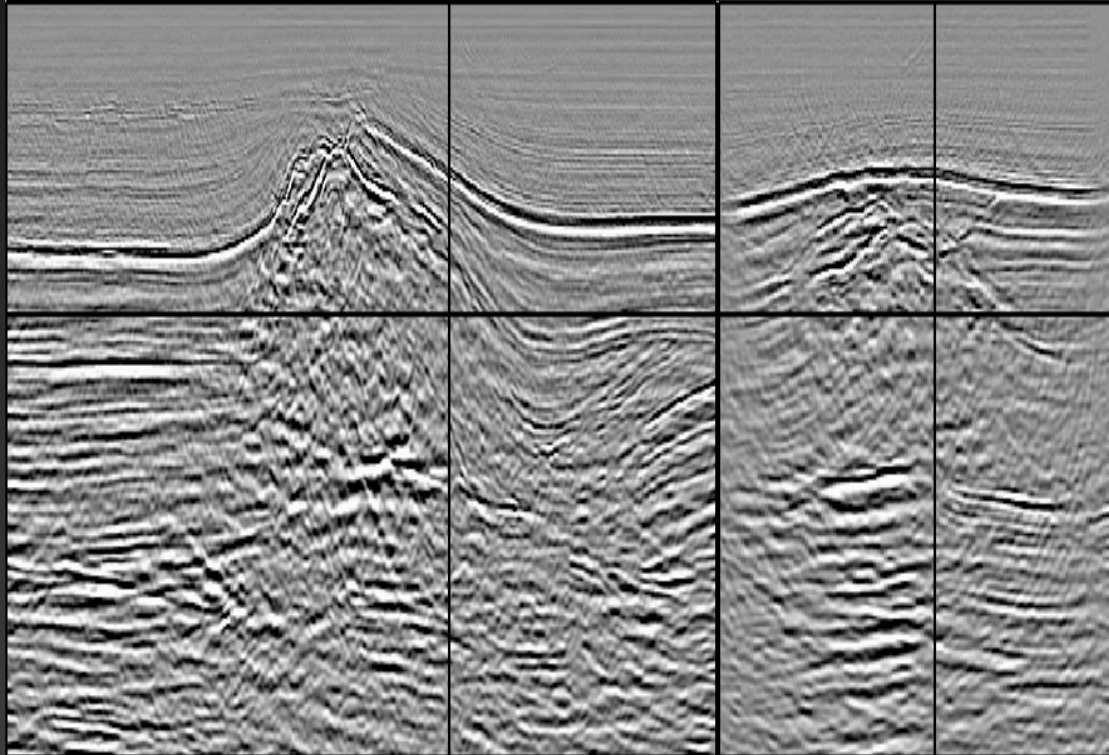
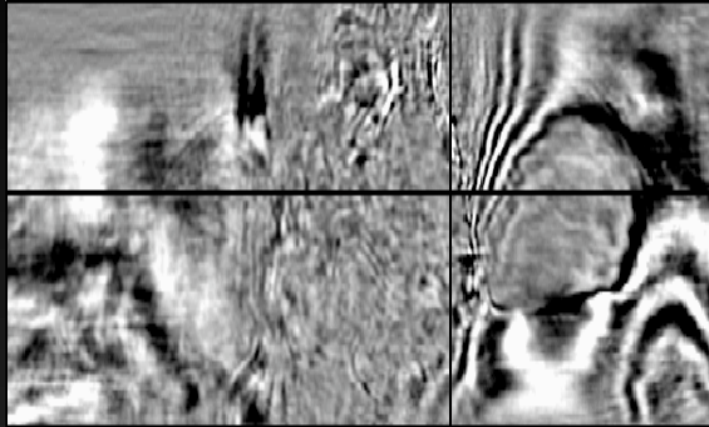
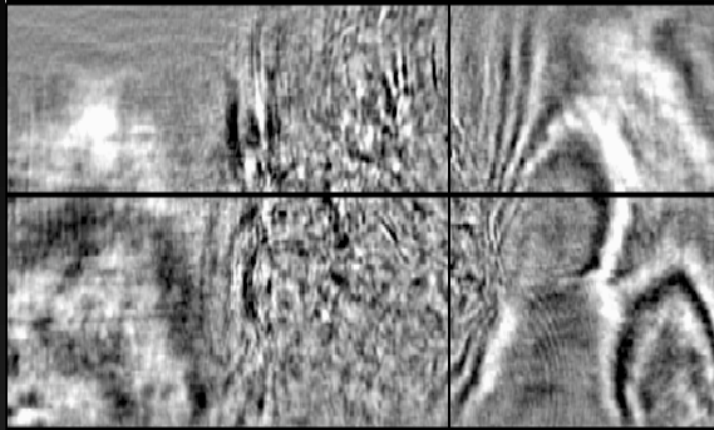


Continuous reflectors & better faults



Initial

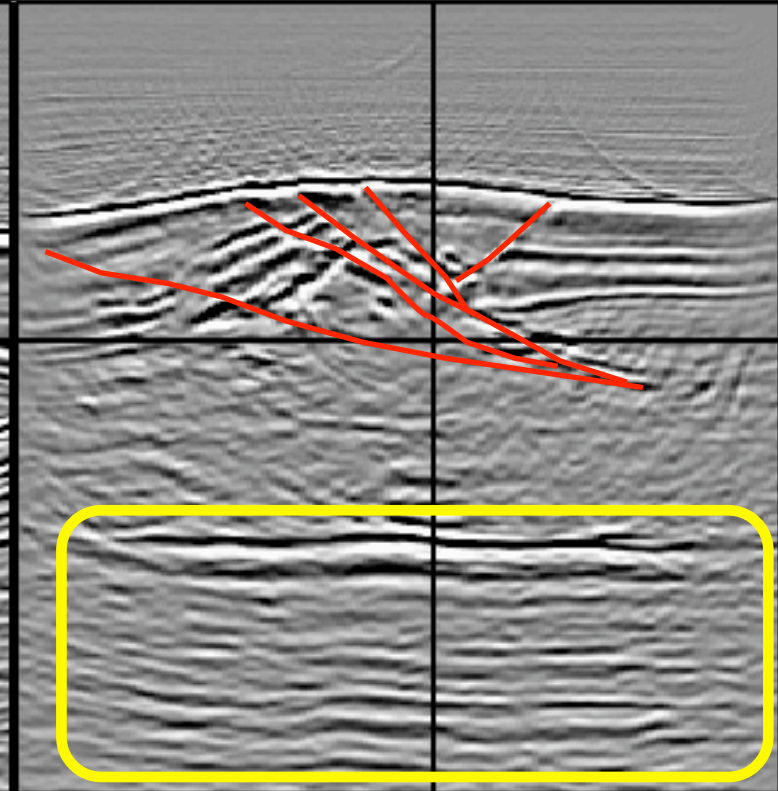
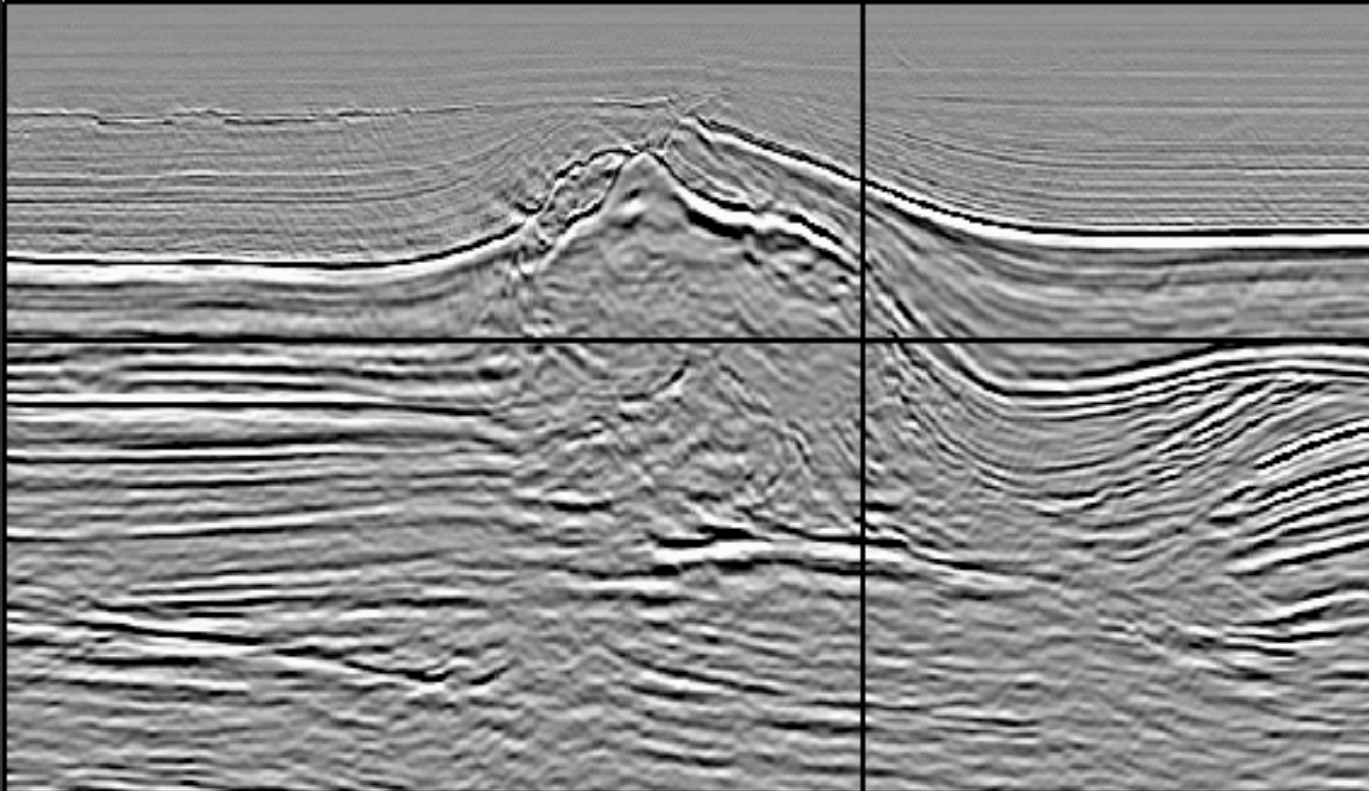
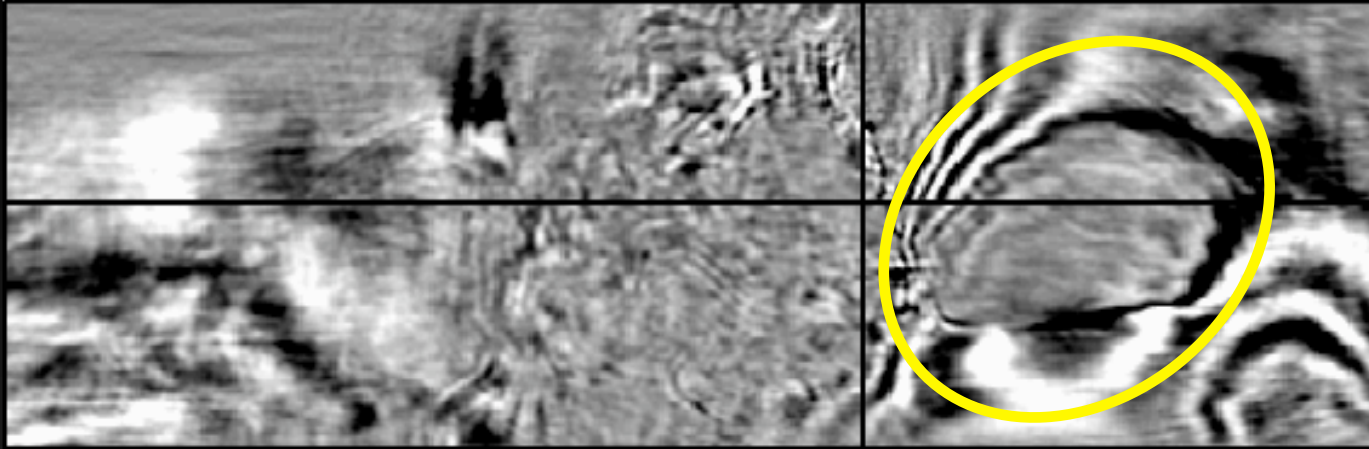
After salt body



Continuous reflectors & better faults



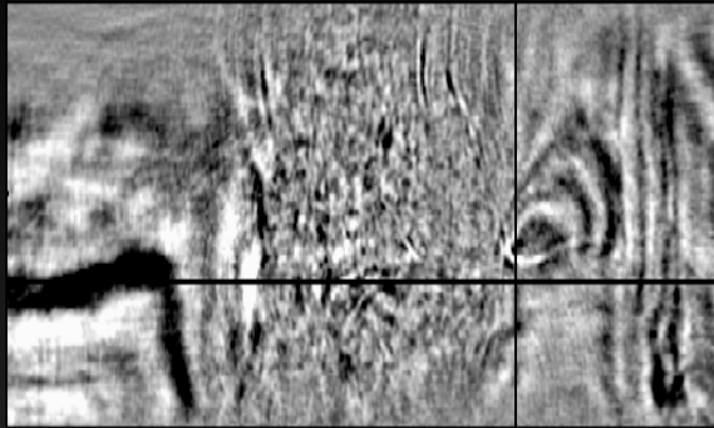
After salt body



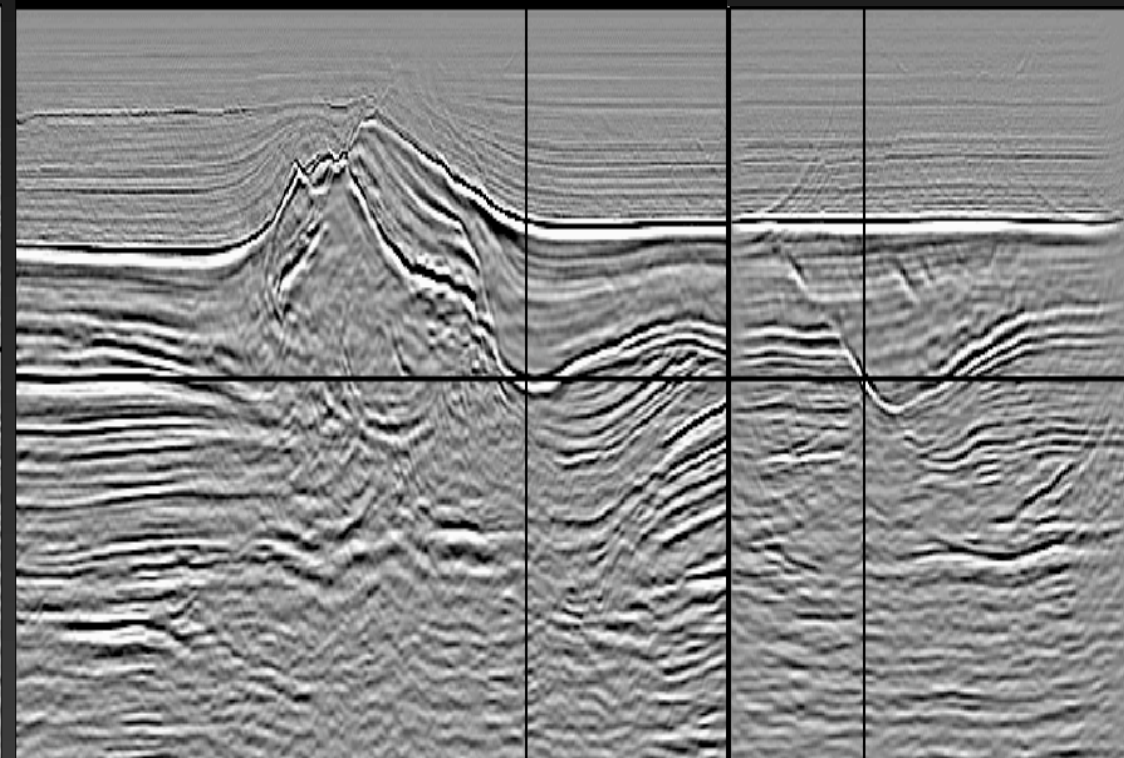
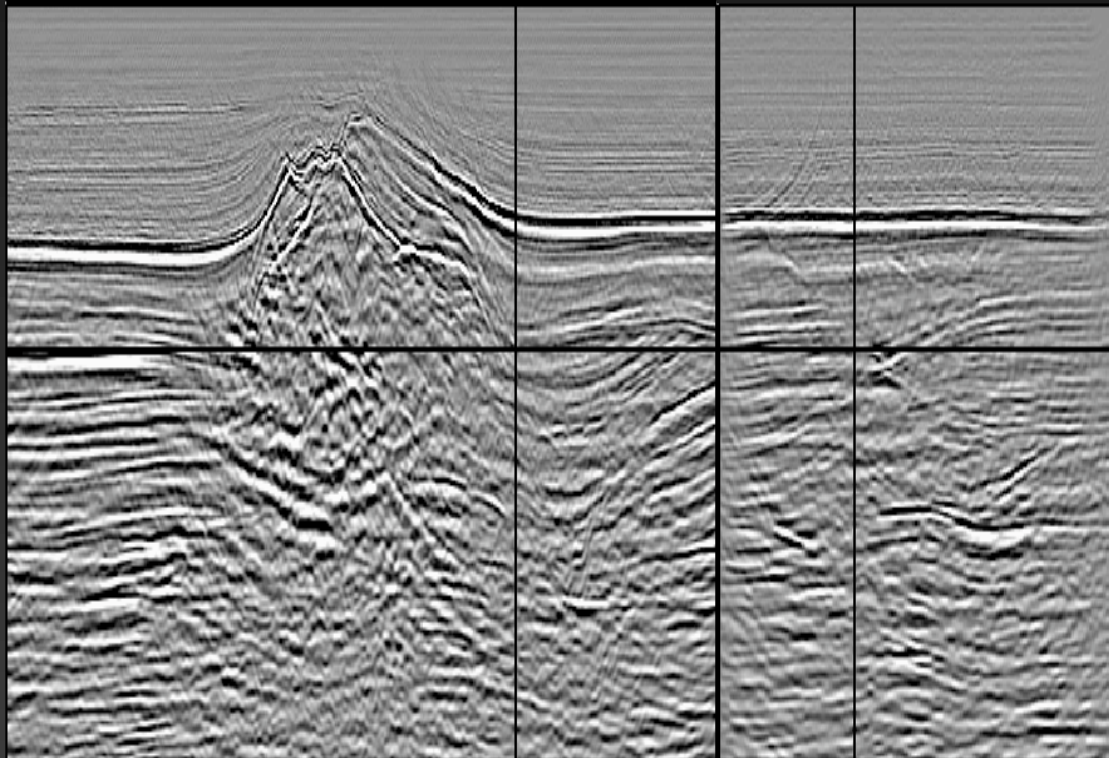
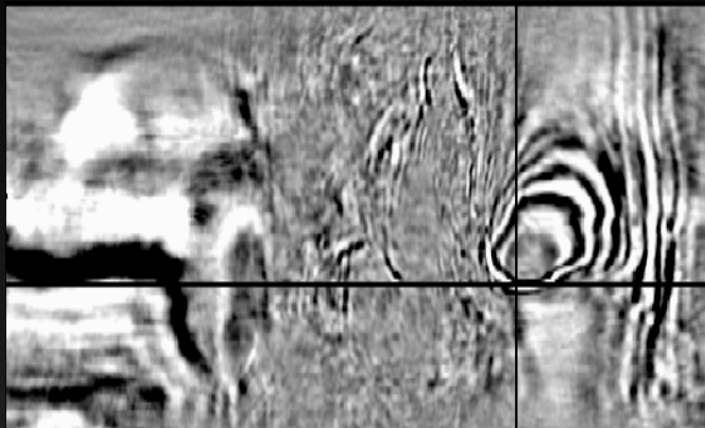
Better faults & focusing



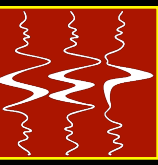
Initial



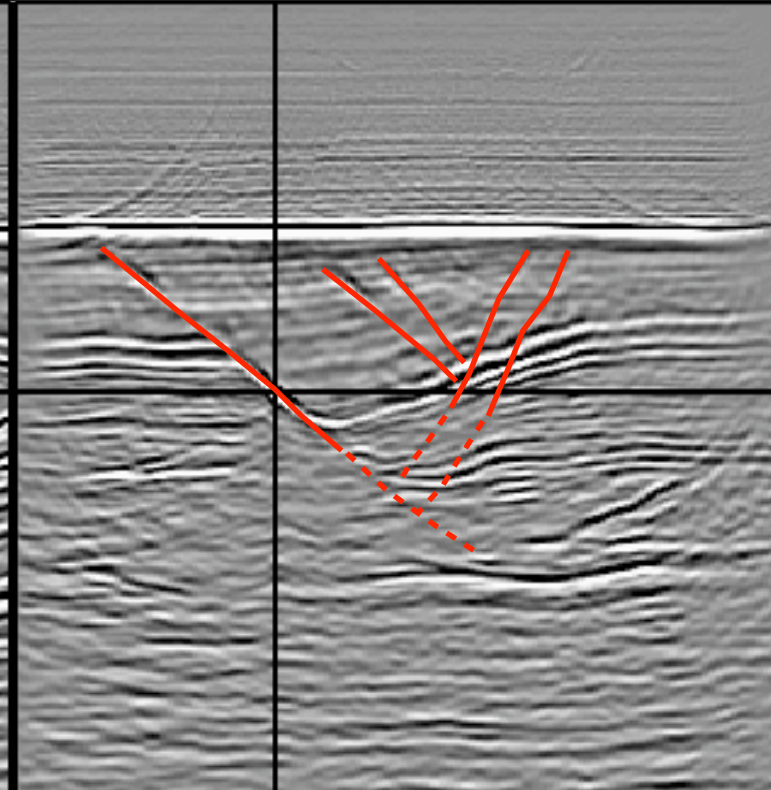
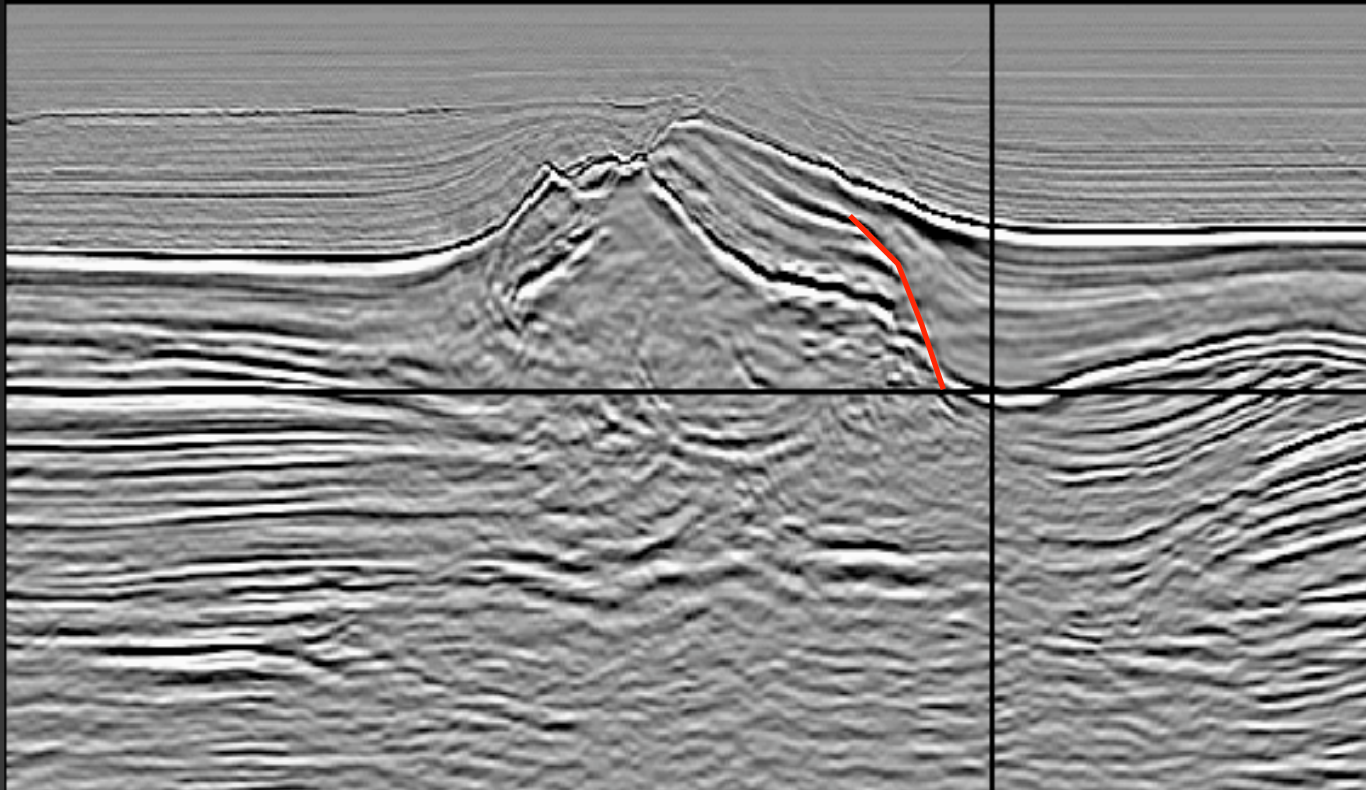
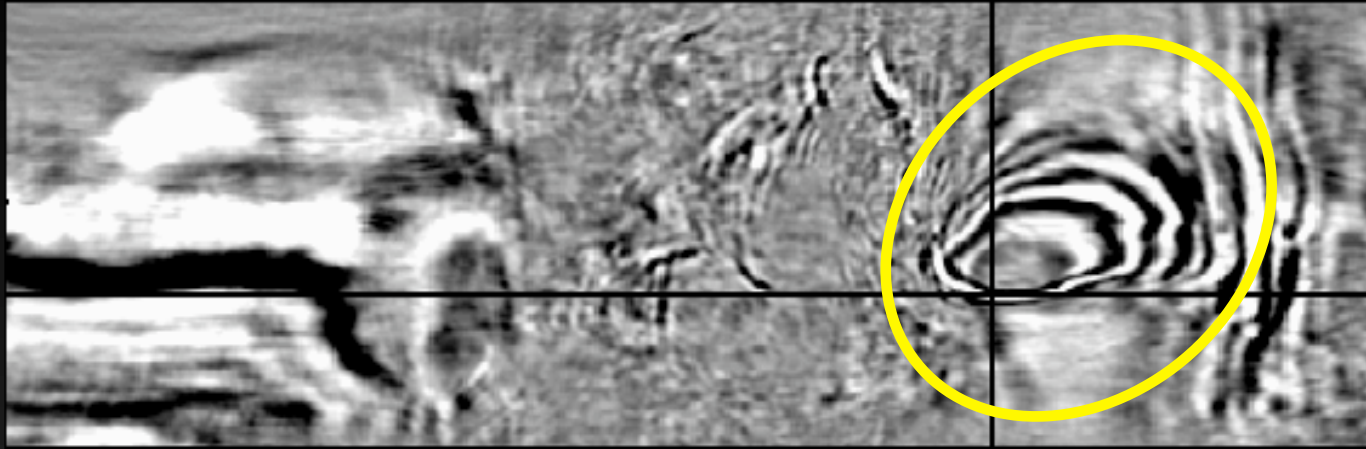
After salt body



Better faults & focusing



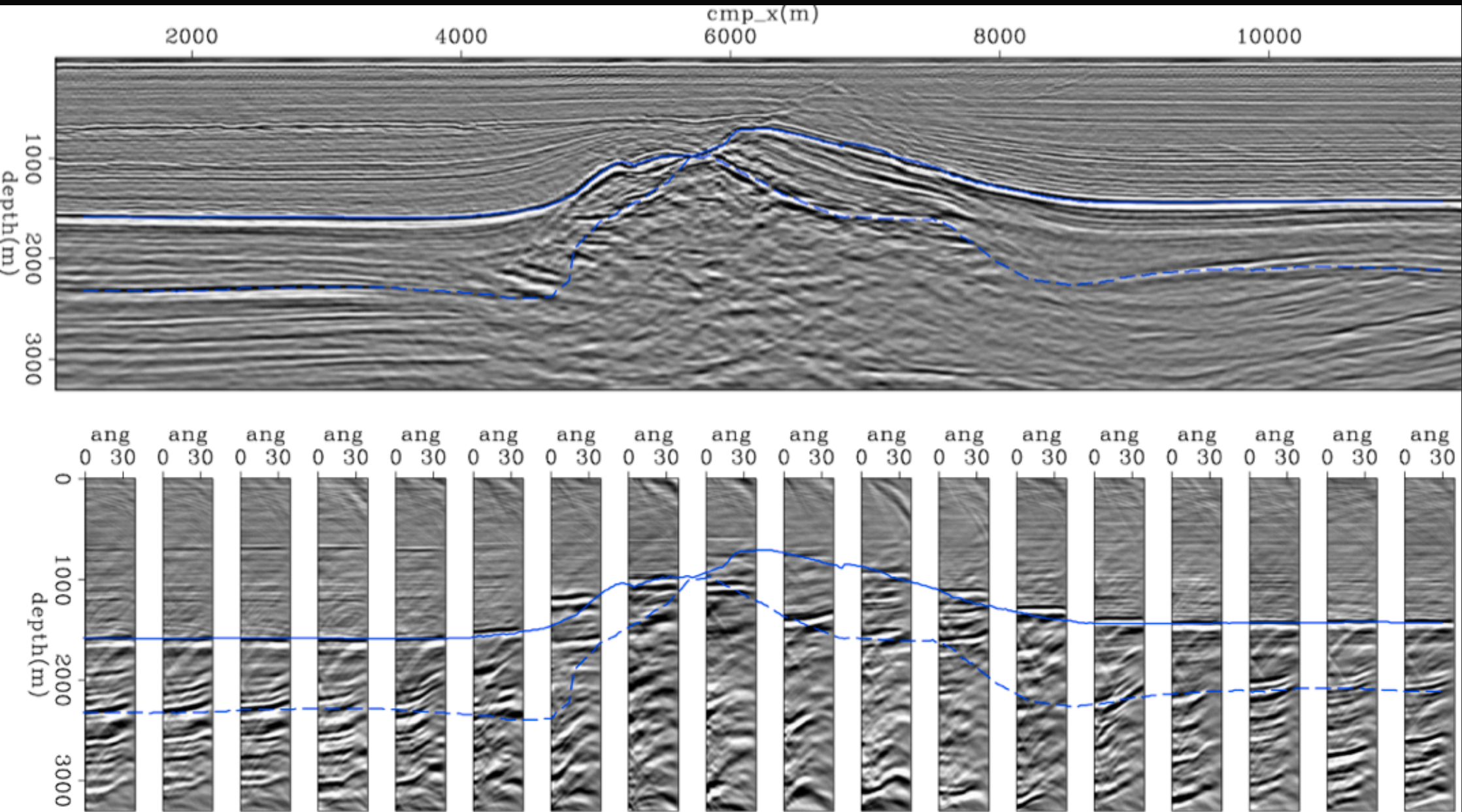
After salt body



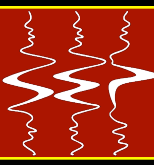
Comparisons: iline = 3200 m



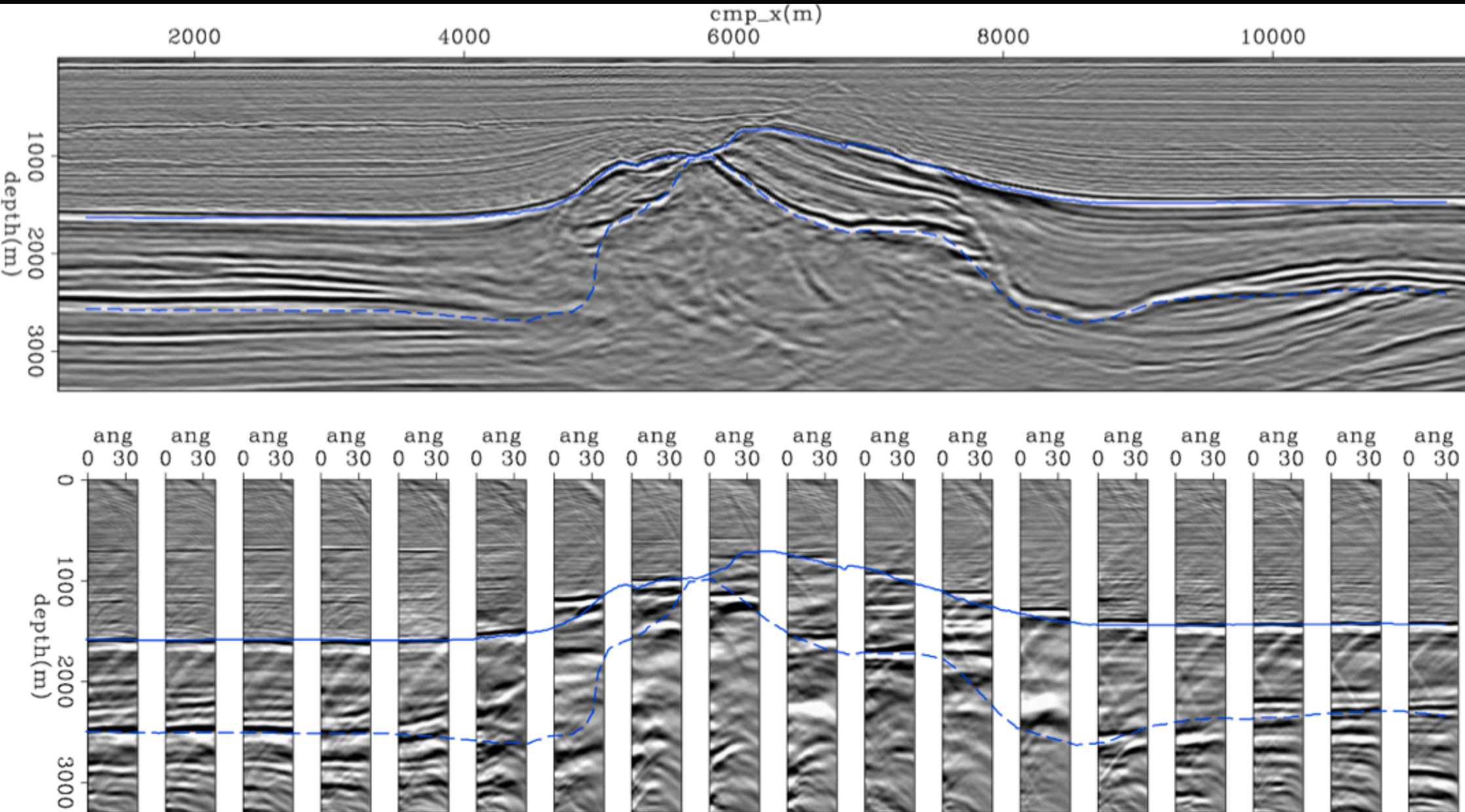
Initial



Flattened reflectors in the angle gathers



Chalk optimized velocity

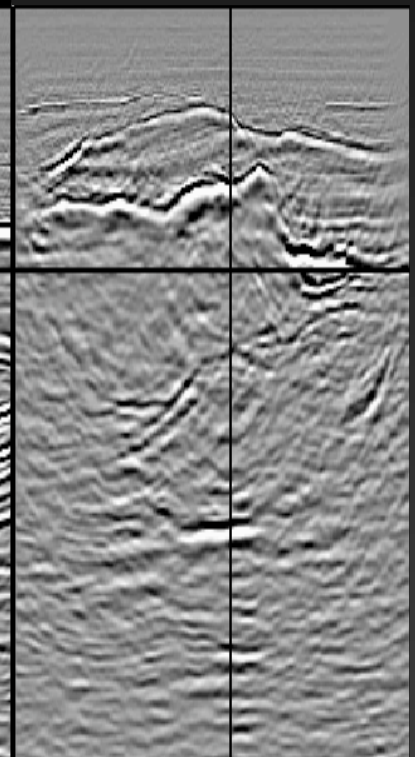
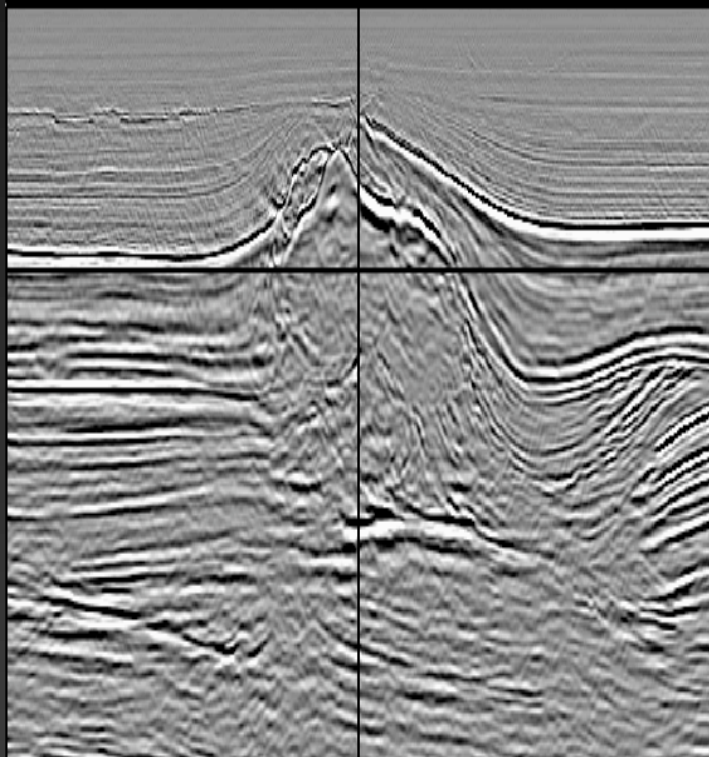
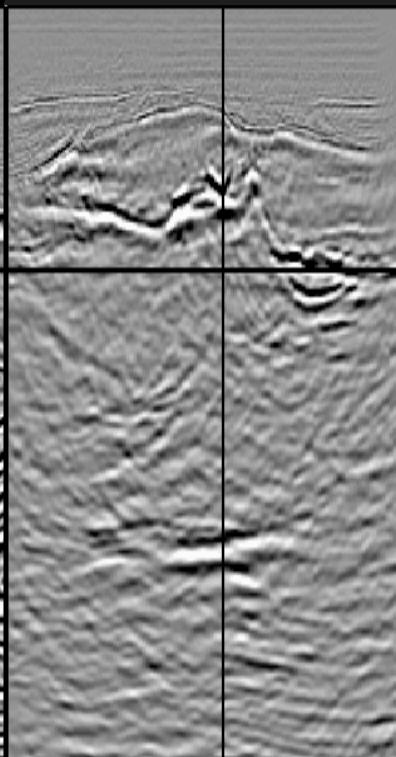
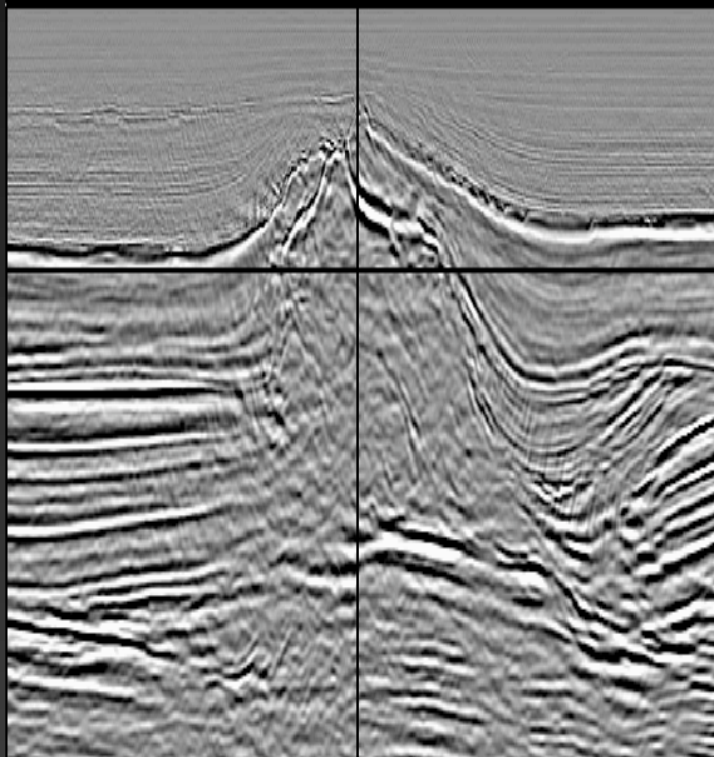
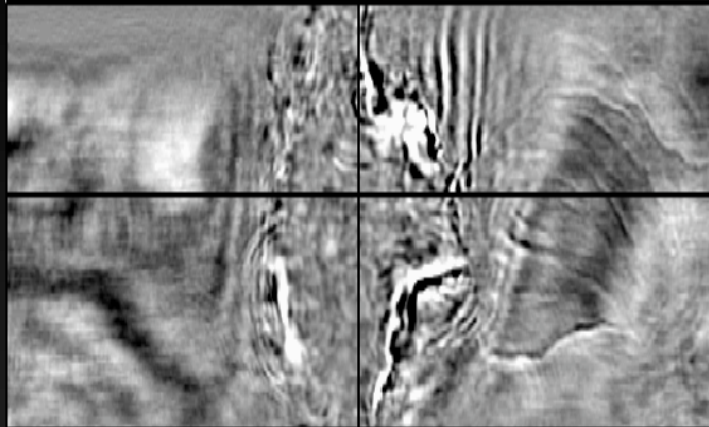
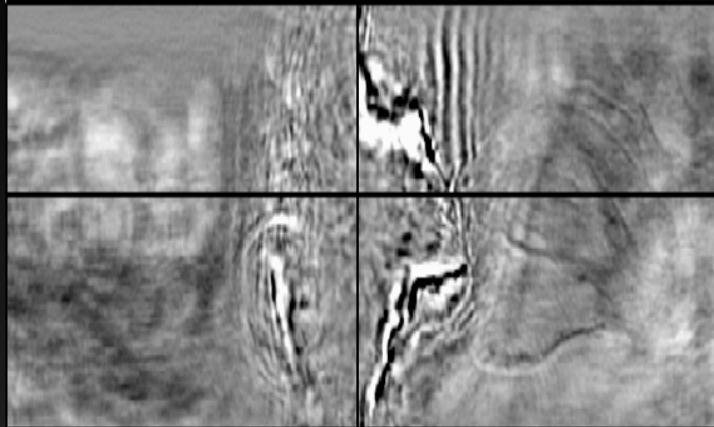


Better base of salt & focusing



Original

After salt body

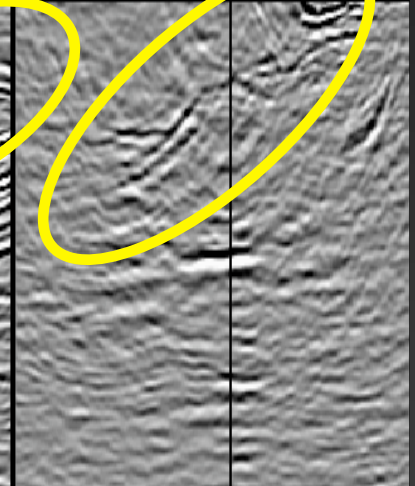
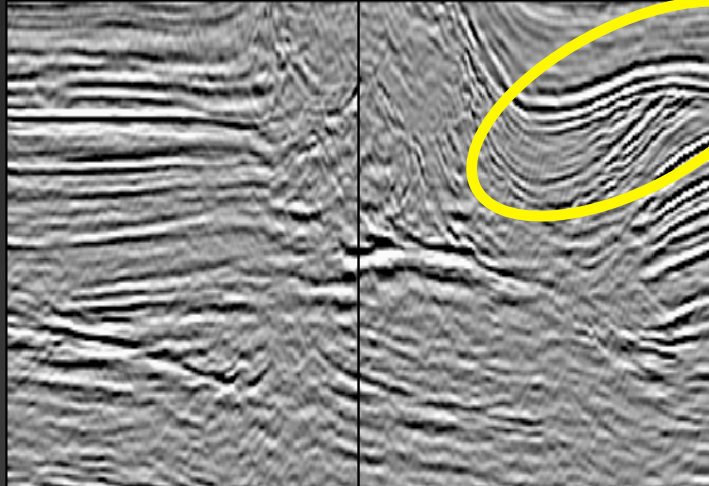
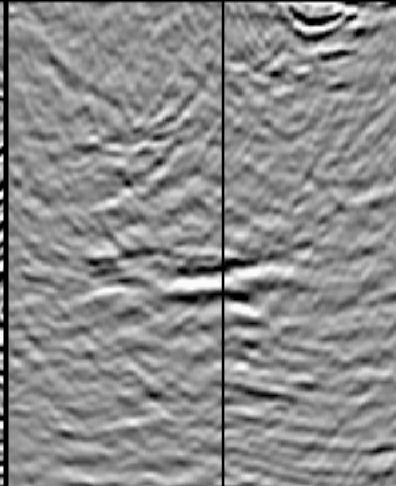
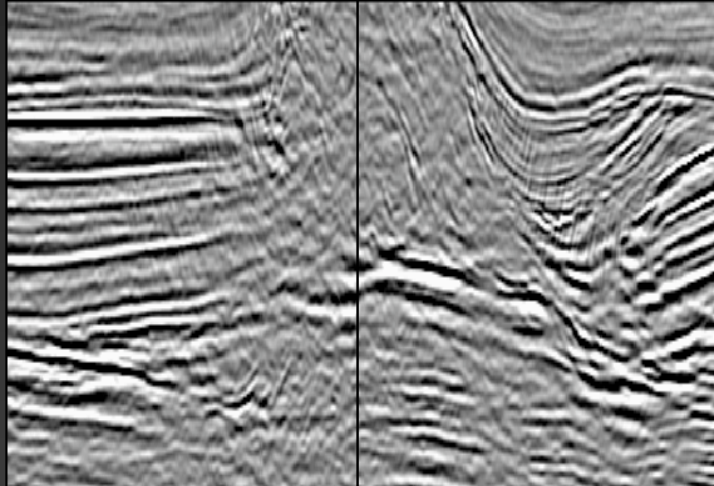
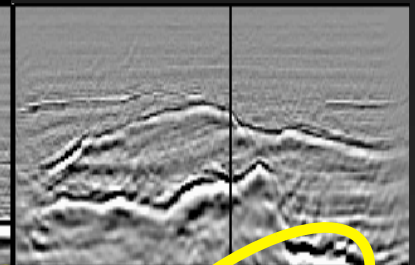
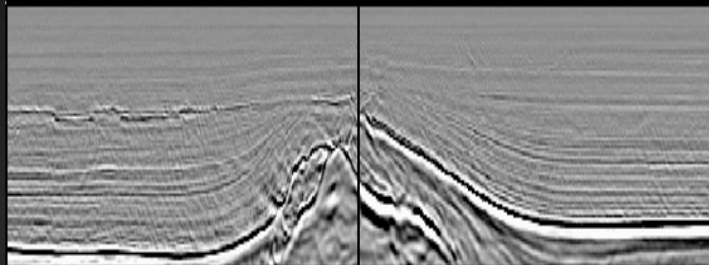
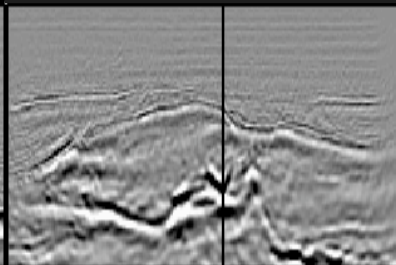
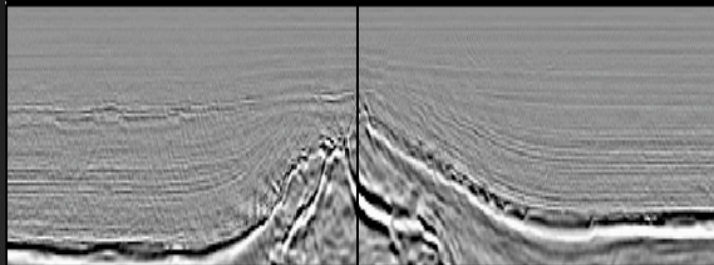
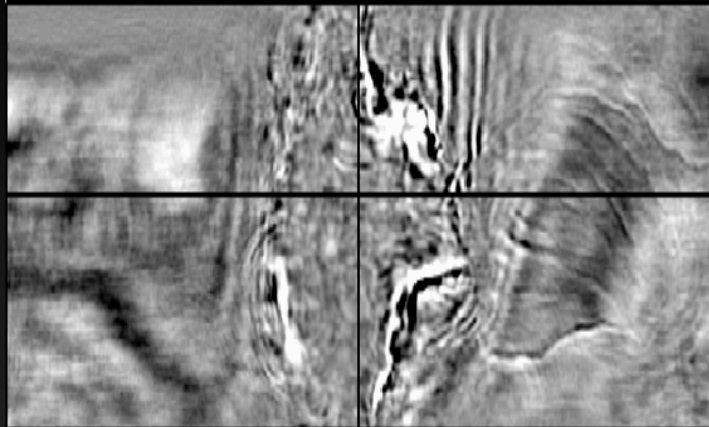
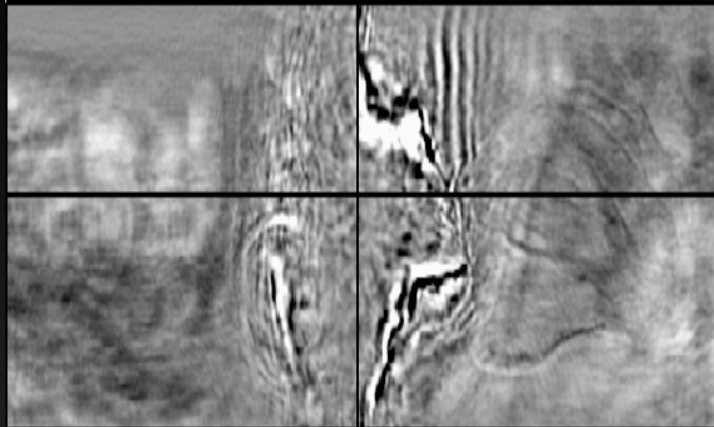


Better base of salt & focusing



Original

After salt body

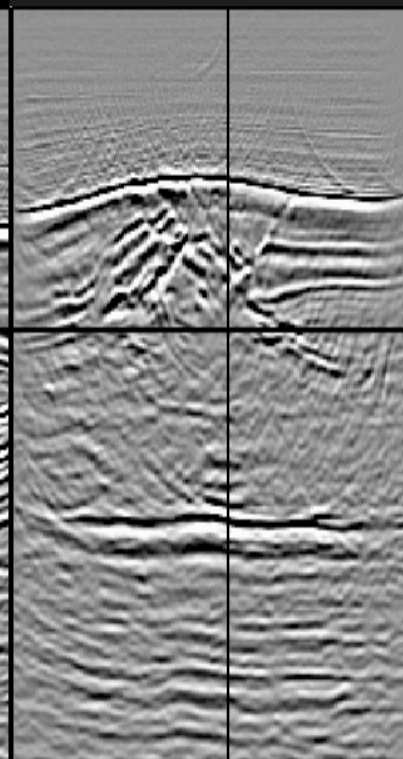
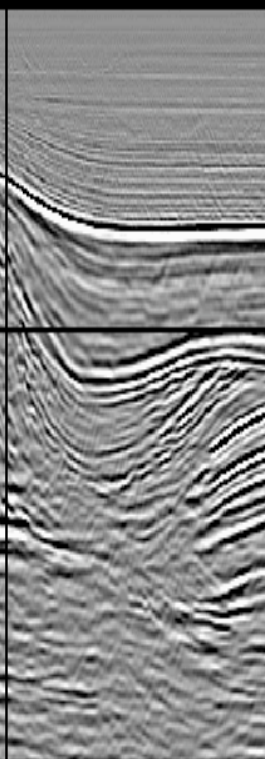
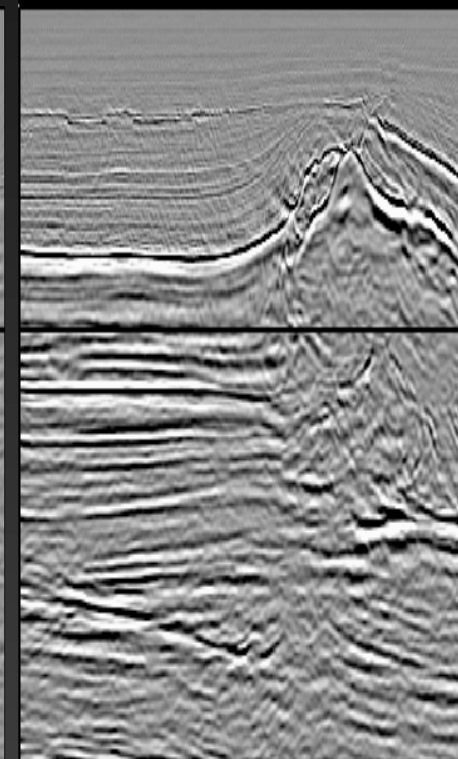
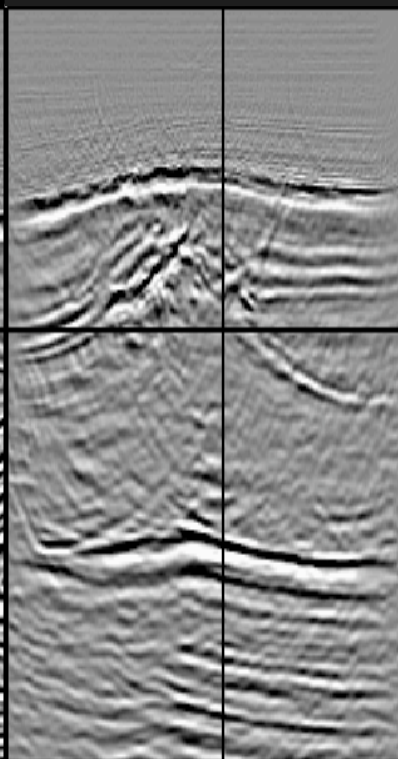
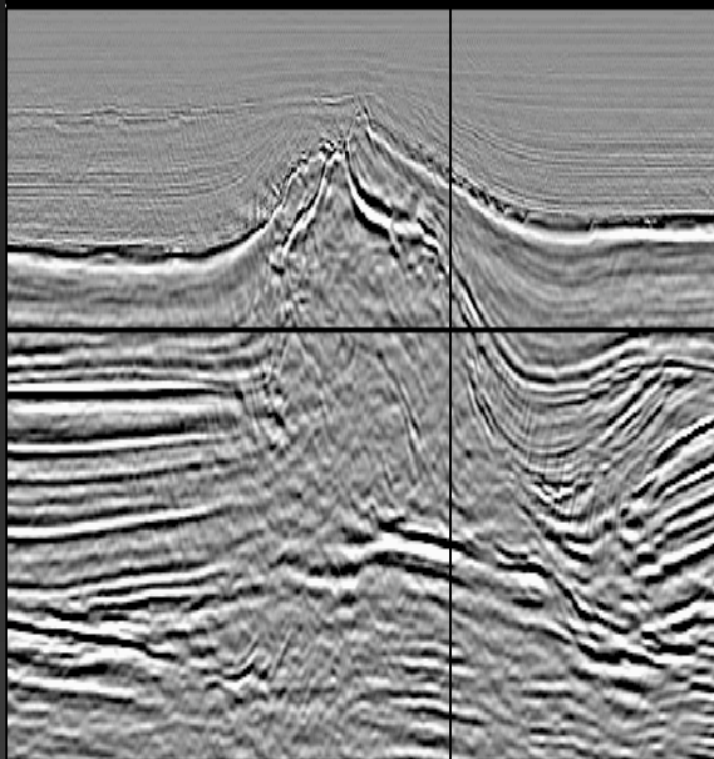
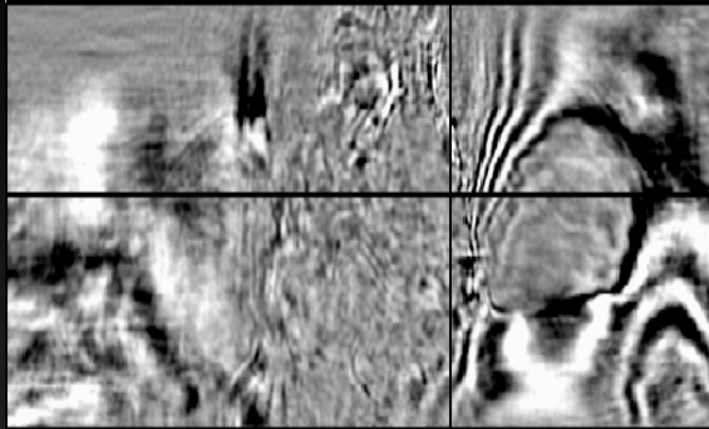
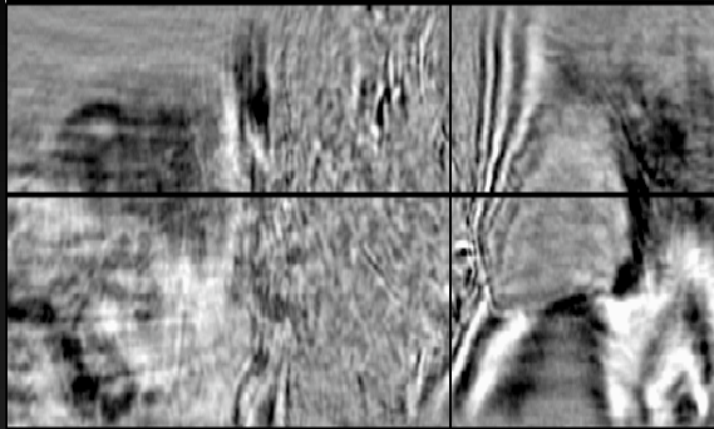


Better sub-salt reflectors & faults



Original

After salt body

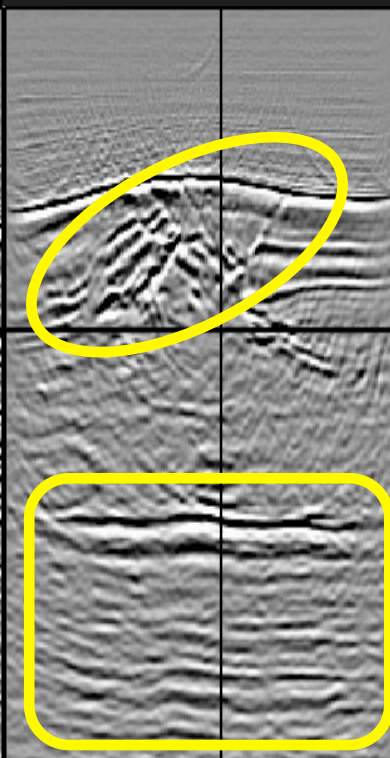
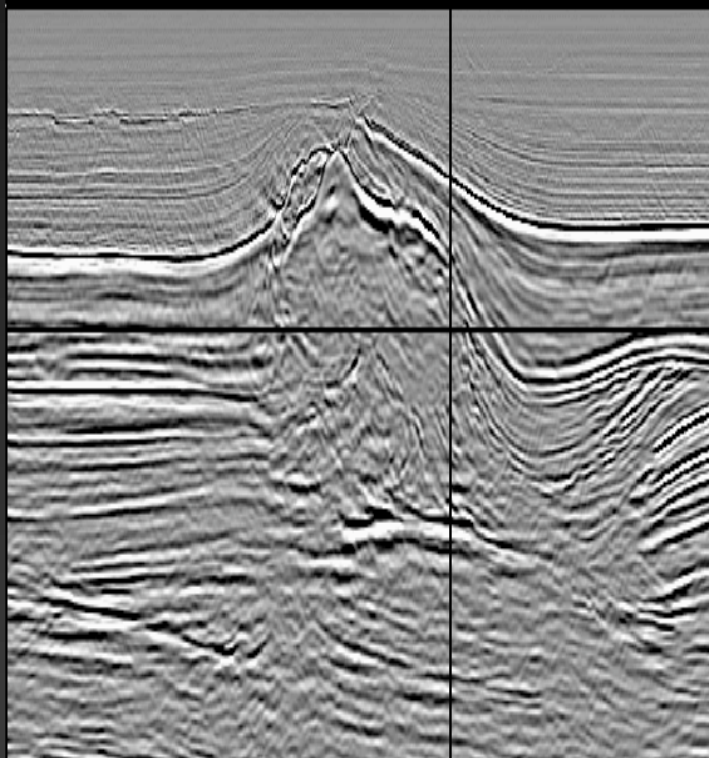
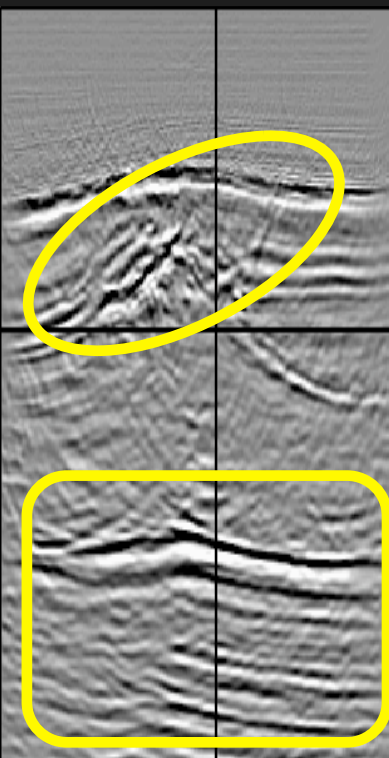
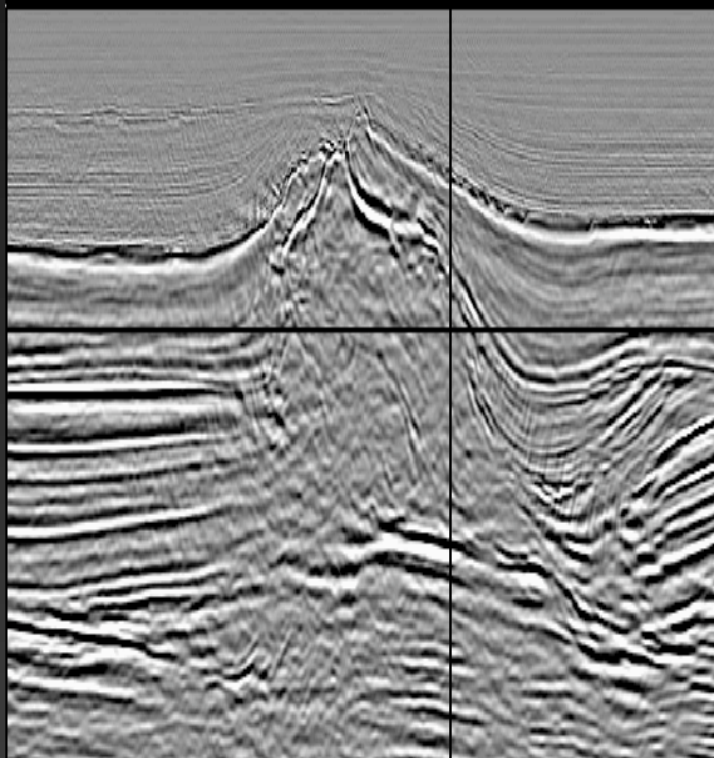
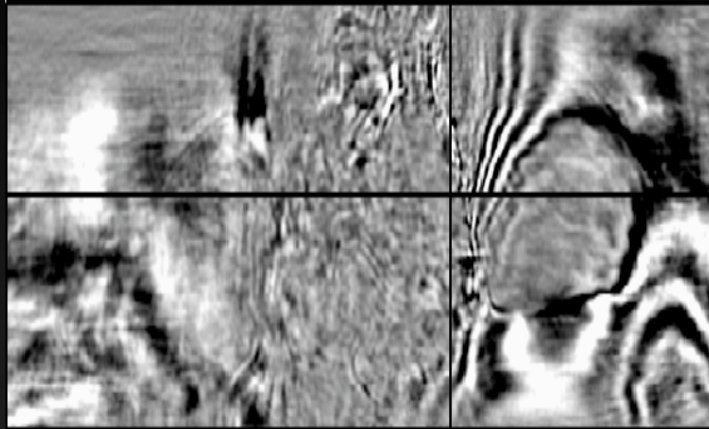
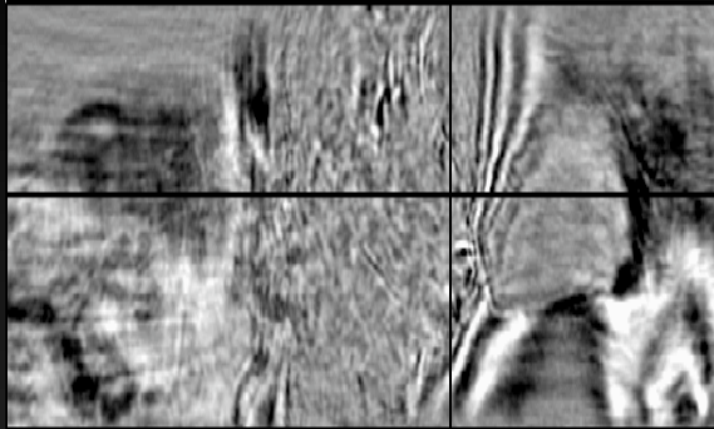


Better sub-salt reflectors & faults



Original

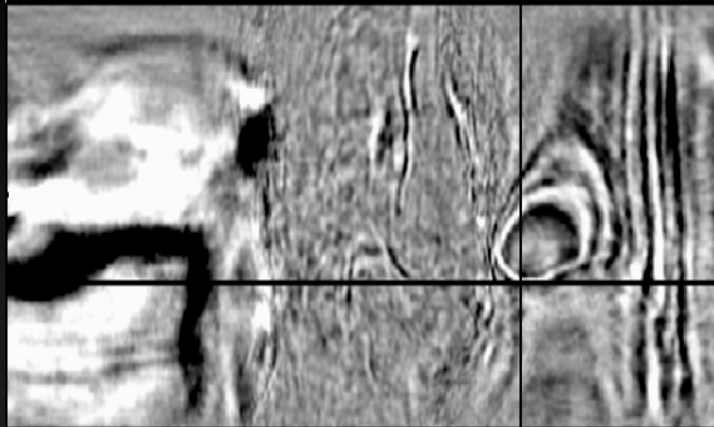
After salt body



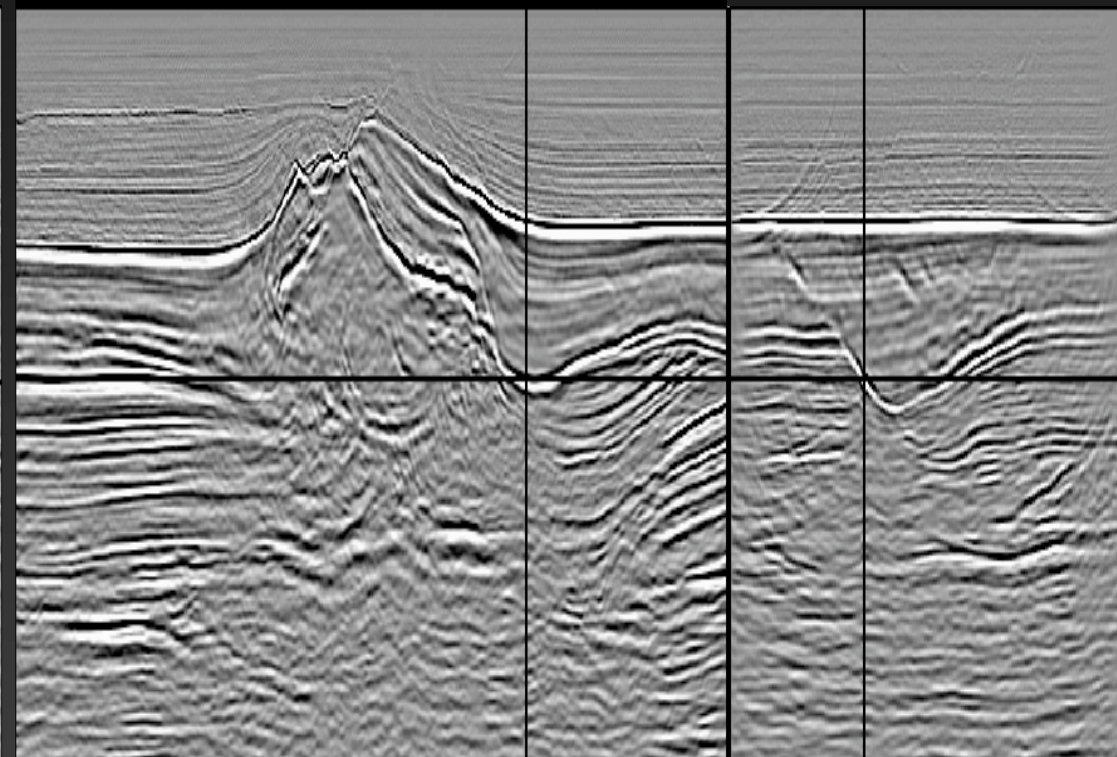
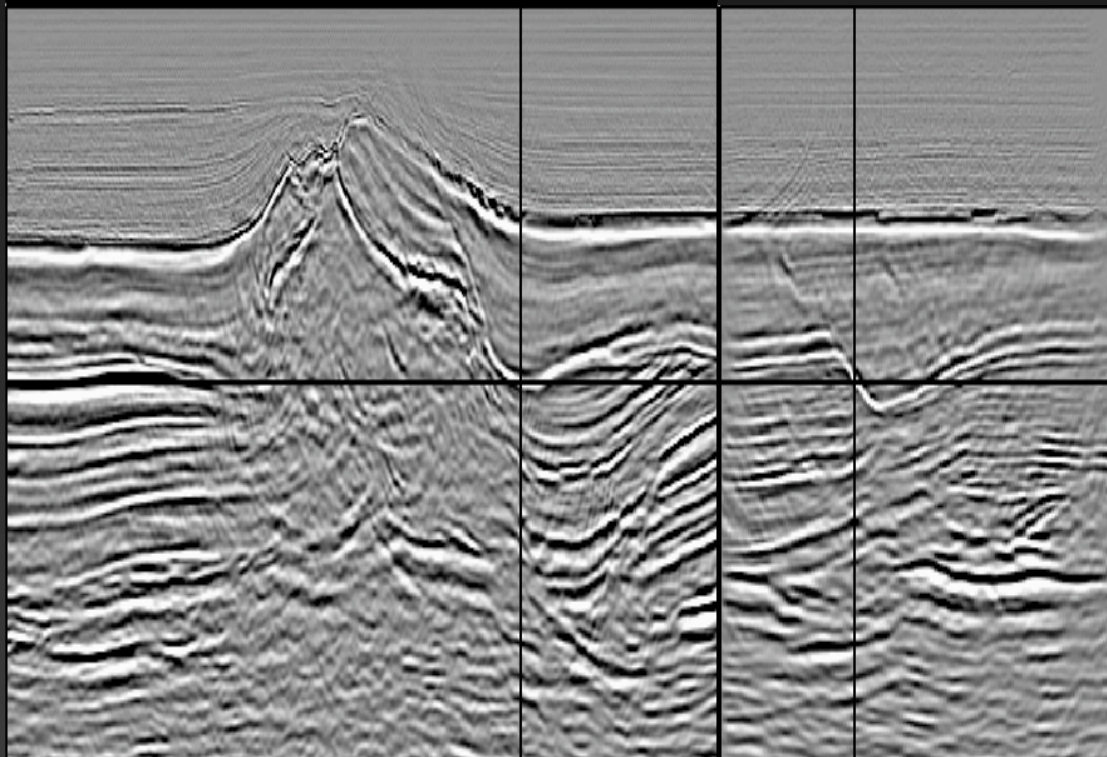
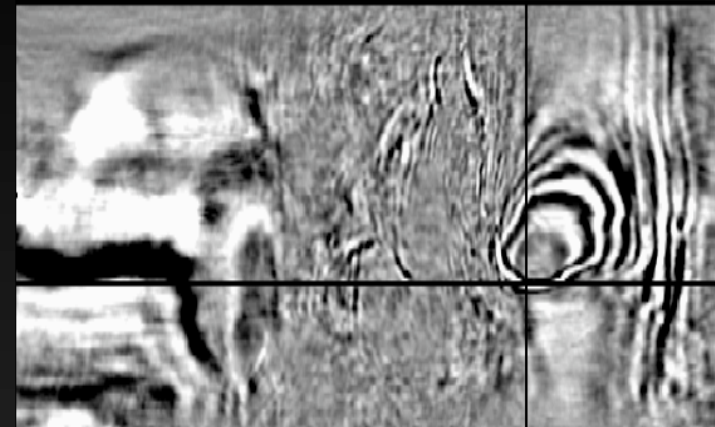
Better faults & focusing



Original



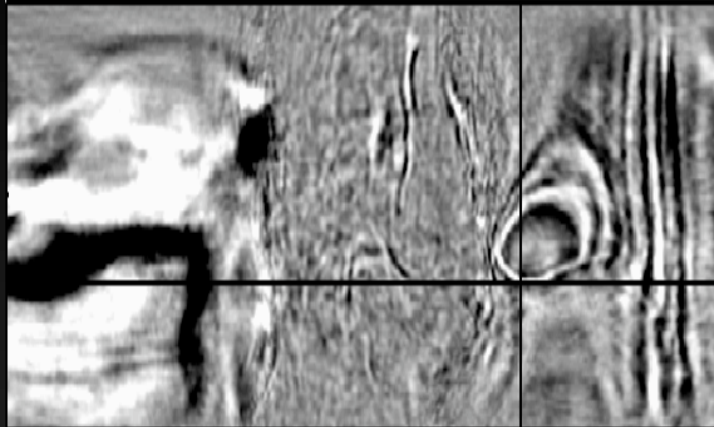
After salt body



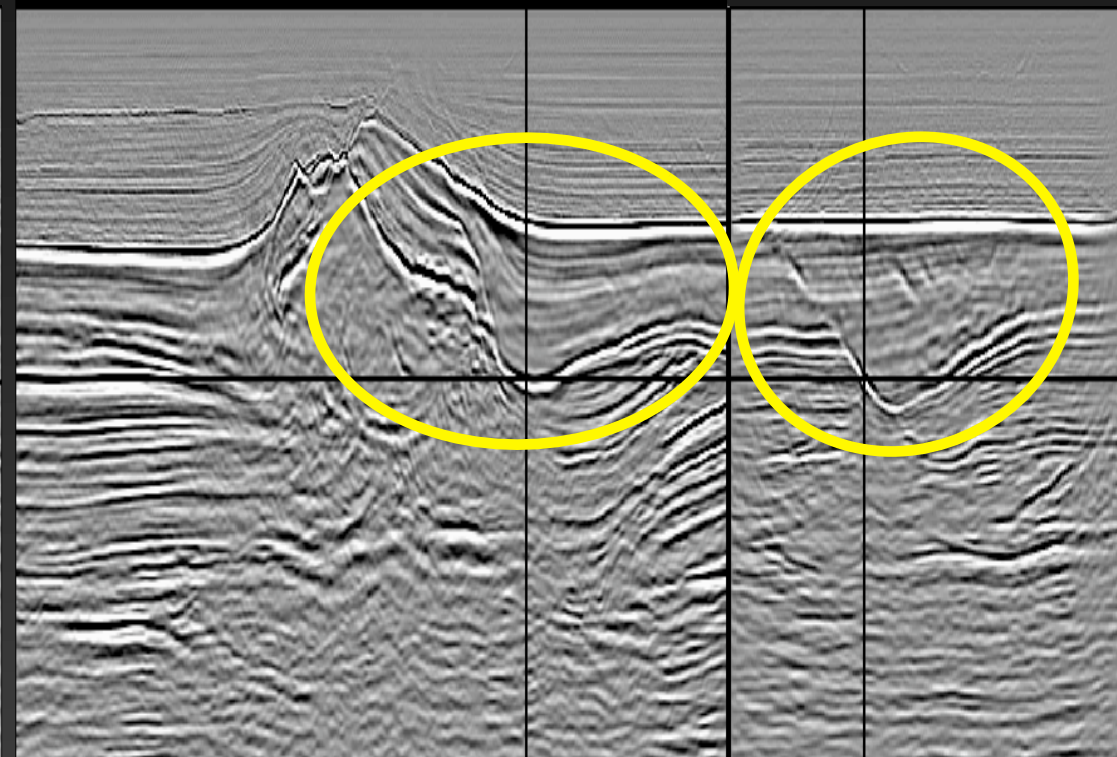
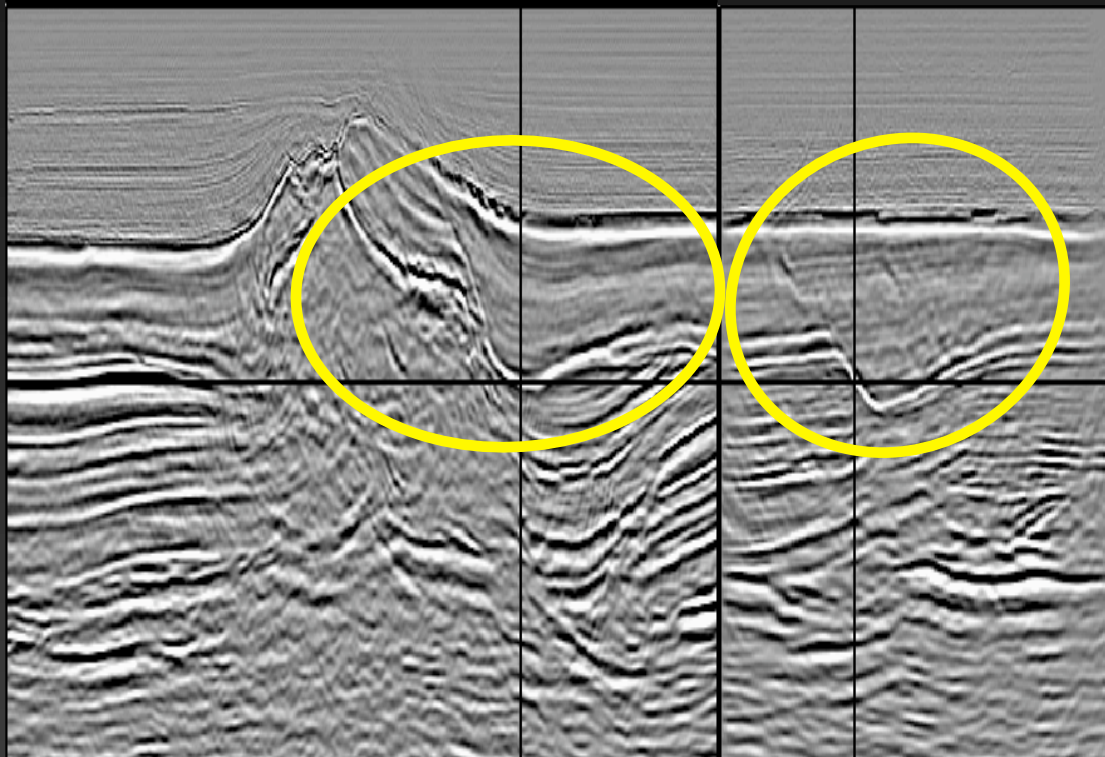
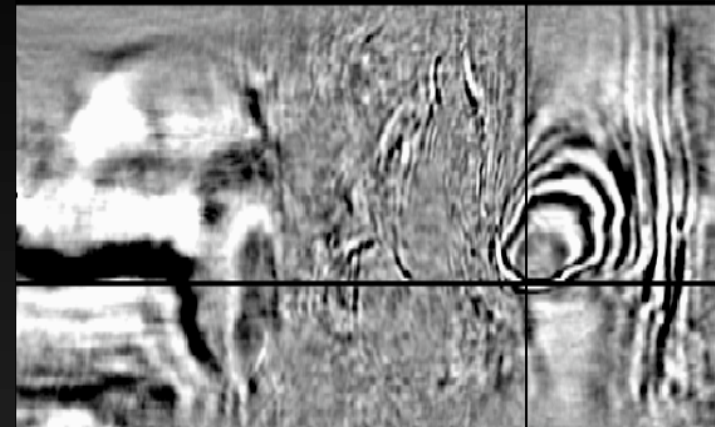
Better faults & focusing



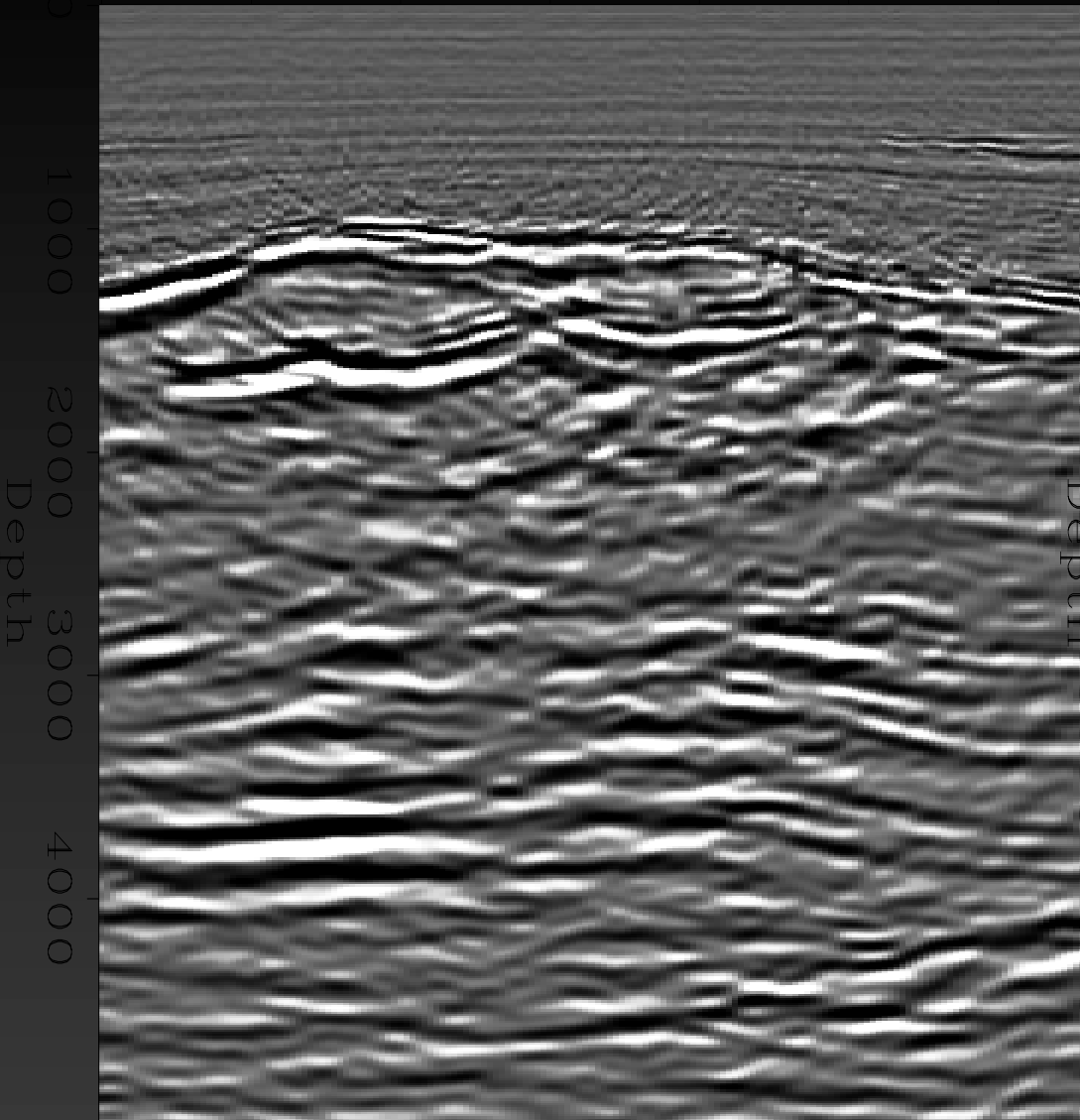
Original



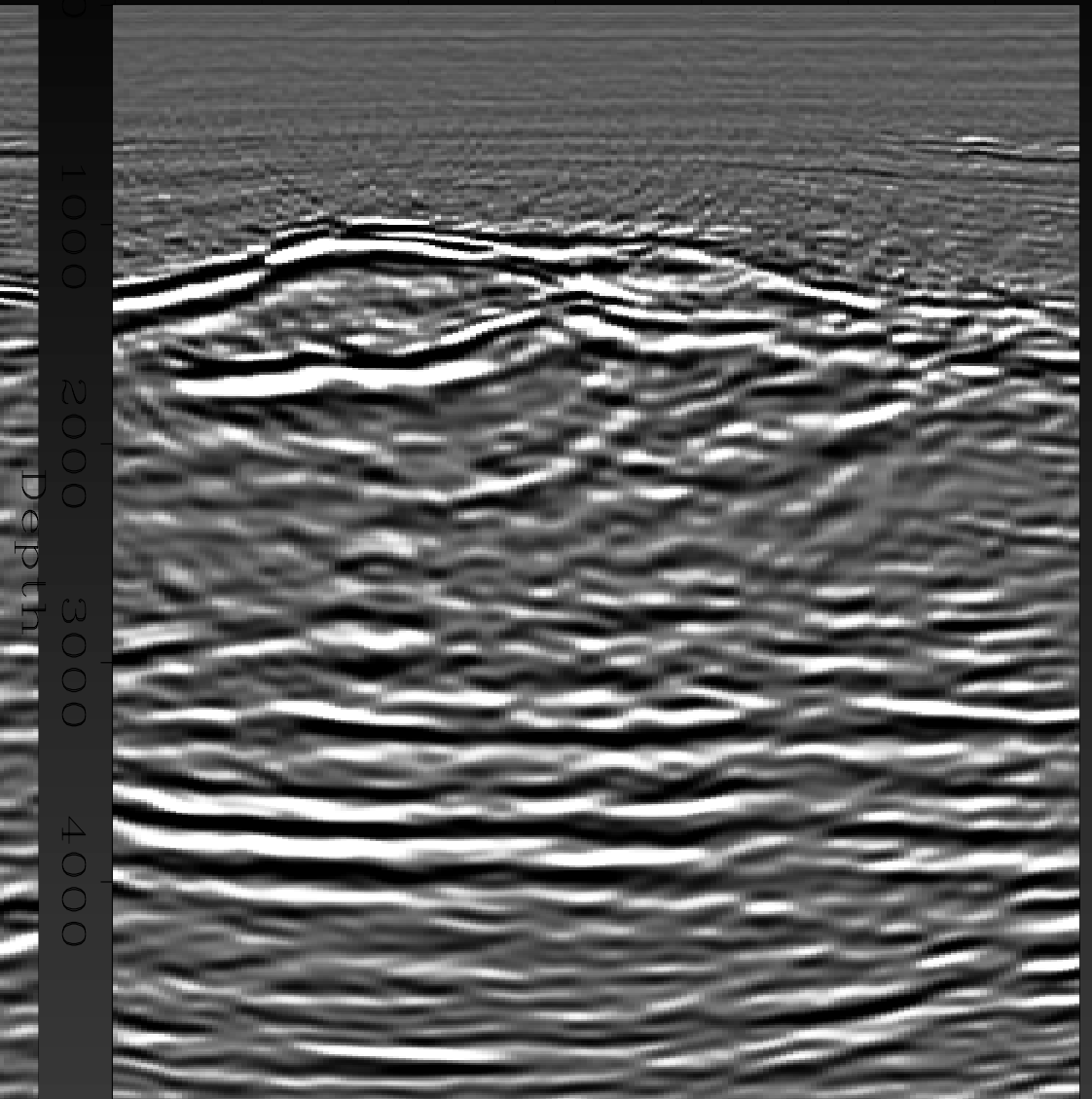
After salt body



Original vs. Optimized (x5220)

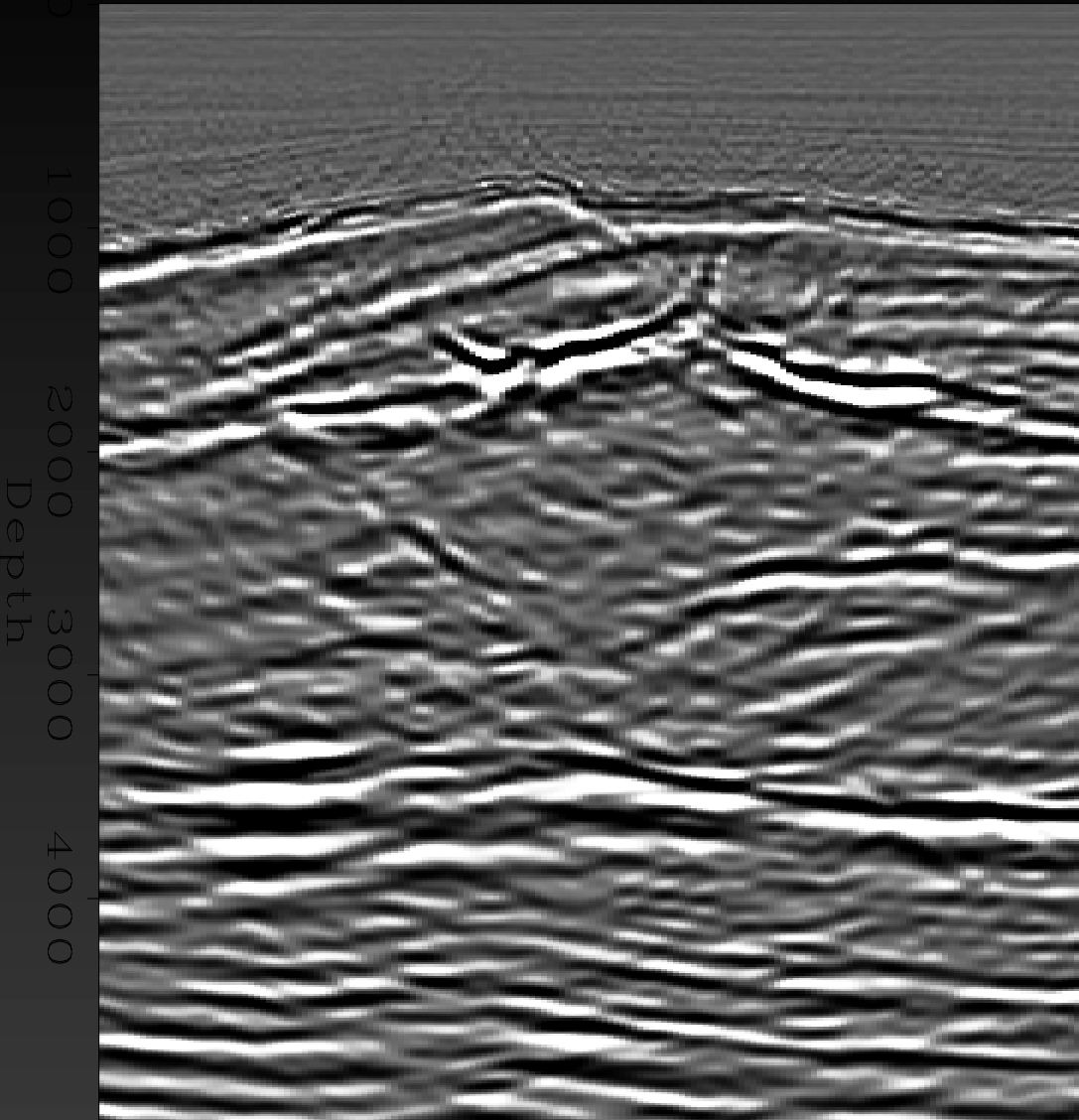


stdin

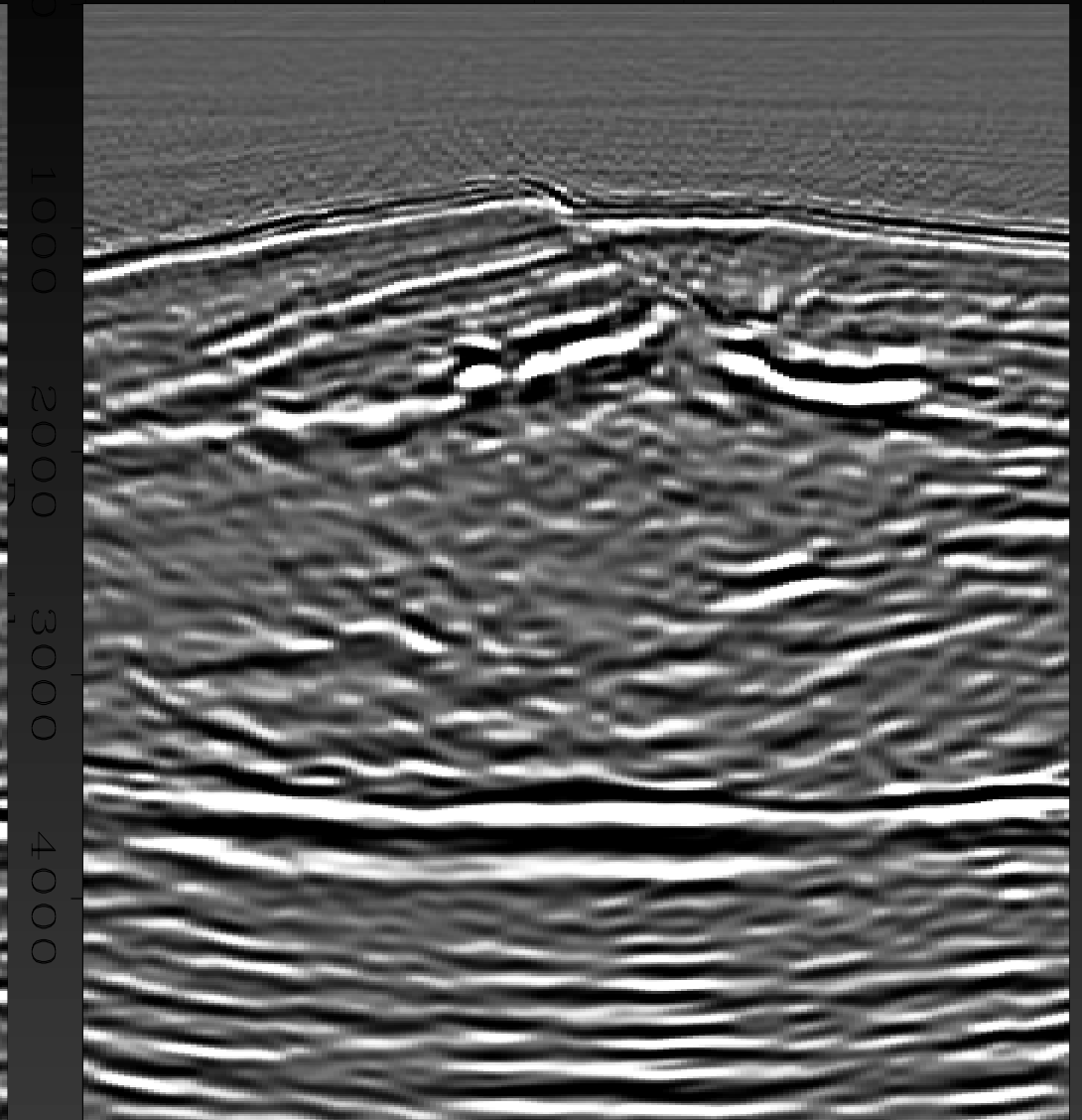


stdin

Original vs. Optimized (x6880)

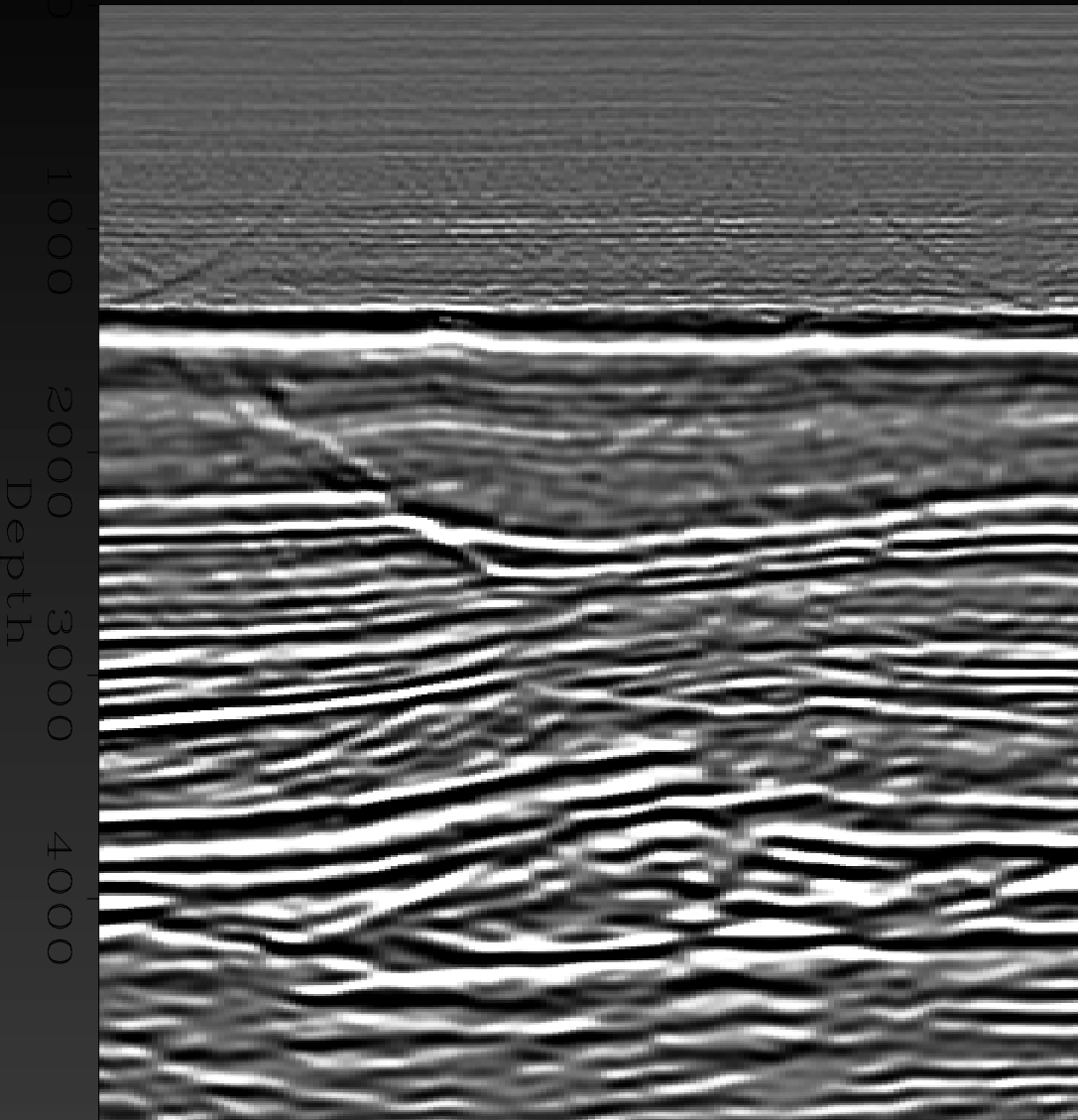
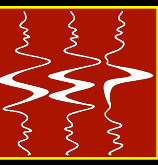


stdin

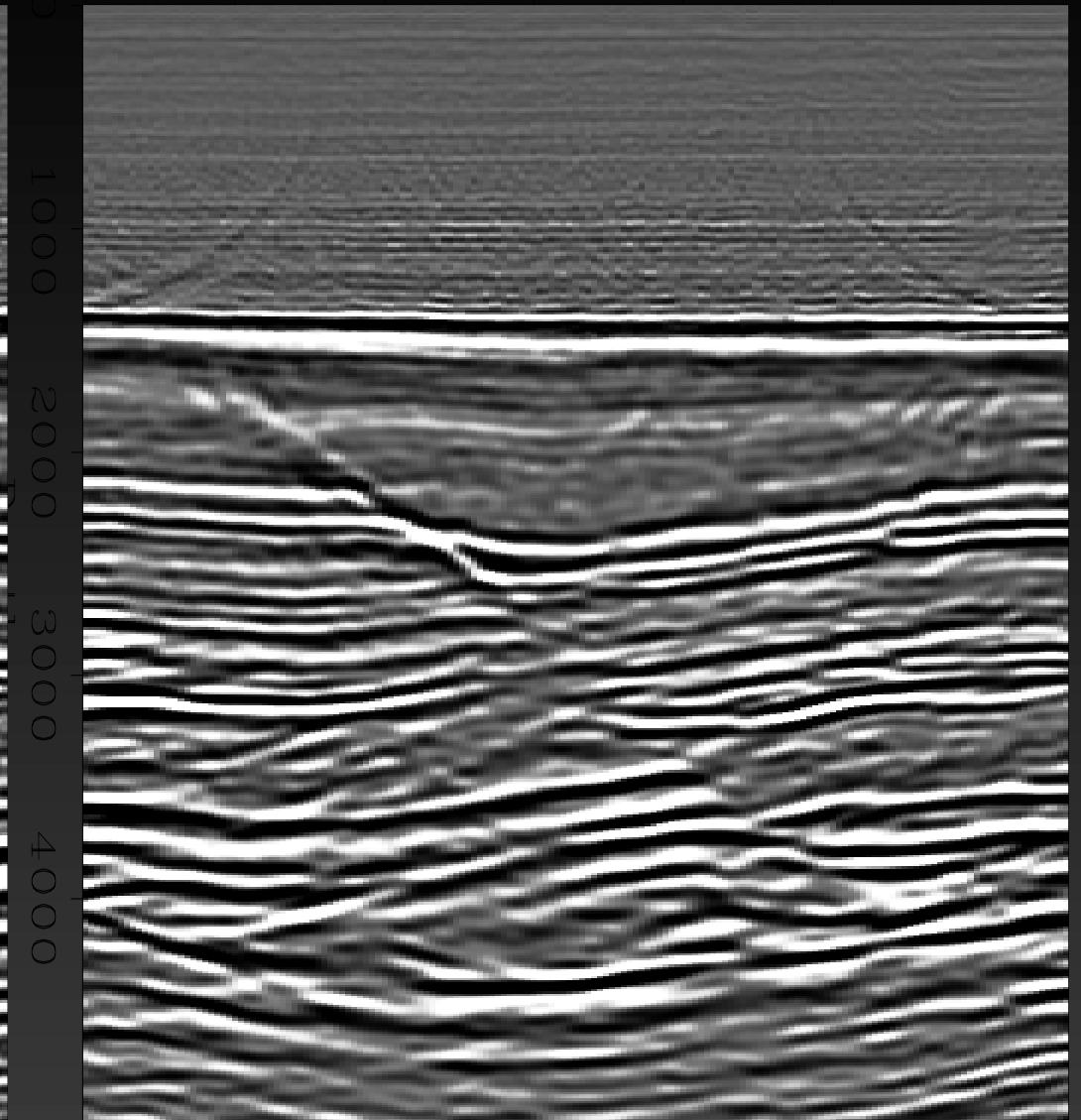


stdin

Original vs. Optimized (x9400)

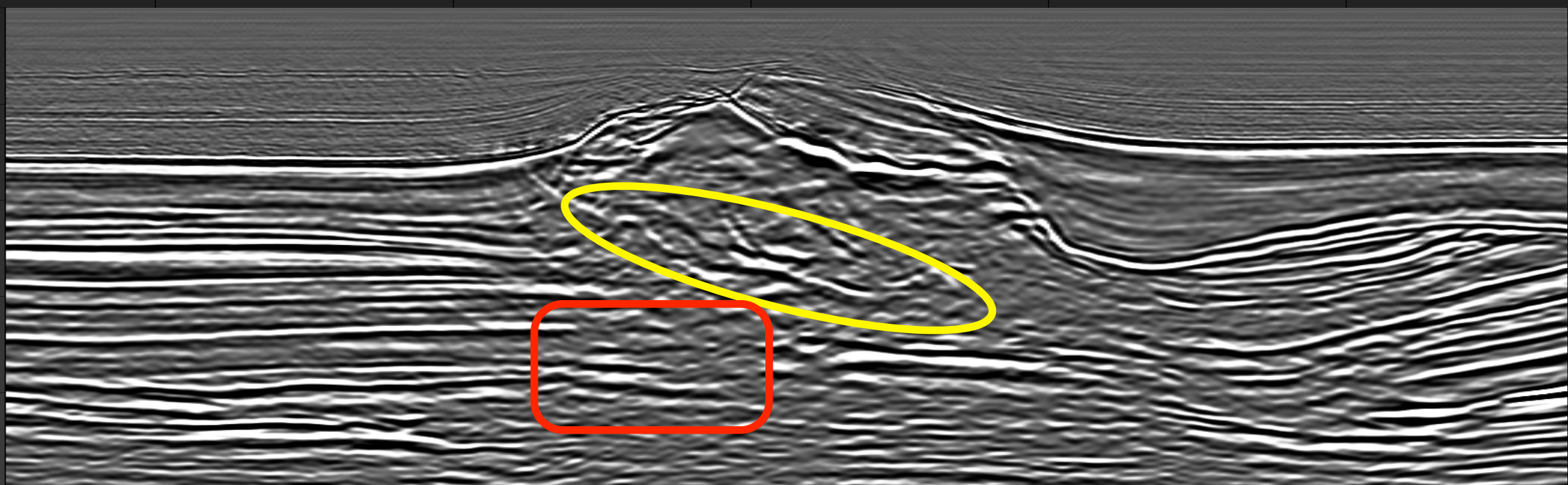
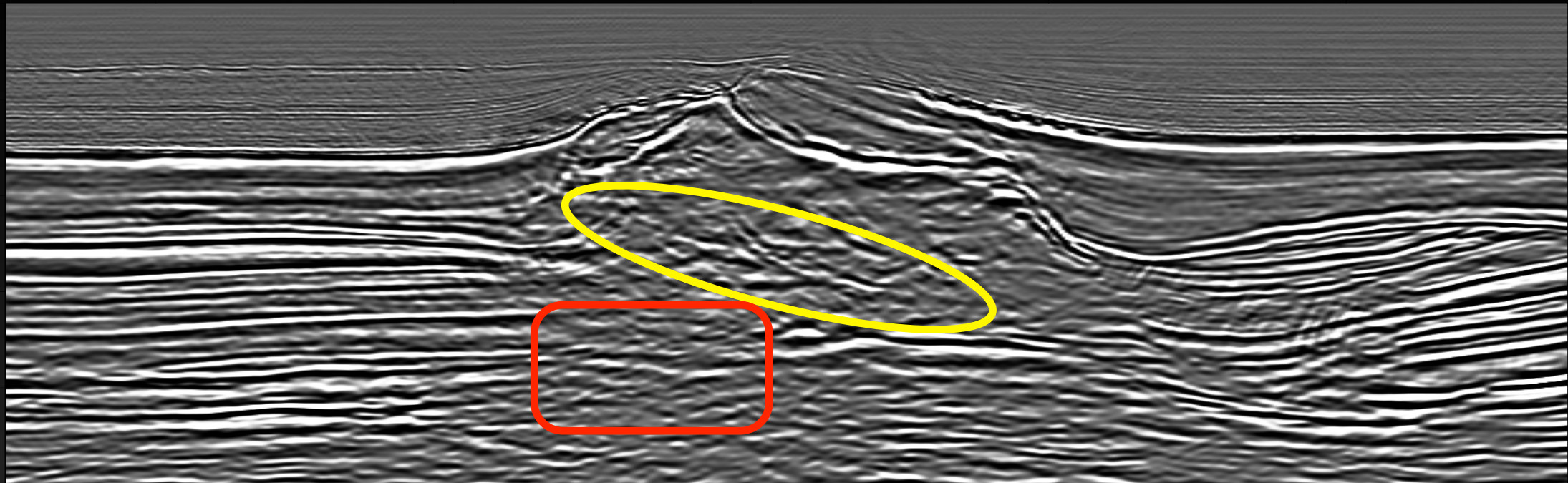


stdin

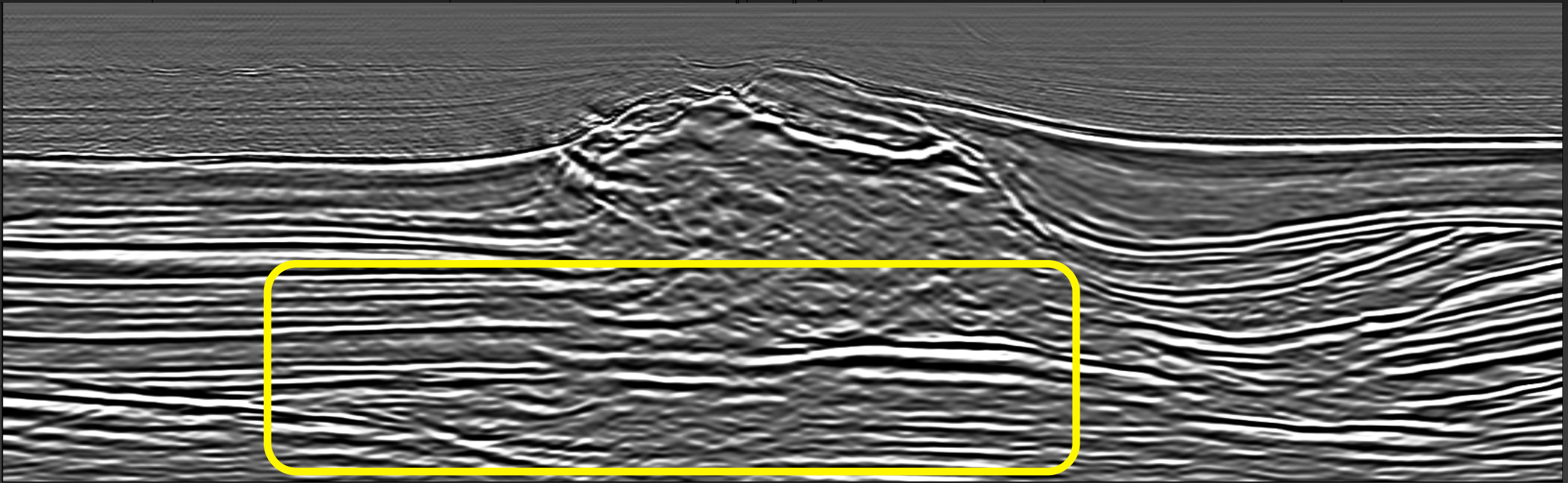
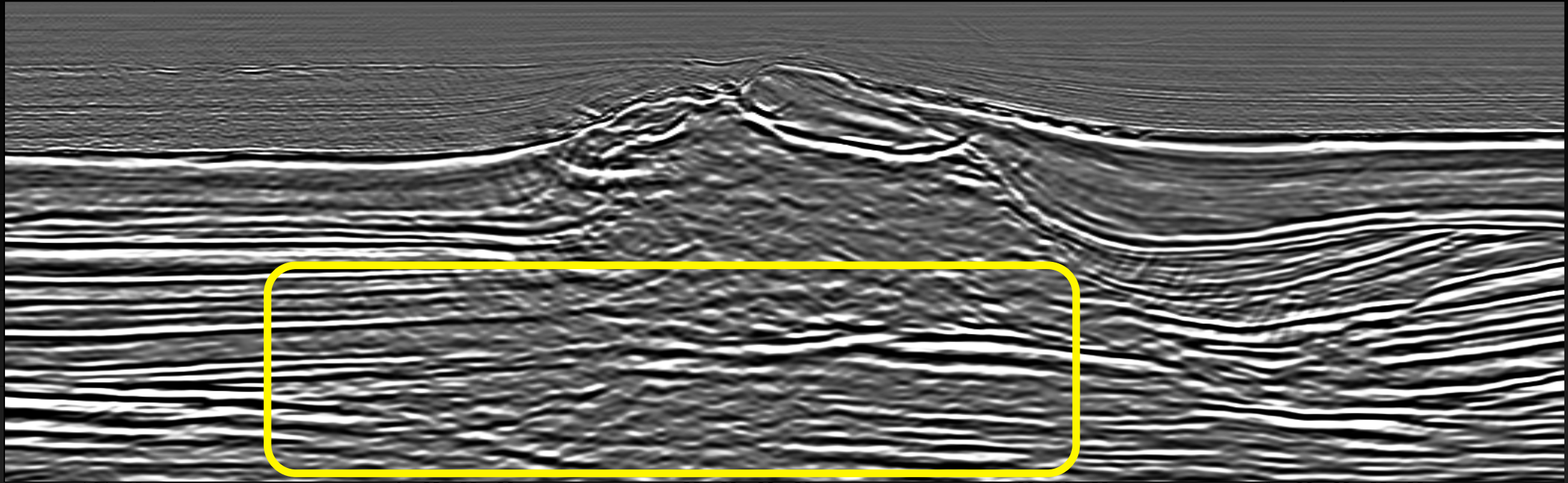


stdin

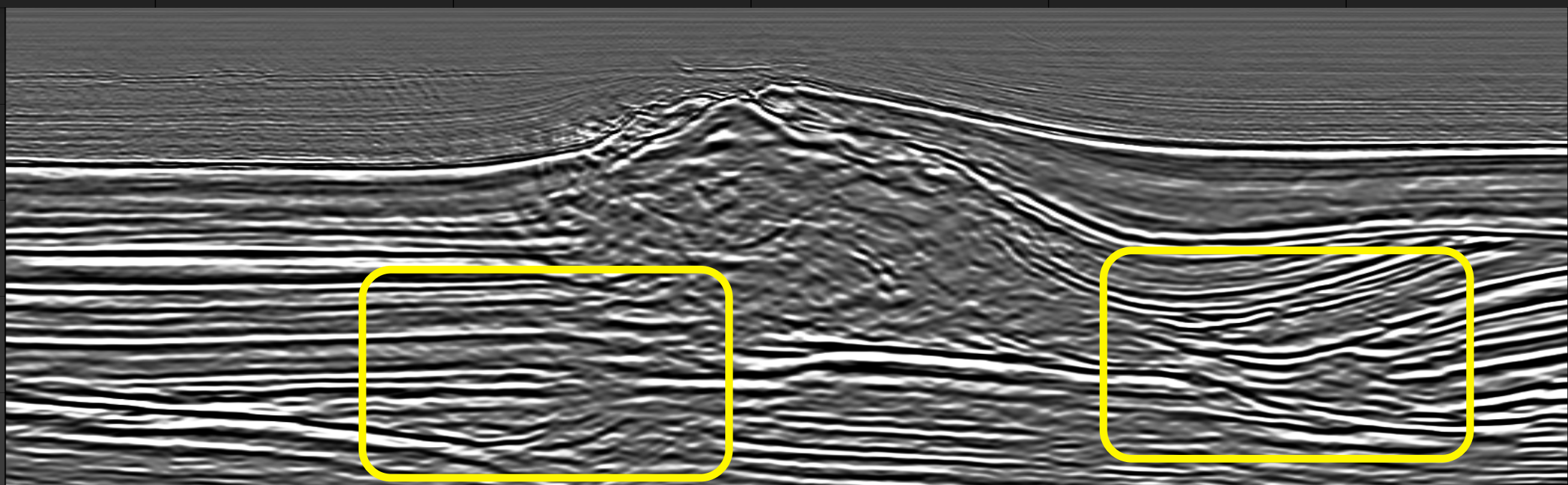
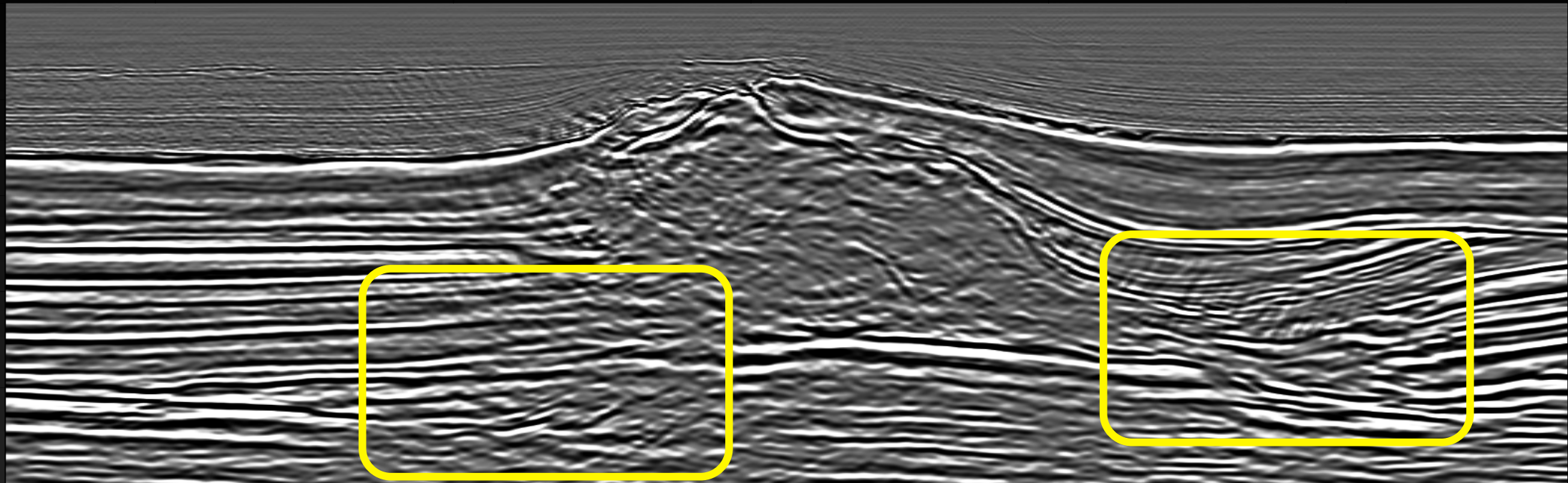
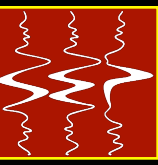
Original vs. Optimized (i3320)



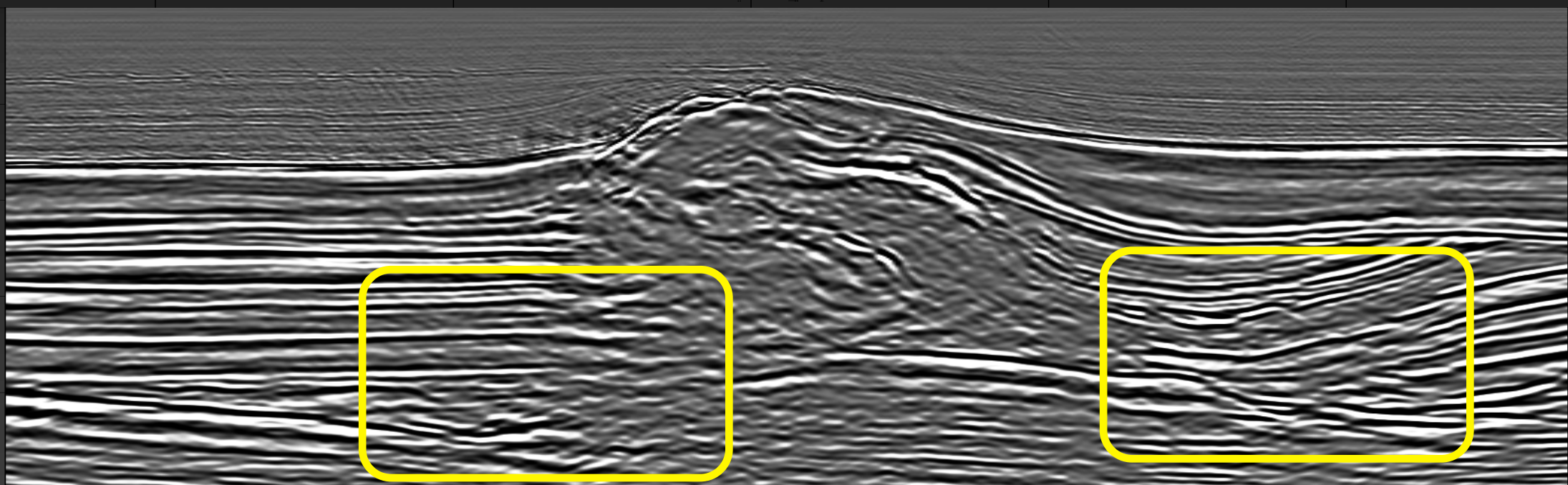
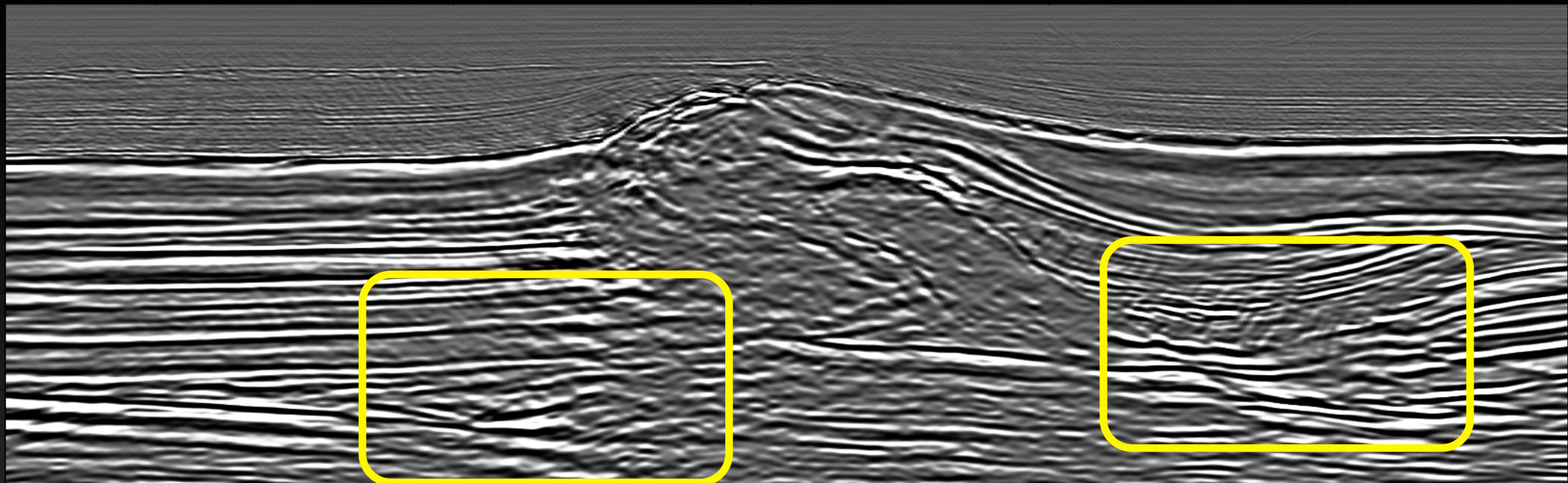
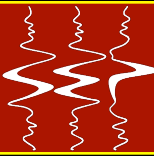
Original vs. Optimized (i3680)



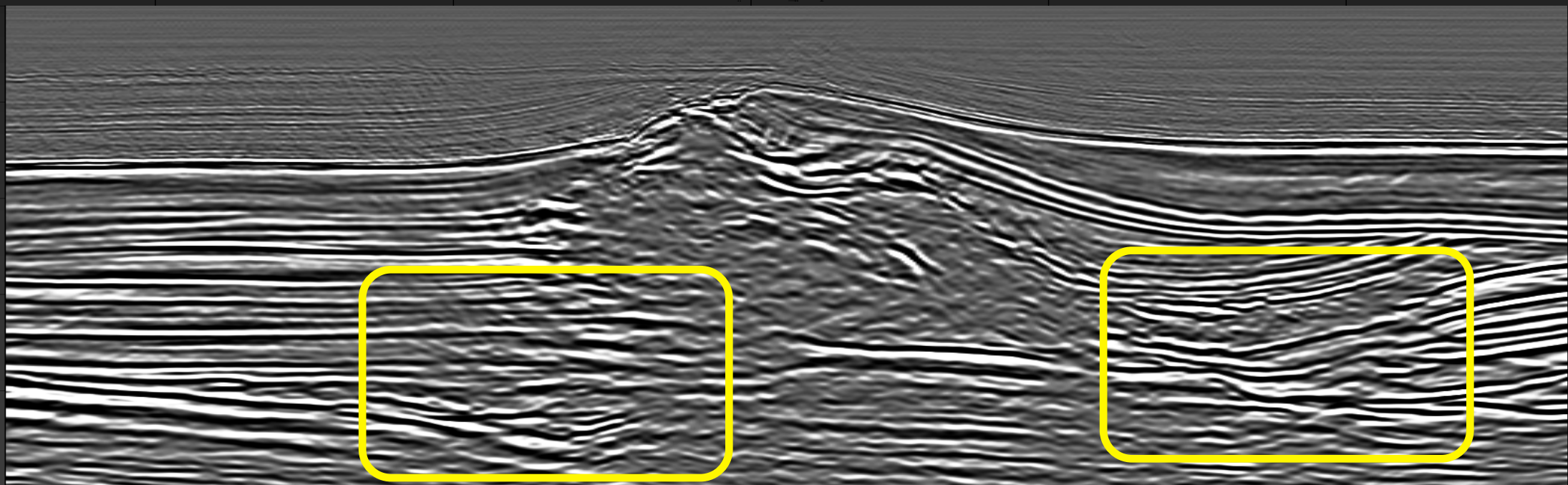
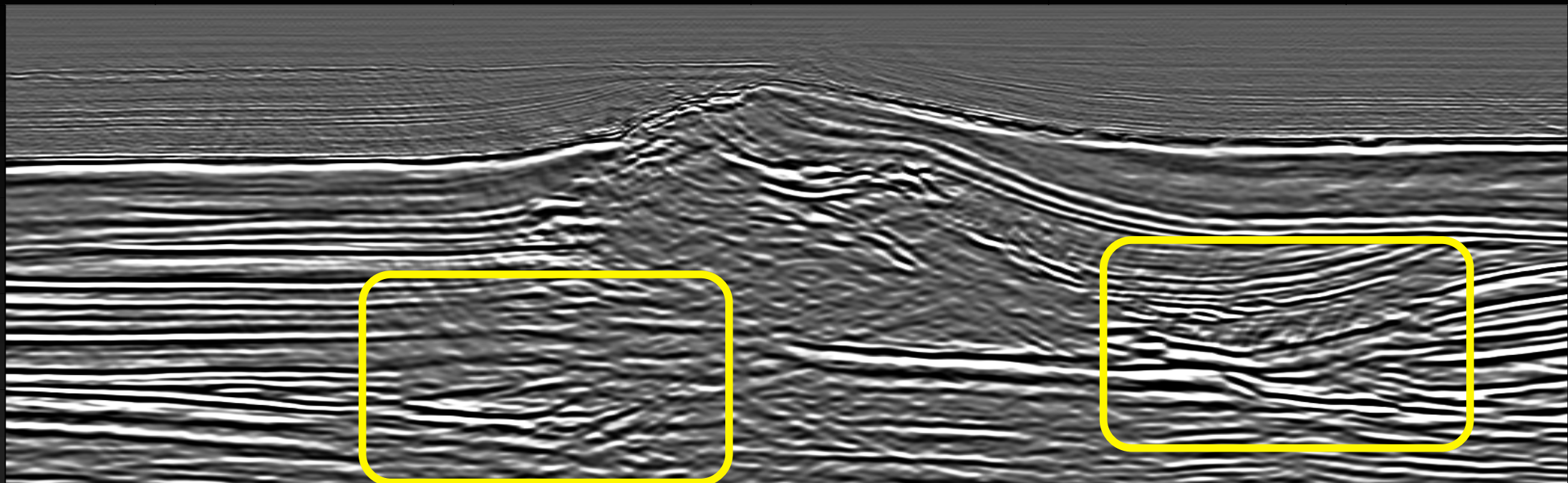
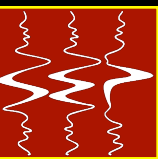
Original vs. Optimized (i4060)

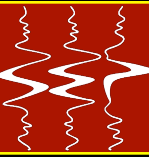


Original vs. Optimized (i4420)

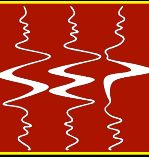


Original vs. Optimized (i4800)

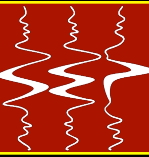




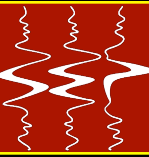
- **Image-space generalized wavefields accelerate ISWET**
 - **reduced data size**
 - **target-oriented strategy**



- **Image-space generalized wavefields accelerate ISWET**
 - reduced data size
 - target-oriented strategy
- **Image-space generalized wavefields naturally incorporate a horizon-based strategy**



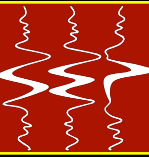
- **Image-space generalized wavefields accelerate ISWET**
 - reduced data size
 - target-oriented strategy
- **Image-space generalized wavefields naturally incorporate a horizon-based strategy**
- **Image-space generalized wavefields yield accurate velocity updates**



**Image-space generalized wavefields enables
the routine use of ISWET**

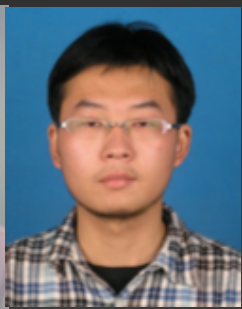
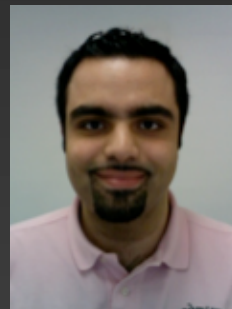
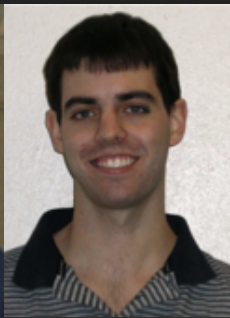
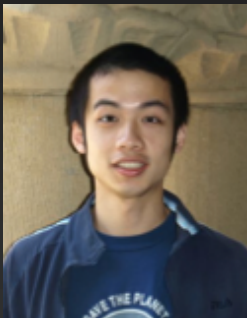
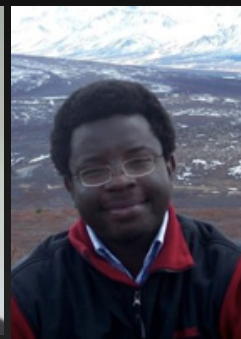


- **Petrobras** for providing all the necessary support
- **Biondo Biondi** for keeping me on track and for his constant encouragement
- **Jon Claerbout** for enlightening discussions
- **Bob Clapp** for always being steps ahead on defining SEP's computational needs
- **Tapan Mukerji** for chairing this defense
- **Jerry Harris** for always being in my committees



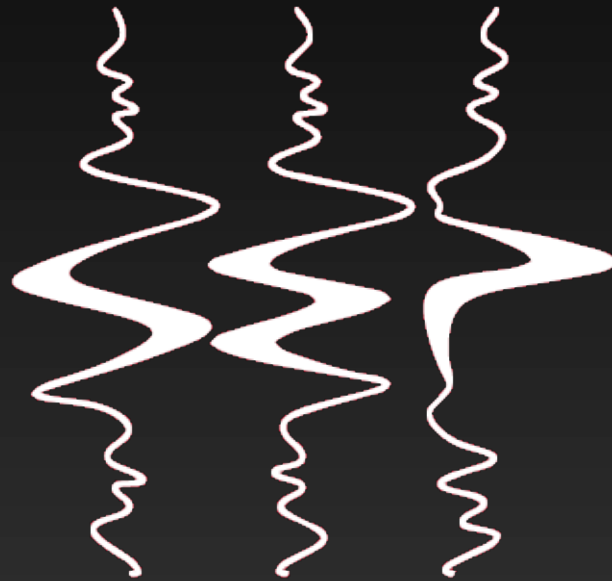
- **Diane Lau** for her unceasing effort to smoothly run SEP
- **Systems administrators** for taking care of our computers
- **TotalFinaElf** for providing the North Sea dataset

Thanks to





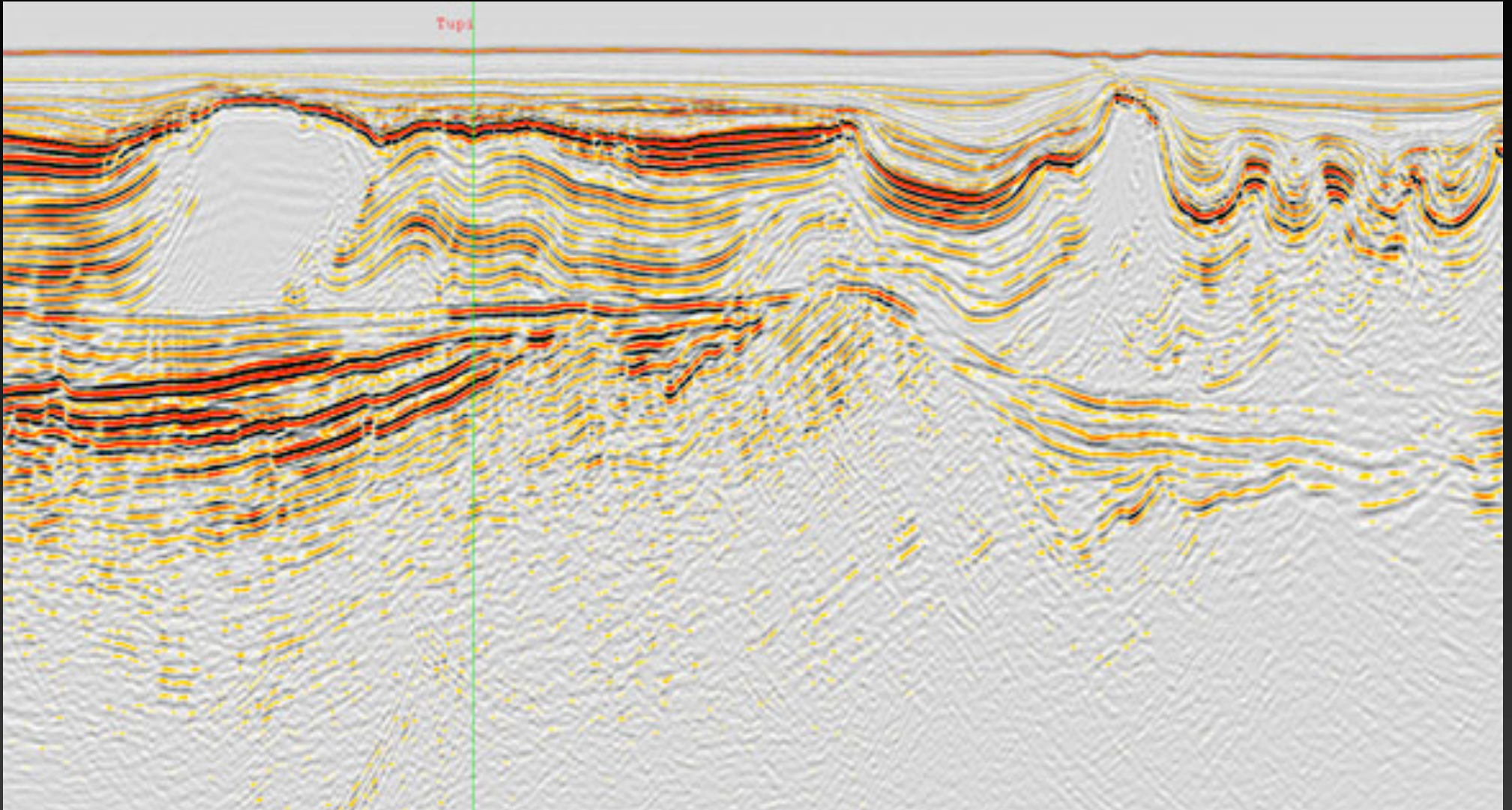
Thanks



STANFORD
EXPLORATION PROJECT

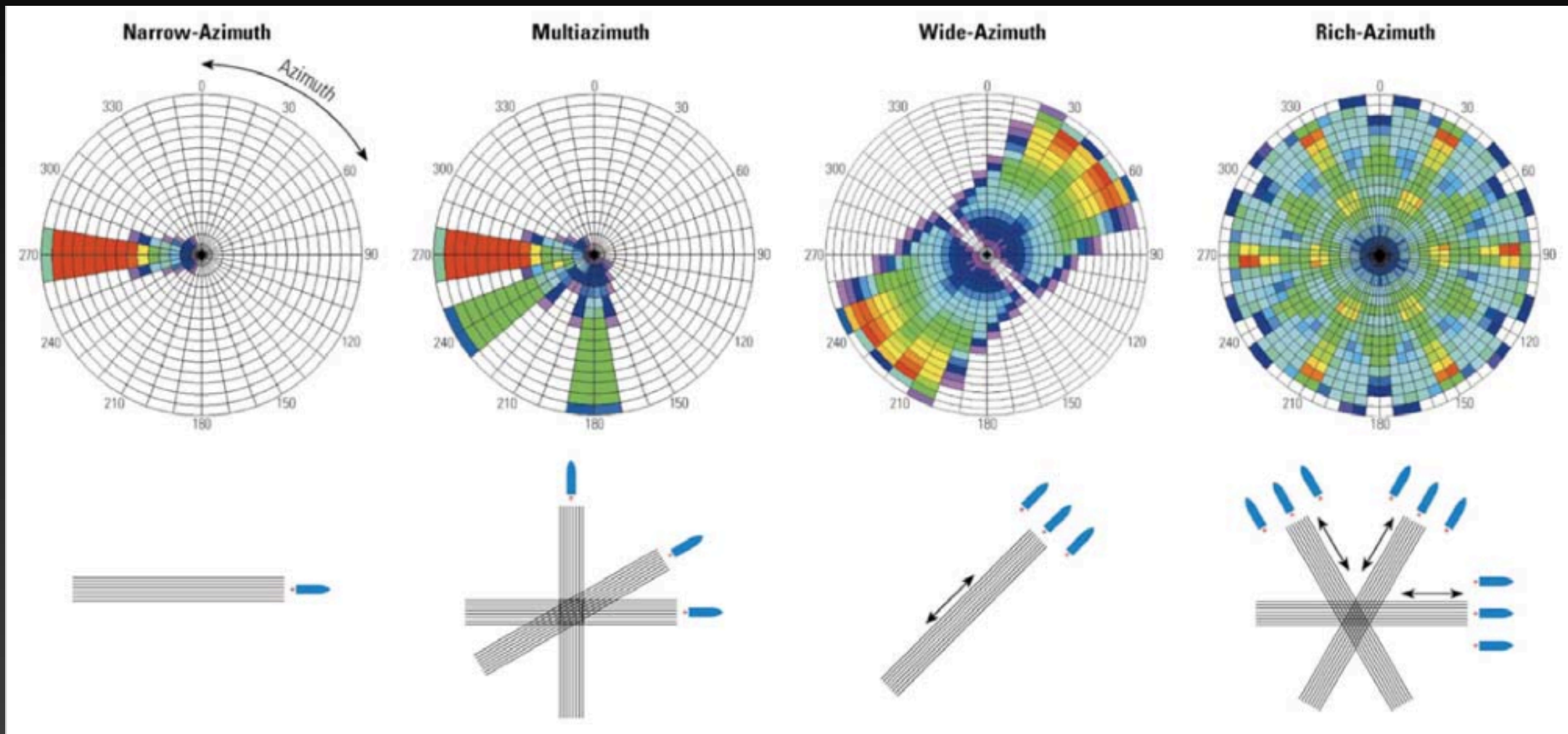
distance

depth



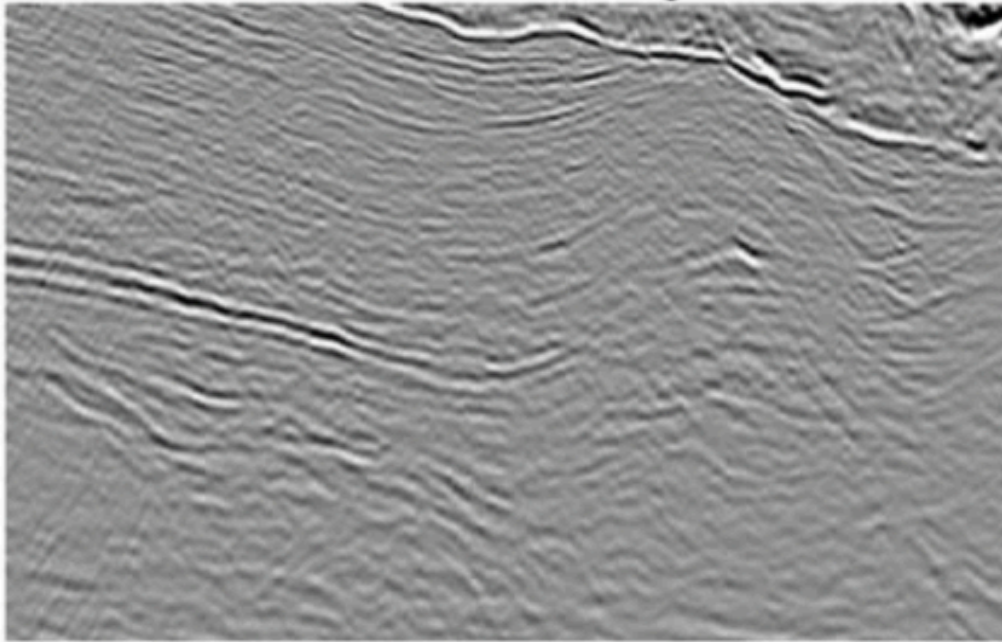
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Acquisition

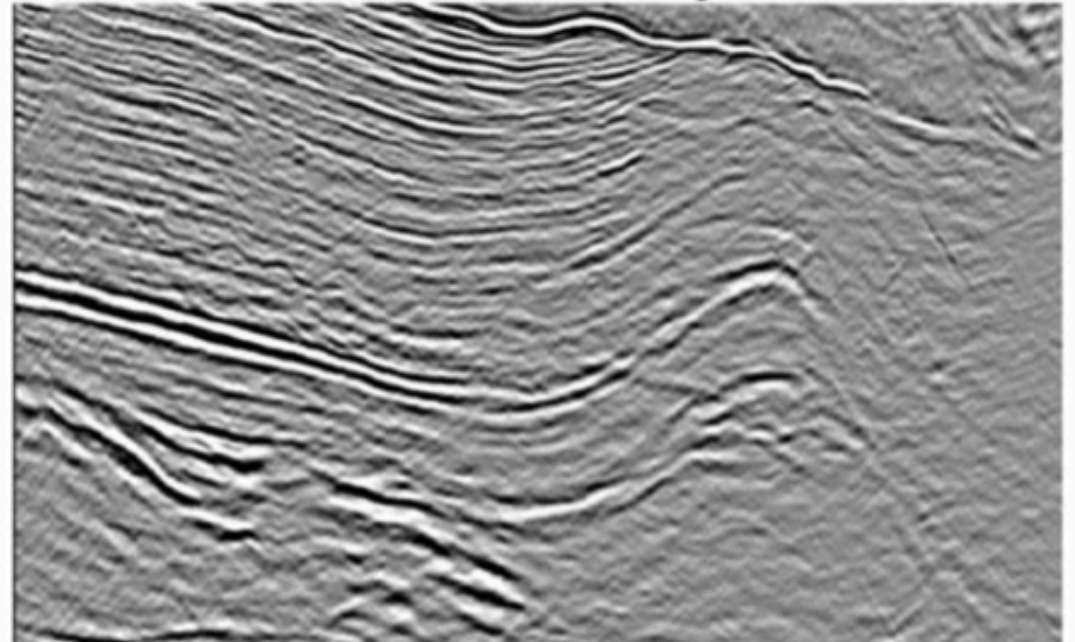


Acquisition

NAZ with demultiple

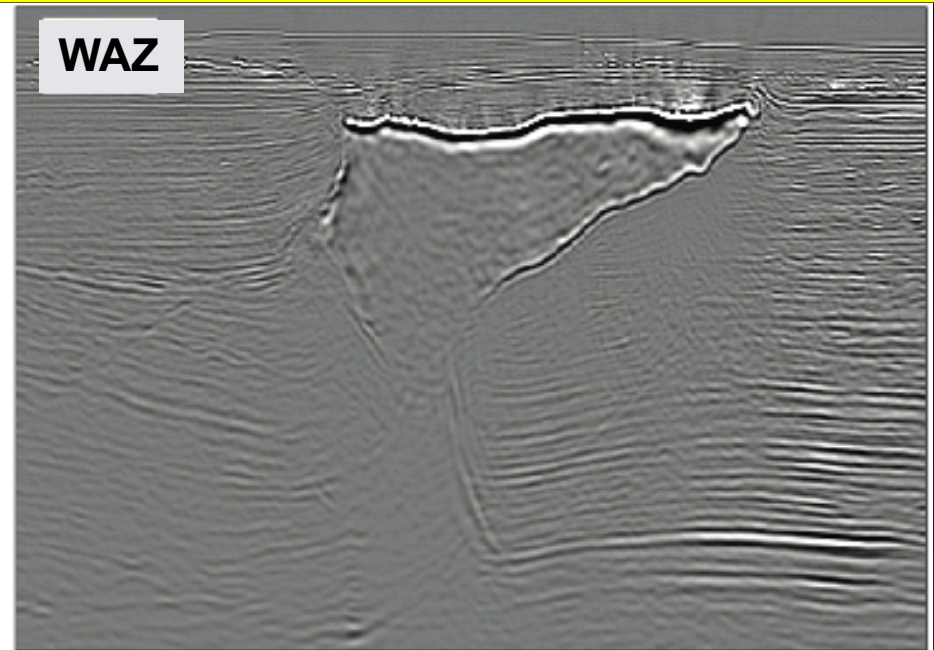
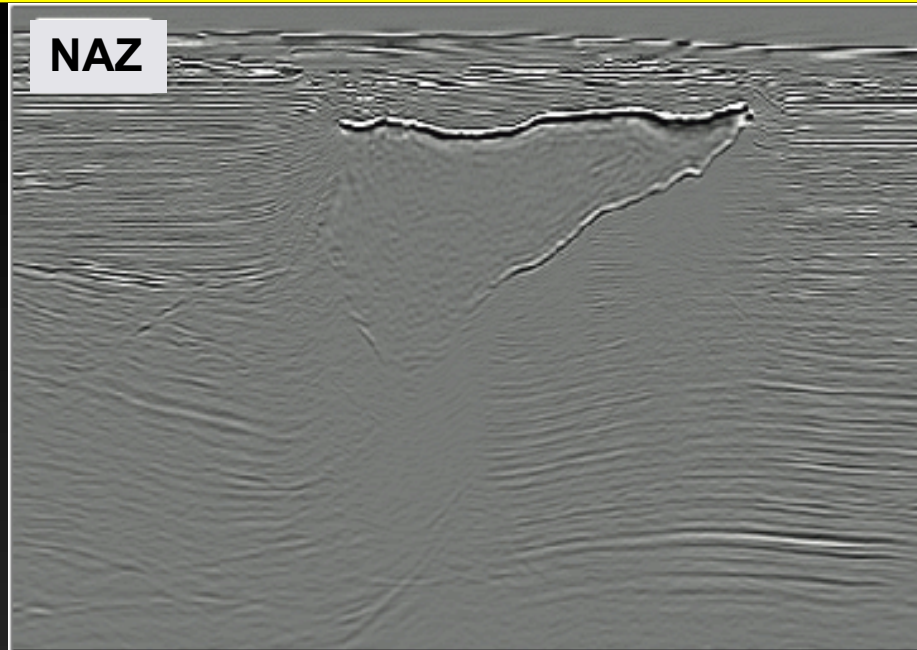


RAZ no demultiple



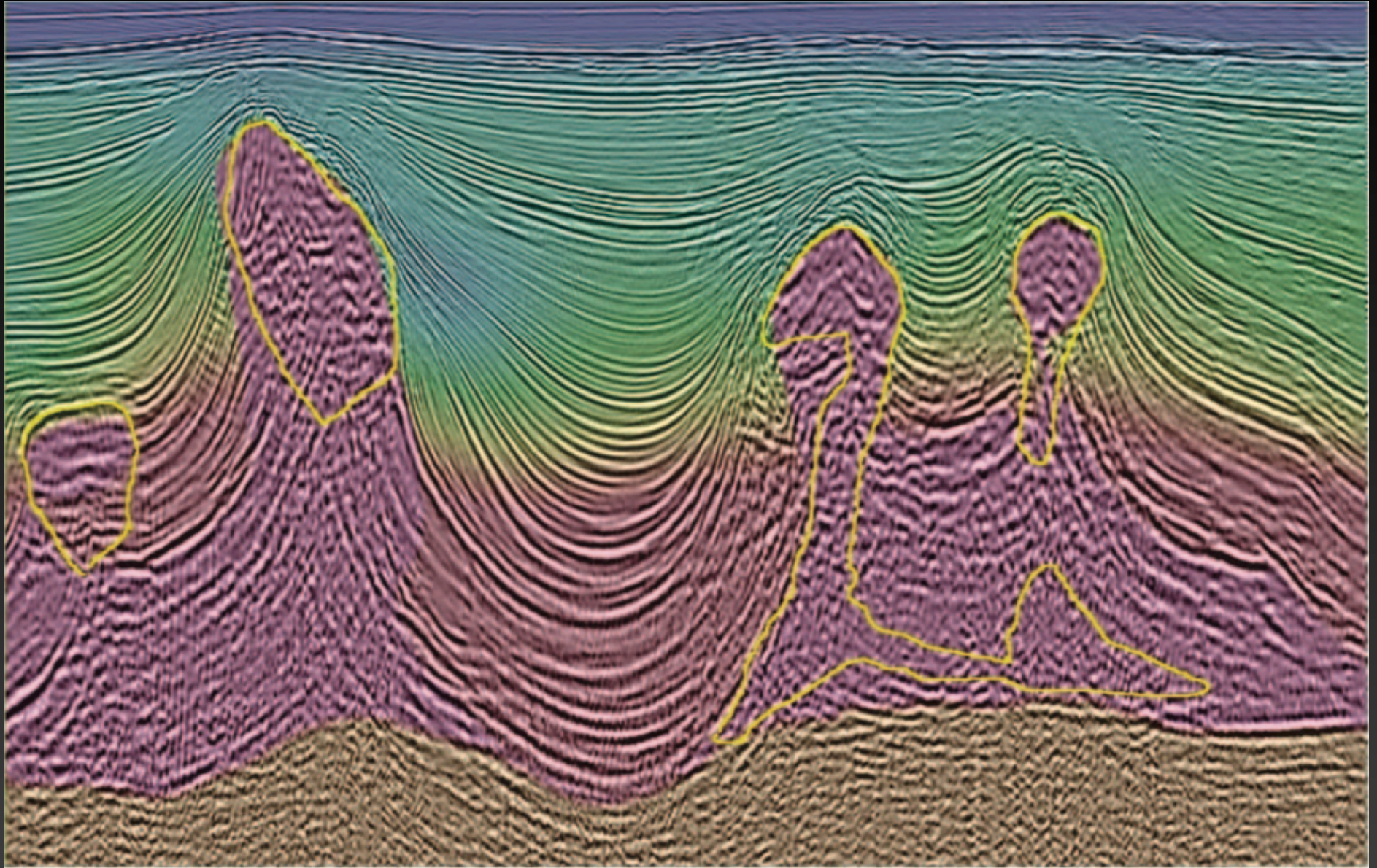
Kapoor et al., 2007

Acquisition and velocity model



distance

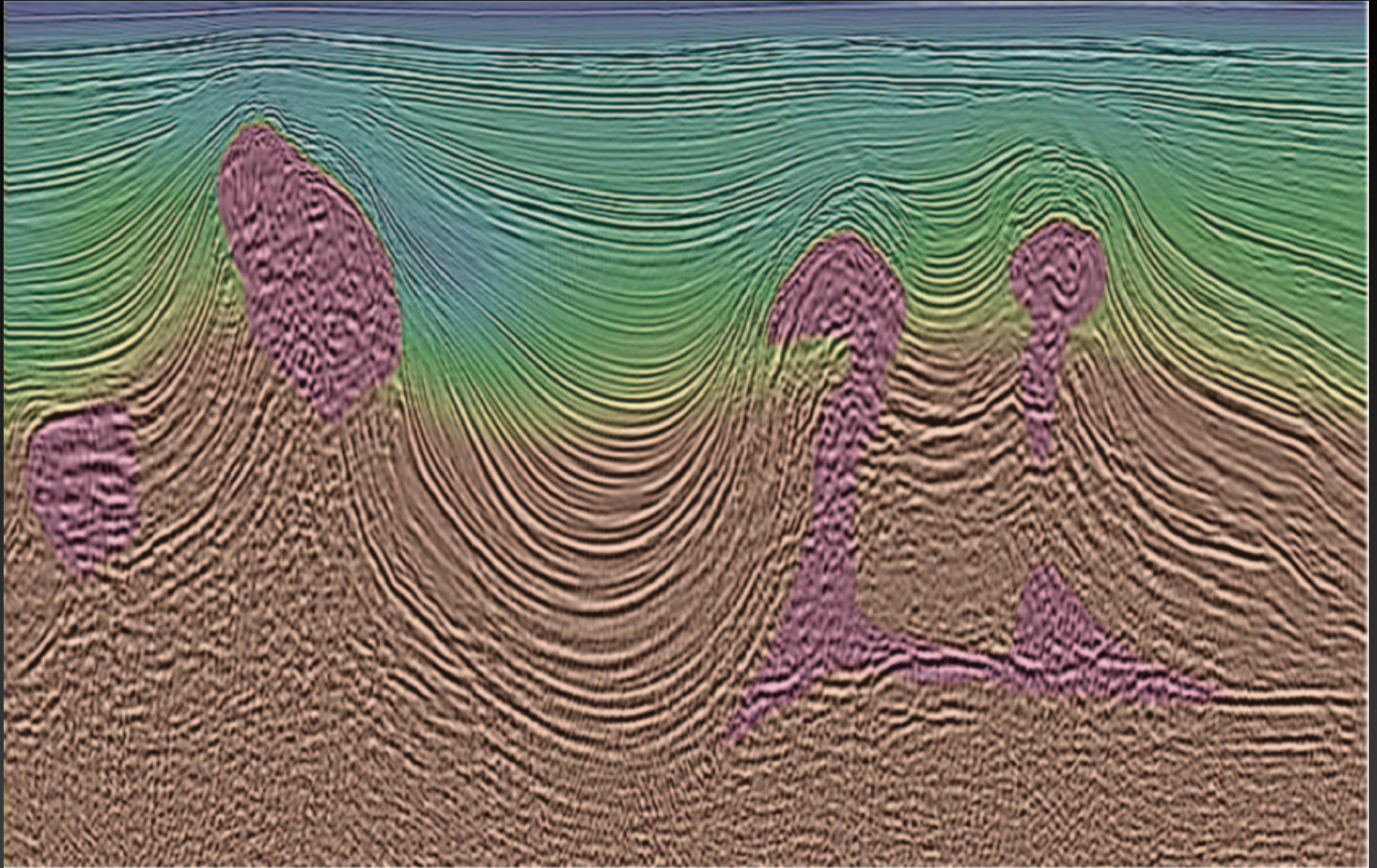
depth



Li et al., 2009

distance

depth



Li et al., 2009

Data-space: 0° plane wave



source

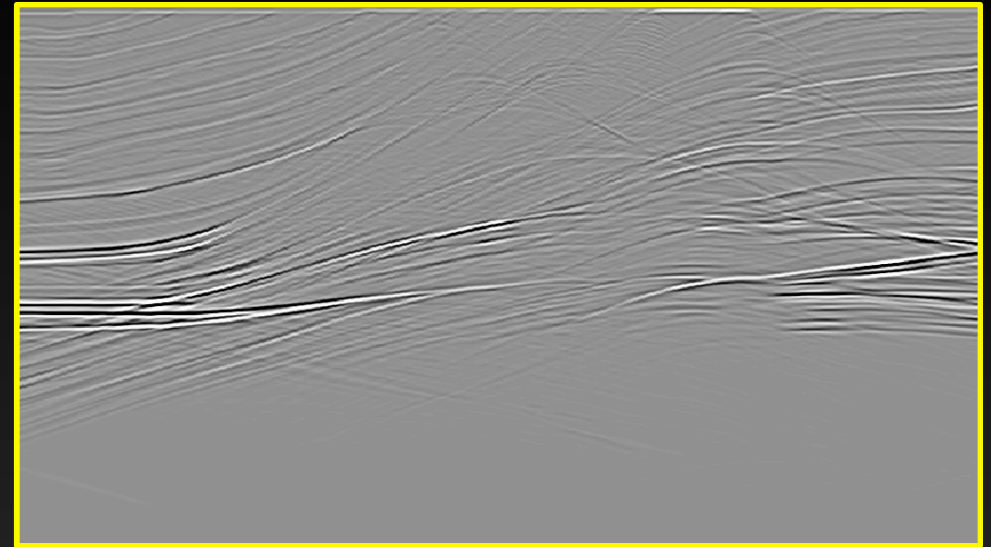
time



distance

receiver

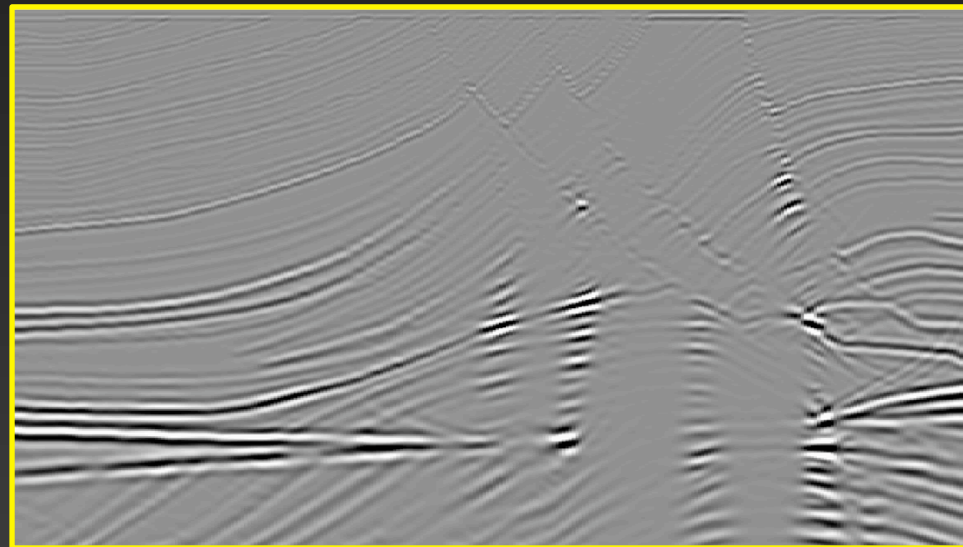
time



distance

image

depth



distance

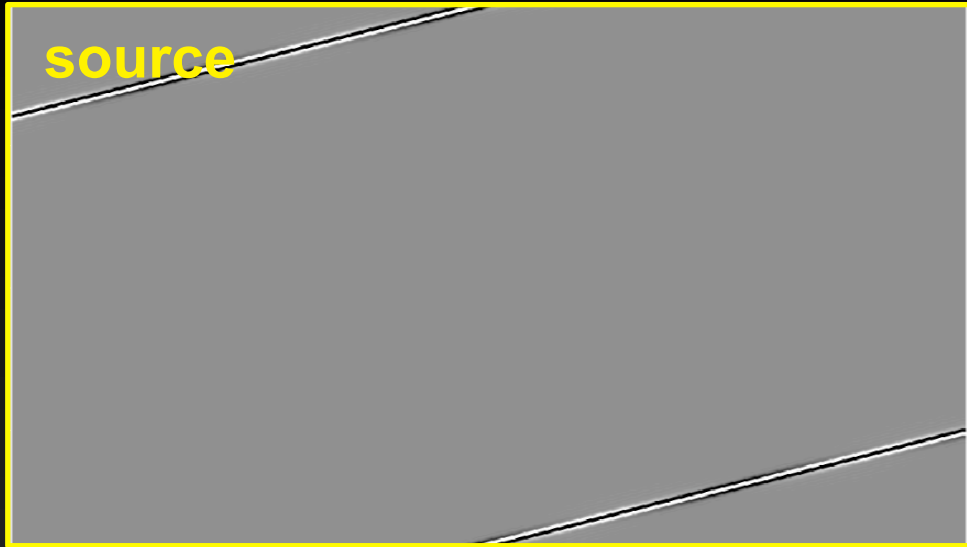
Data-space: plane waves



distance

source

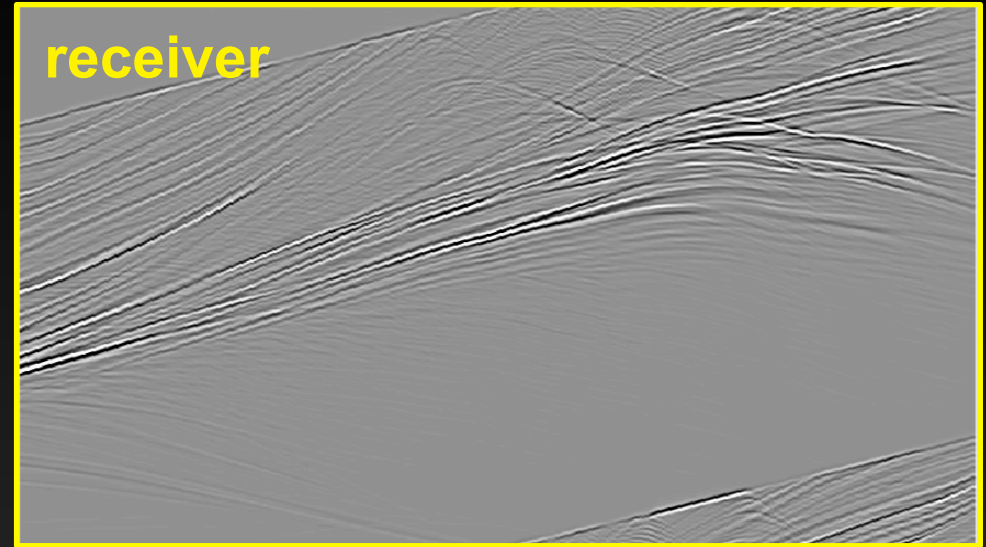
time



distance

receiver

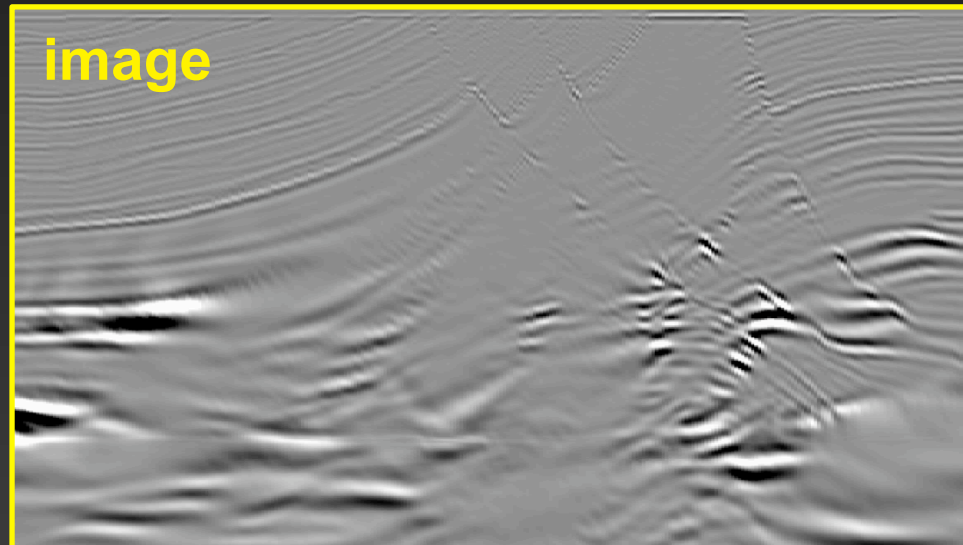
time



distance

image

depth

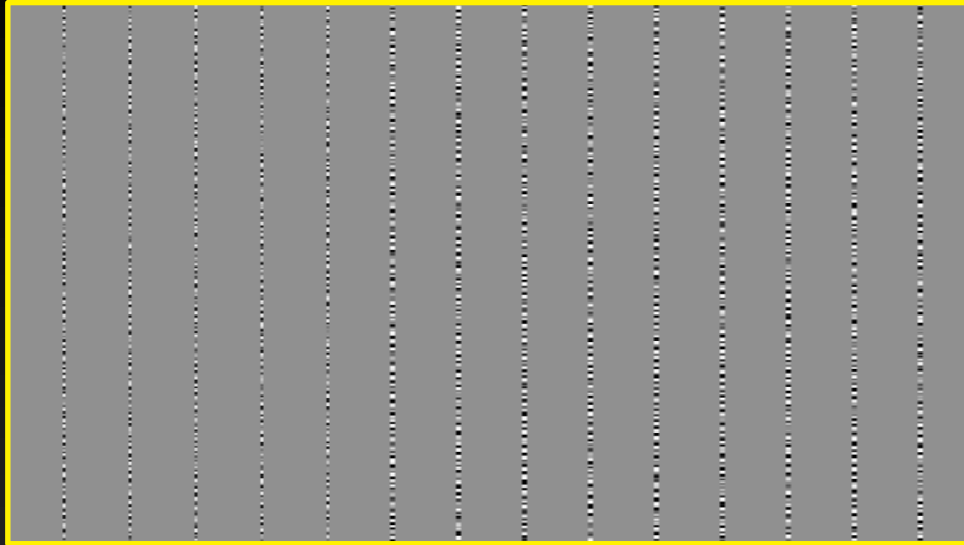


Data-space: random phases



source

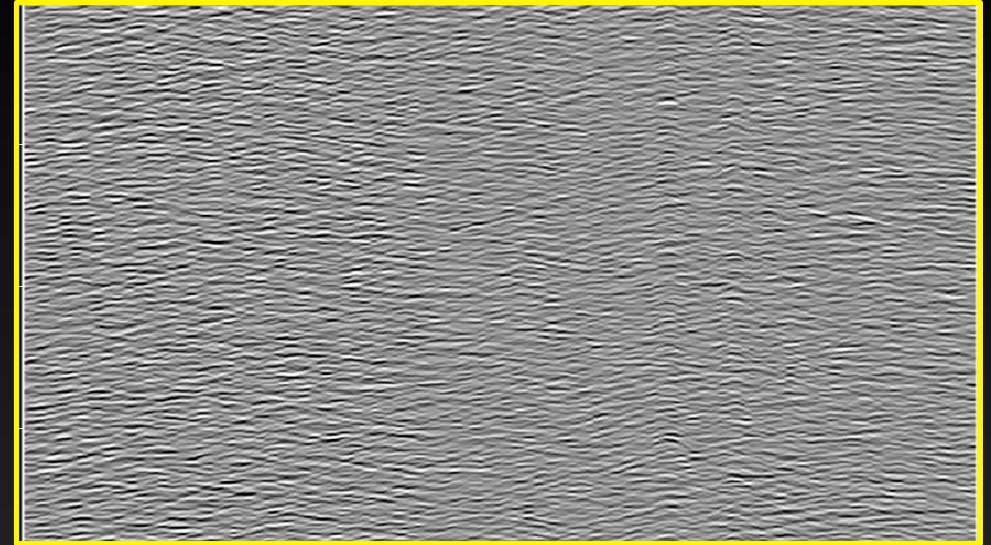
time



distance

receiver

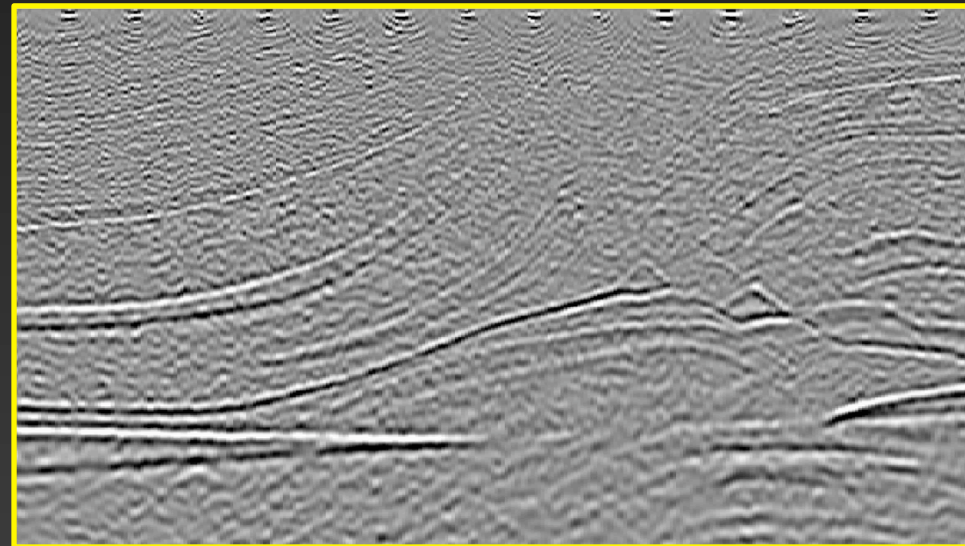
time



distance

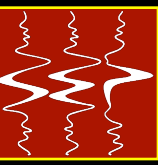
image

depth



distance

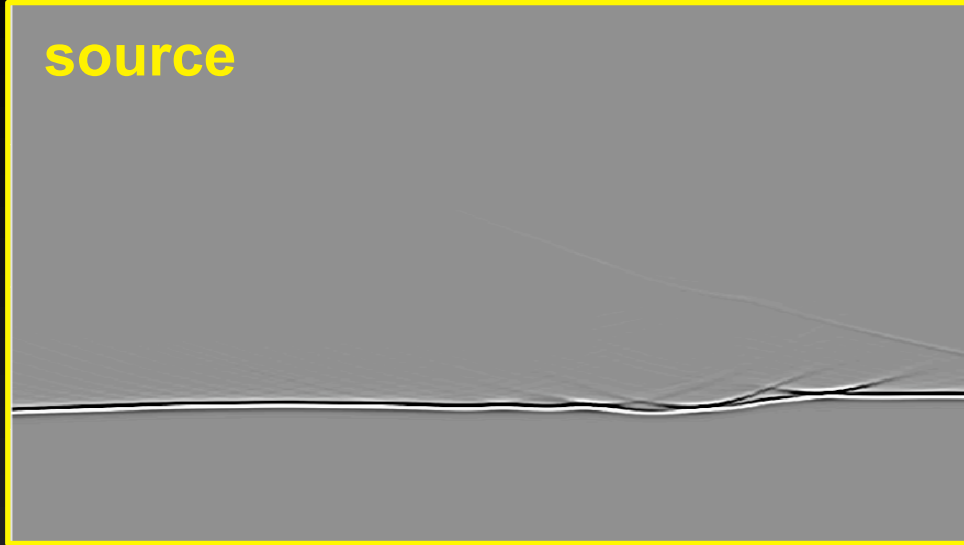
Data-space: controlled illumination



distance

source

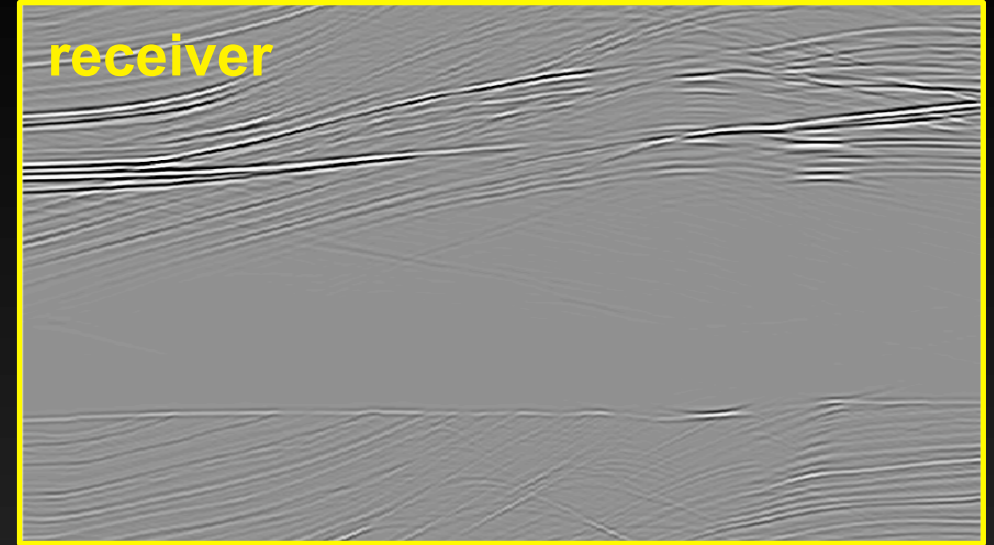
time



distance

receiver

time



distance

image

depth

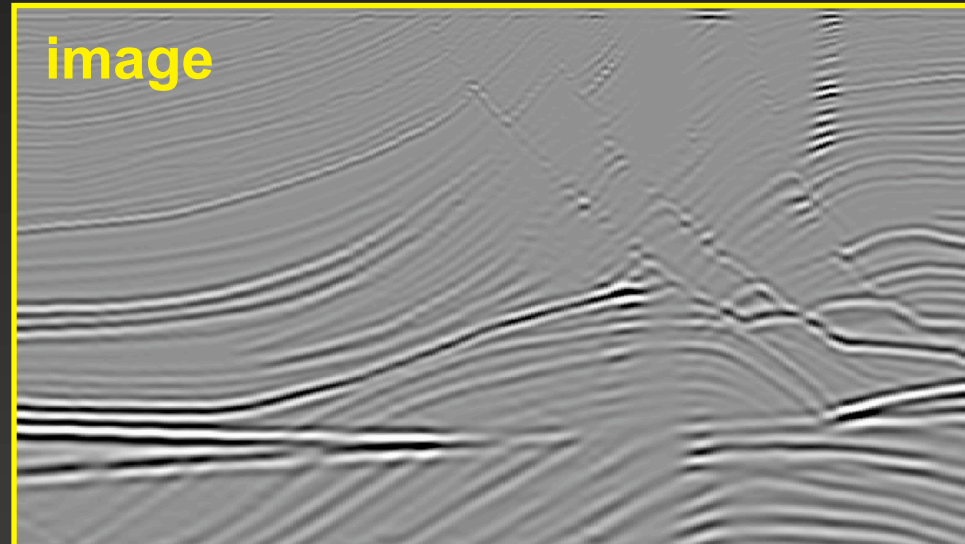


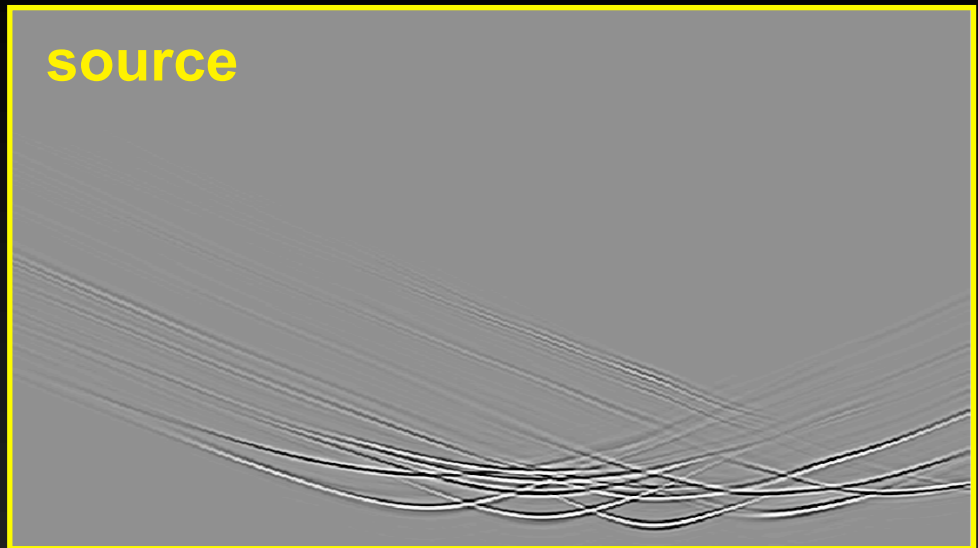
Image-space: prestack-exploding reflector



distance

source

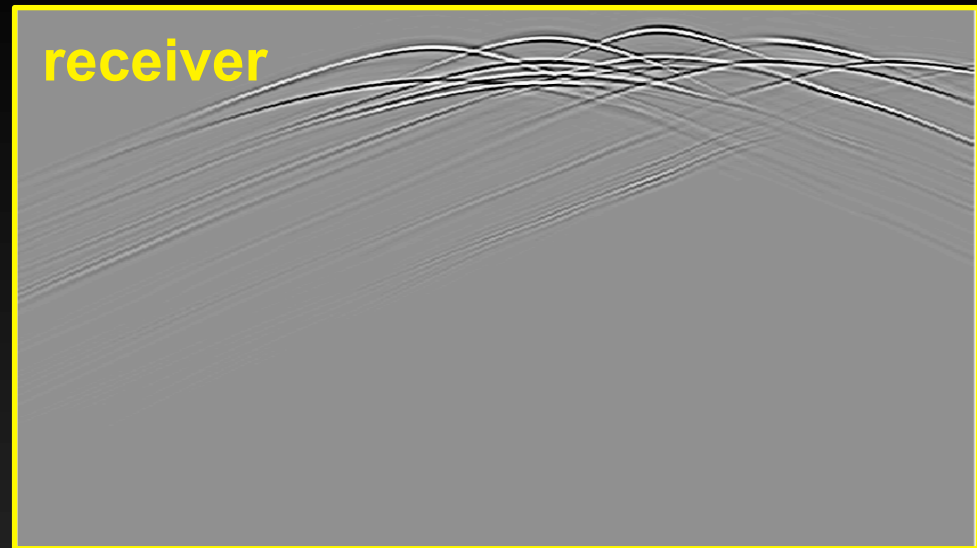
time



distance

receiver

time



distance

image

depth

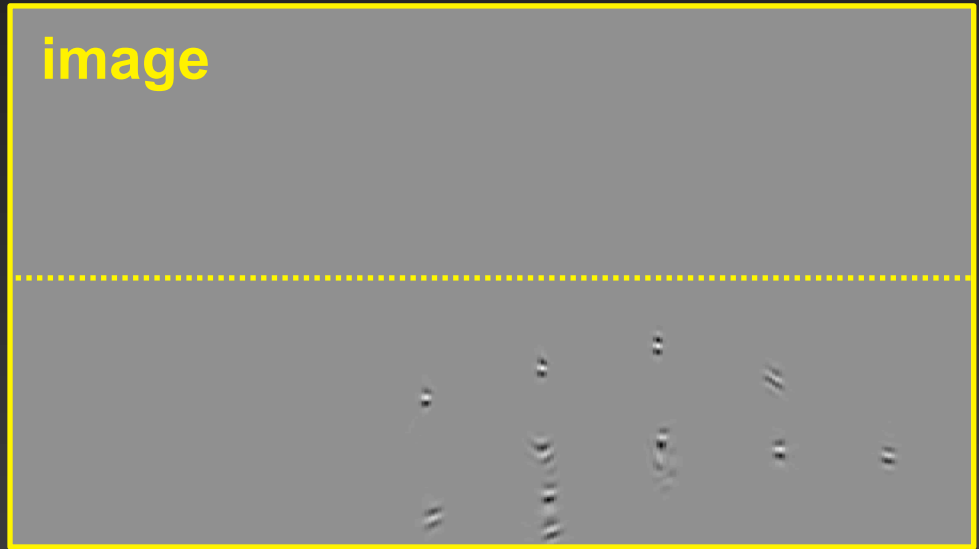
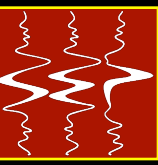


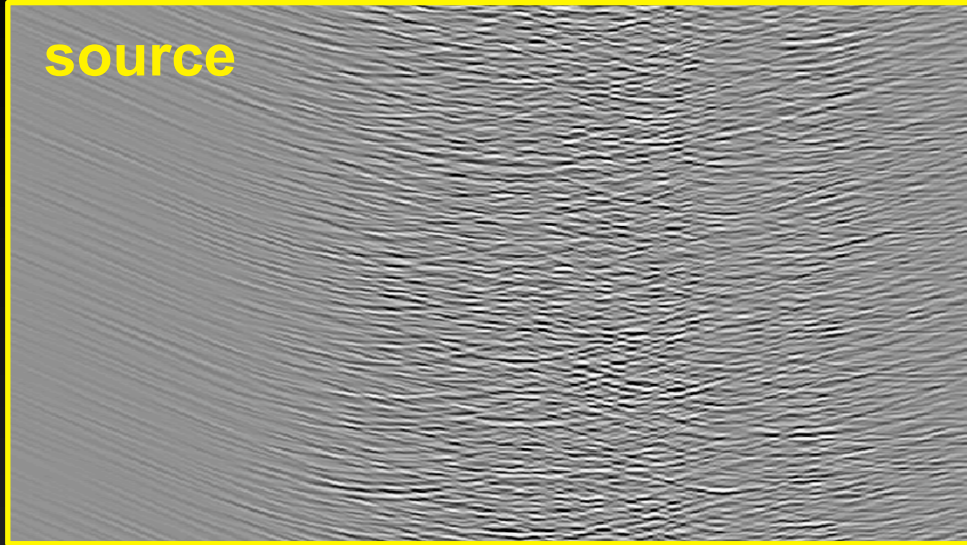
Image-space: random phases (ISPEW)



distance

source

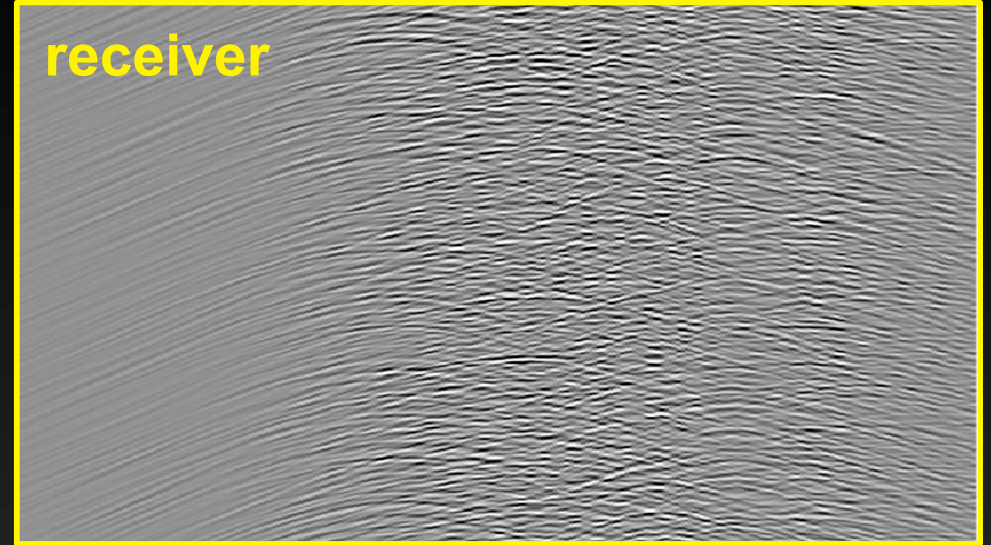
time



distance

receiver

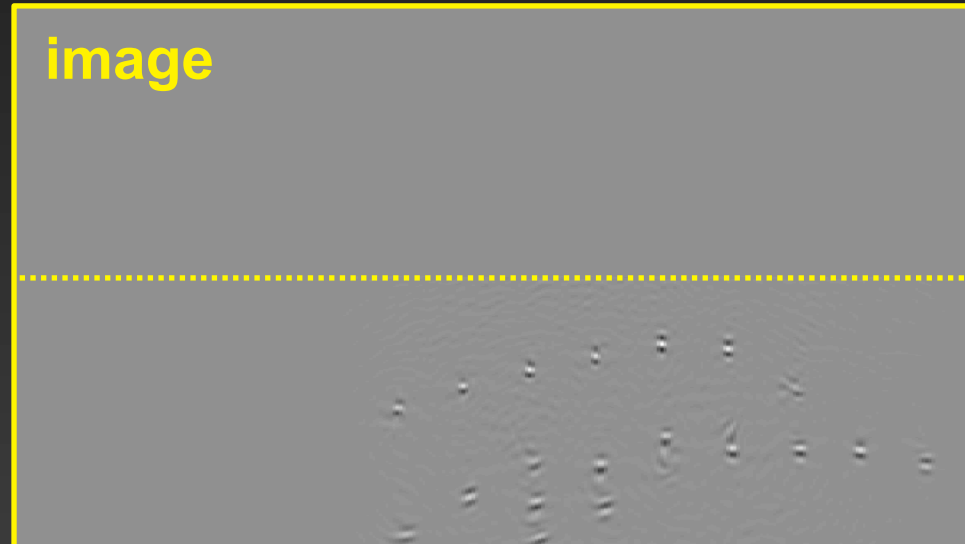
time

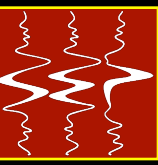


distance

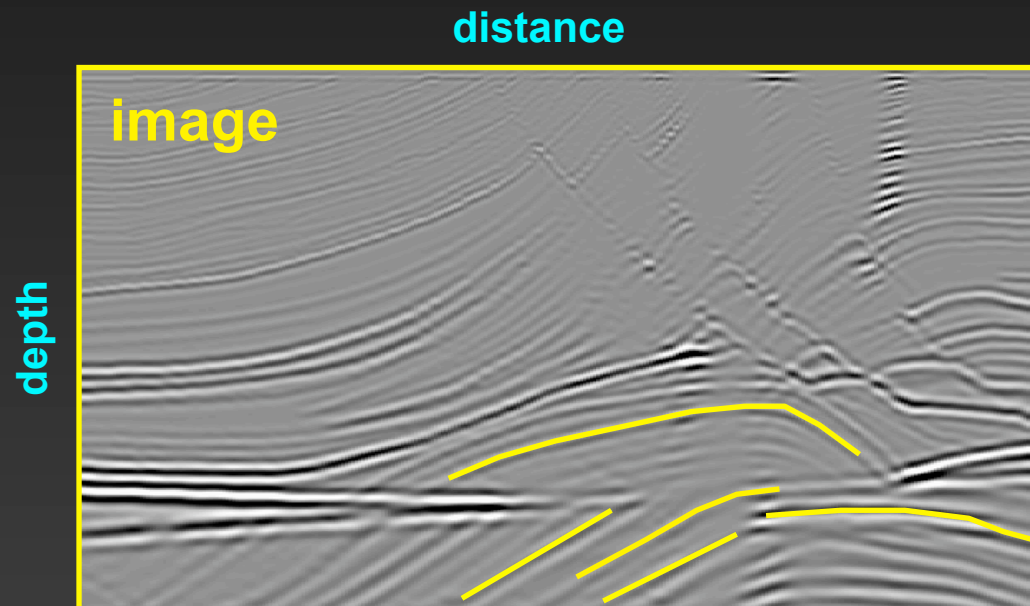
image

depth

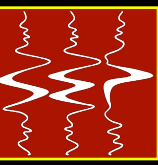




- Models wavefields from selected reflectors



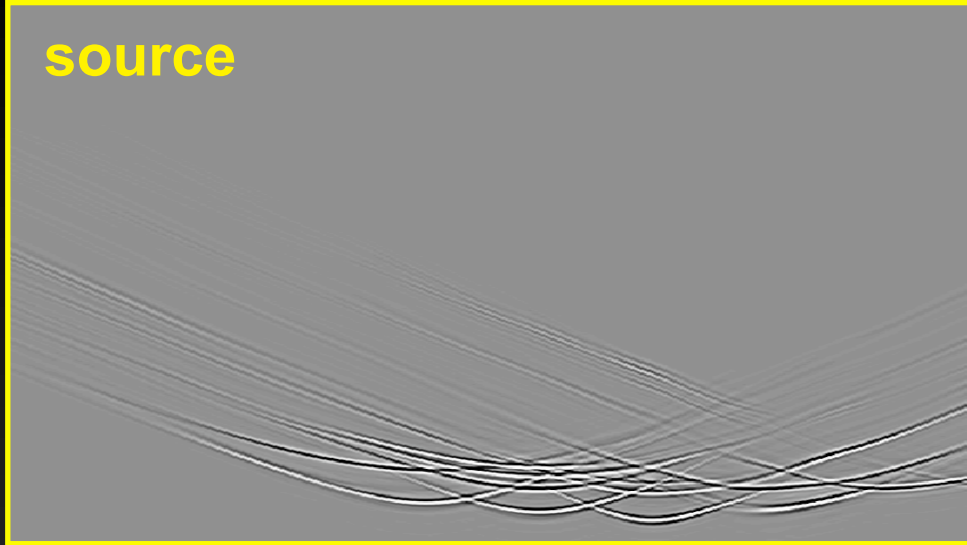
PERM



distance

source

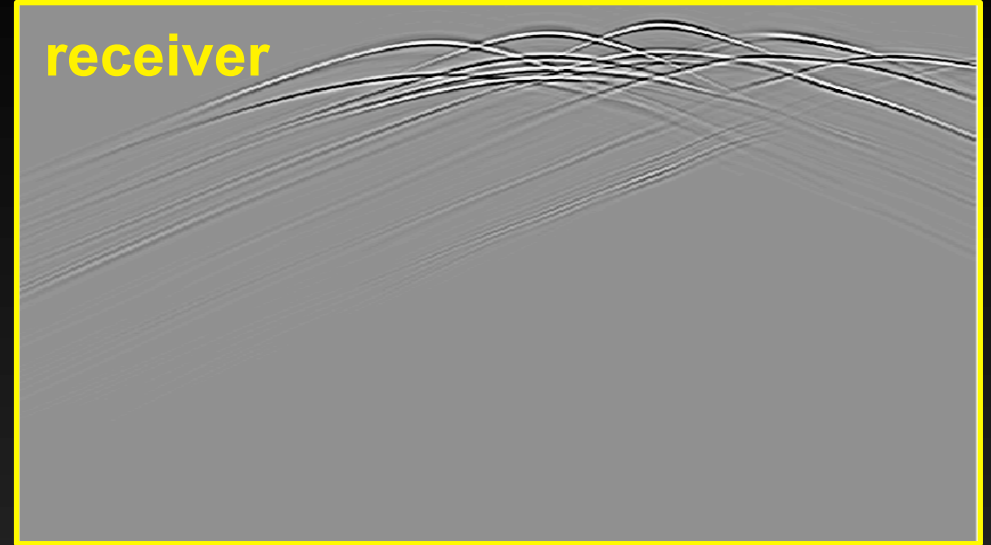
time



distance

receiver

time

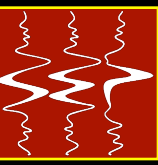


distance

image

depth

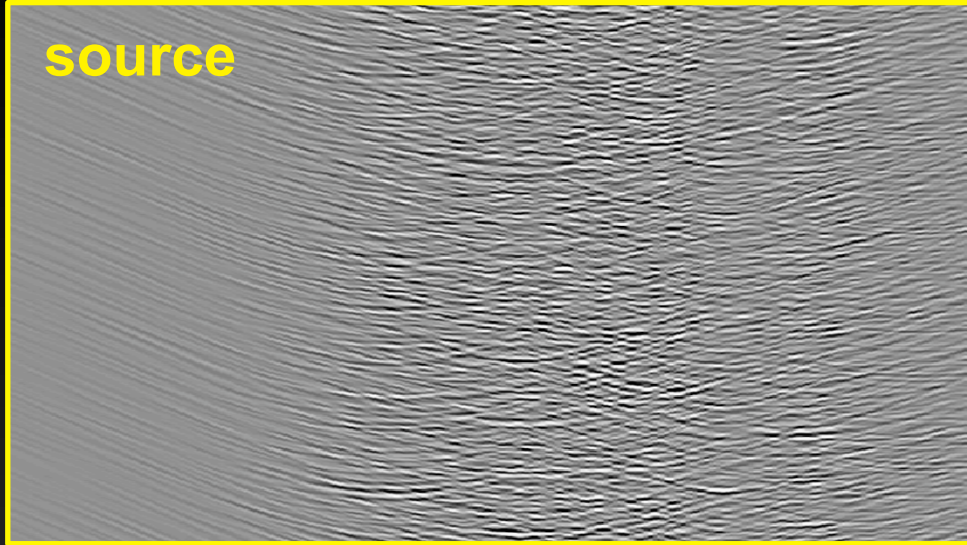




distance

source

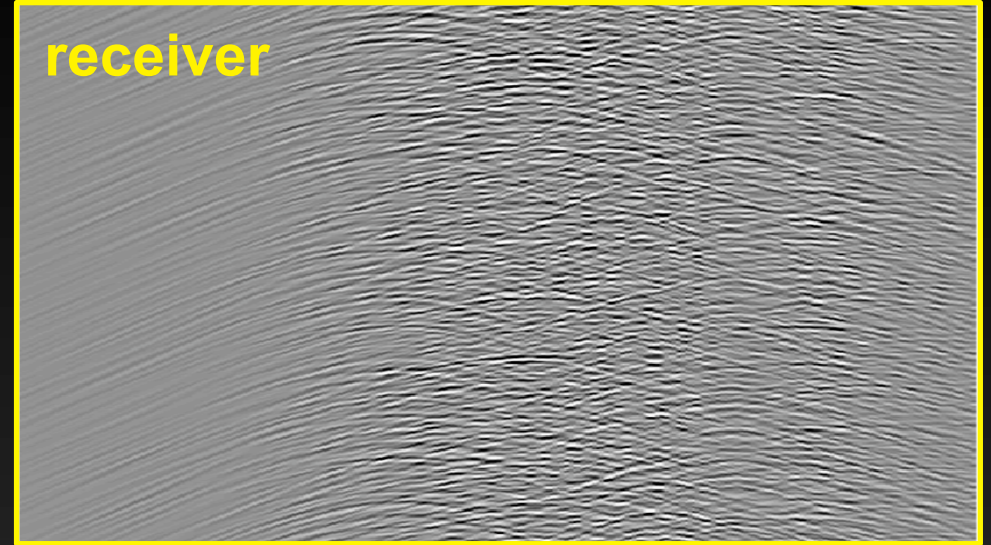
time



distance

receiver

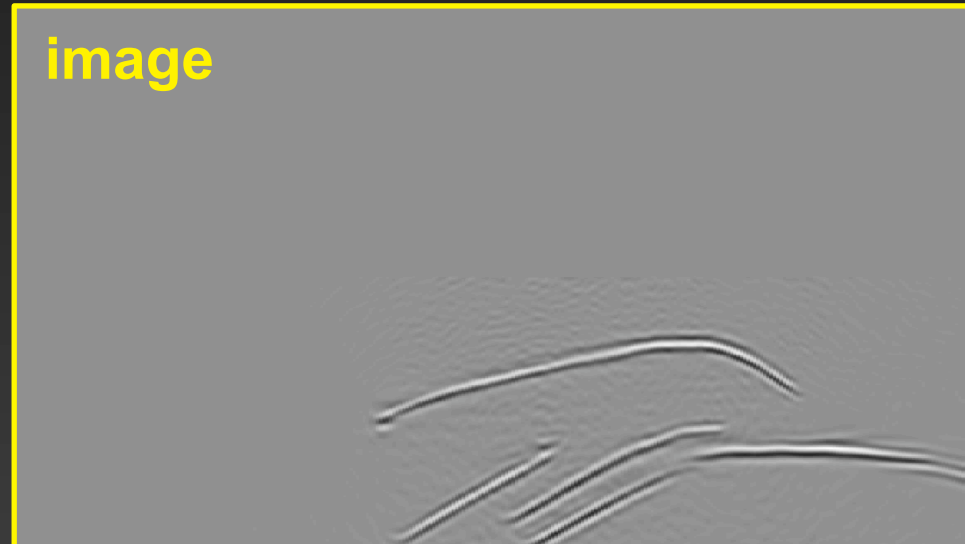
time

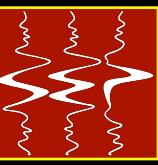


distance

image

depth





$$I(s) = \mathbf{F}[s]$$

s = slowness

I = image



$$I(\mathbf{s}) = \mathbf{F}[\mathbf{s}]$$
$$I(\mathbf{s}) \approx I_o + \left. \frac{\partial I}{\partial \mathbf{s}} \right|_{\mathbf{s}=\mathbf{s}_o} \Delta \mathbf{s}$$

s = slowness

s_o = background slowness

Δs = slowness perturbation

I = image

I_o = background image



$$I(s) \approx I_o + \left. \frac{\partial I}{\partial s} \right|_{s=s_o} \Delta s$$

$$\Delta I(s) = \mathbf{T} \Delta s$$

s = slowness

s_o = background slowness

Δs = slowness perturbation

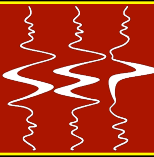
\mathbf{T} = IS – tomographic operator

I = image

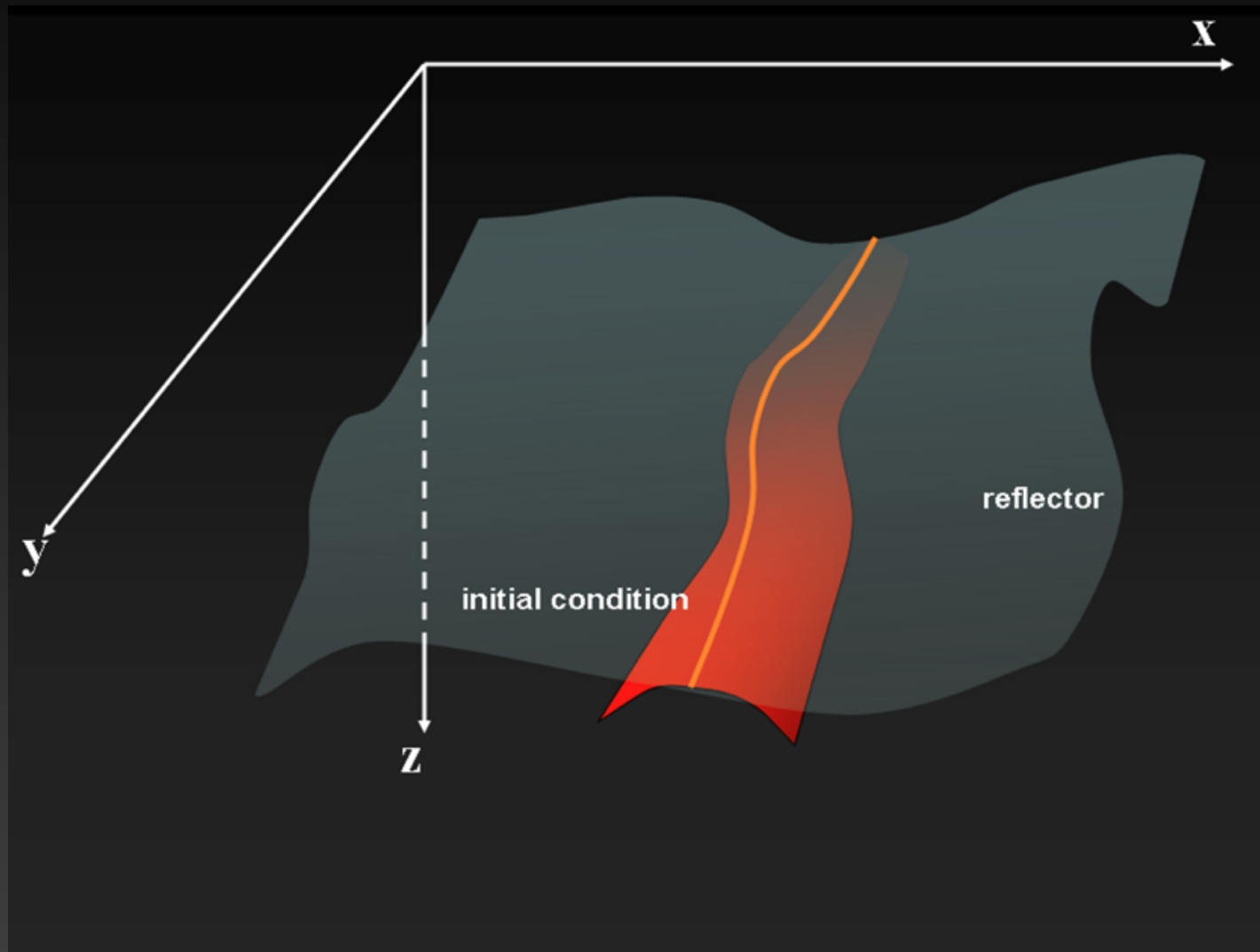
I_o = background image

ΔI = image perturbation

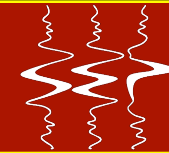
Using Common-azimuth migrated images



- **Less than 100 PERM wavefields**
 - **Only inline subsurface-offsets are computed**

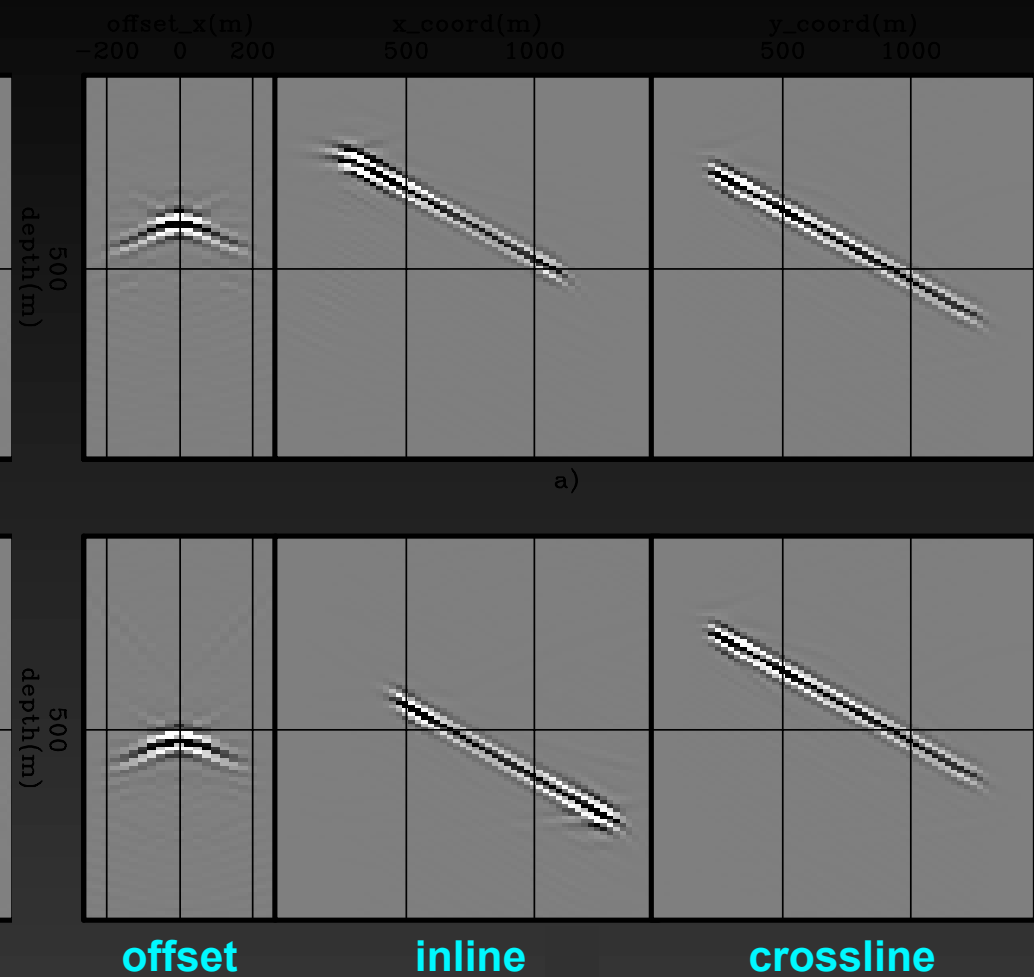
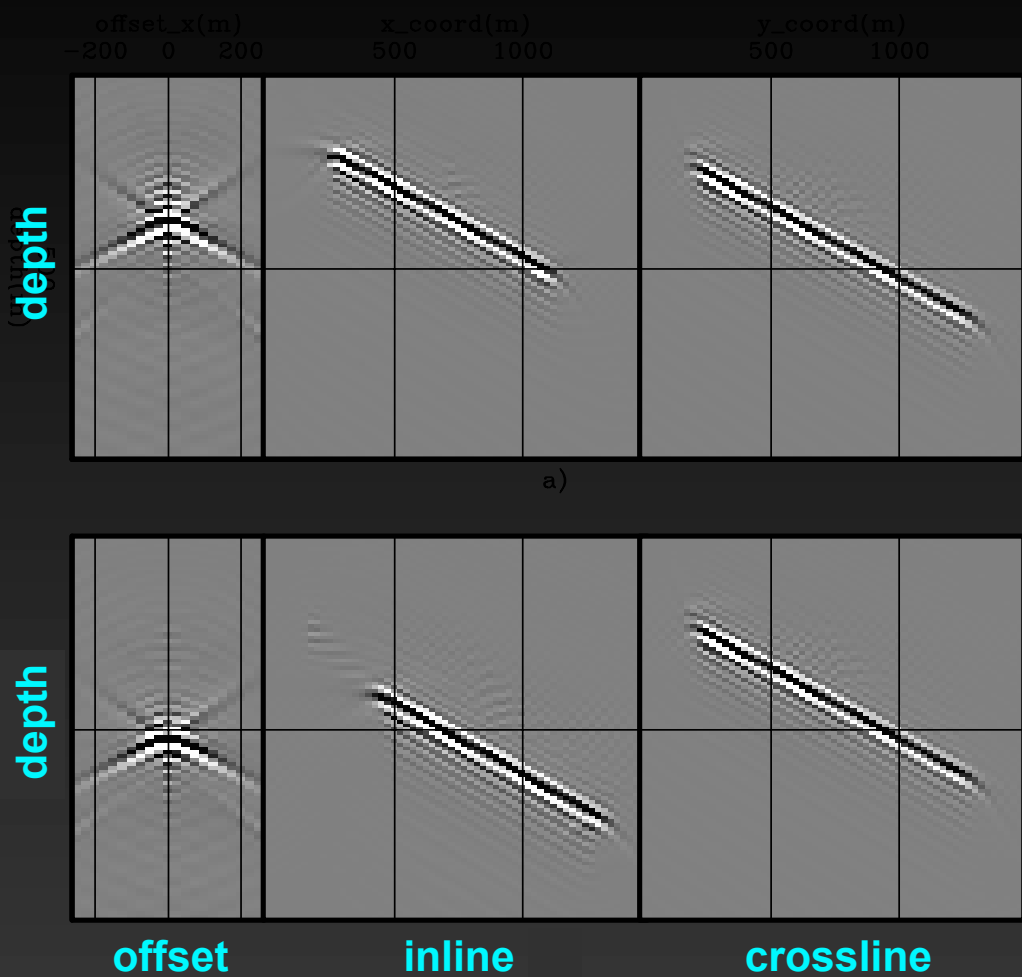


Using CAM images as the initial conditions

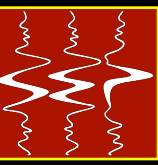


CAM

PERM

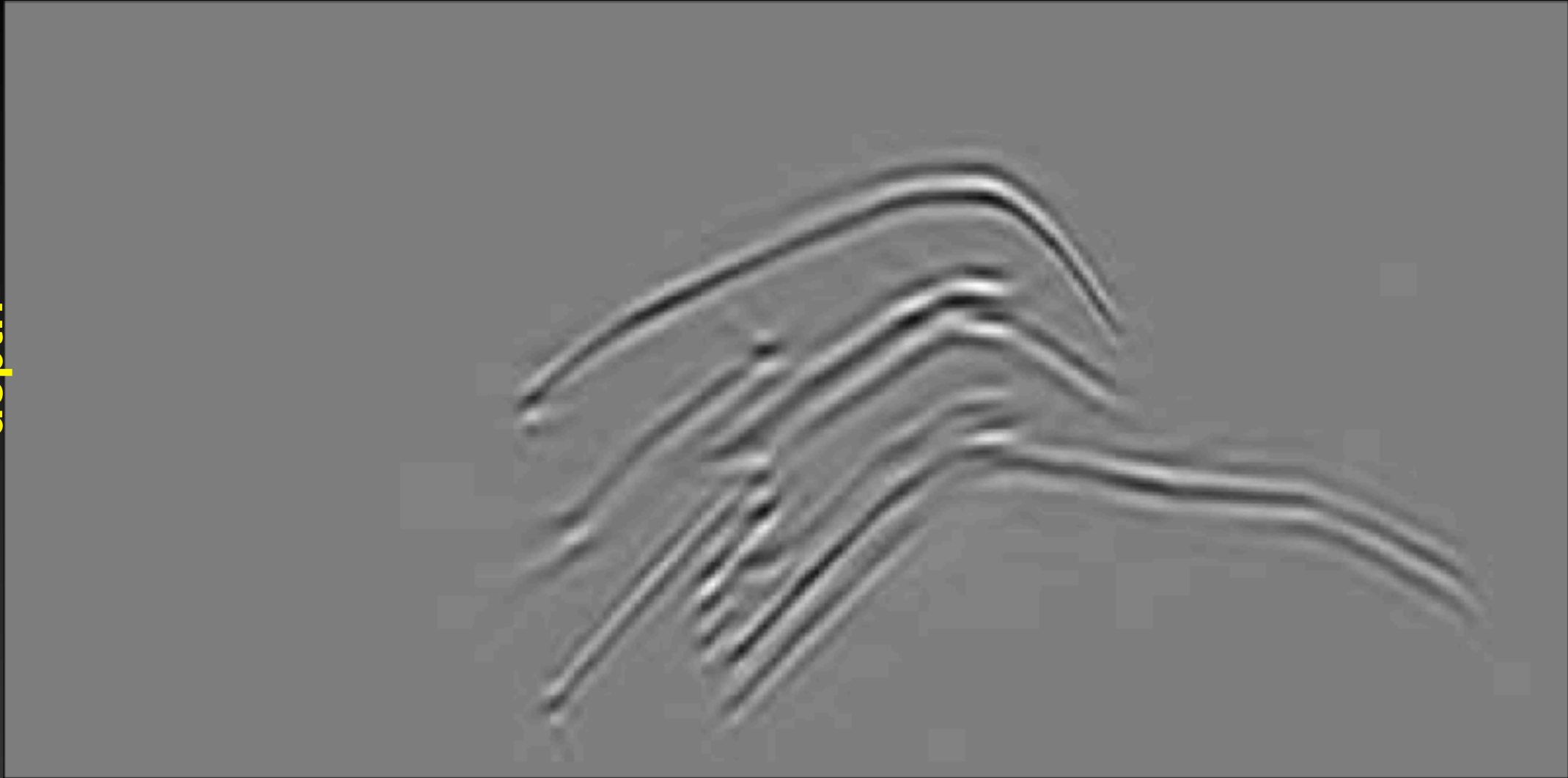


35 PERM migrated image



distance

depth





Source wavefield

$$\begin{cases} \left(\frac{\partial}{\partial z} - i\Lambda \right) \tilde{P}_d(\mathbf{x}, \mathbf{r}_m, \omega) & = \tilde{I}_d(\mathbf{x}, \mathbf{h}, \mathbf{r}_m, \omega) \\ \tilde{P}_d(x, y, z = z_{\max}, \mathbf{r}_m, \omega) & = 0 \end{cases}$$

Receiver wavefield

$$\begin{cases} \left(\frac{\partial}{\partial z} + i\Lambda \right) \tilde{P}_u(\mathbf{x}, \mathbf{r}_m, \omega) & = \tilde{I}_u(\mathbf{x}, \mathbf{h}, \mathbf{r}_m, \omega) \\ \tilde{P}_u(x, y, z = z_{\max}, \mathbf{r}_m, \omega) & = 0 \end{cases}$$

Λ = SSR operator

\tilde{P}_d = phase encoded source wavefield

\tilde{I}_d = source wavefield initial condition

\mathbf{r}_m = index of random realizations

\tilde{P}_u = phase encoded receiver wavefield

\tilde{I}_u = receiver wavefield initial condition

Image-space phase-encoded wavefields

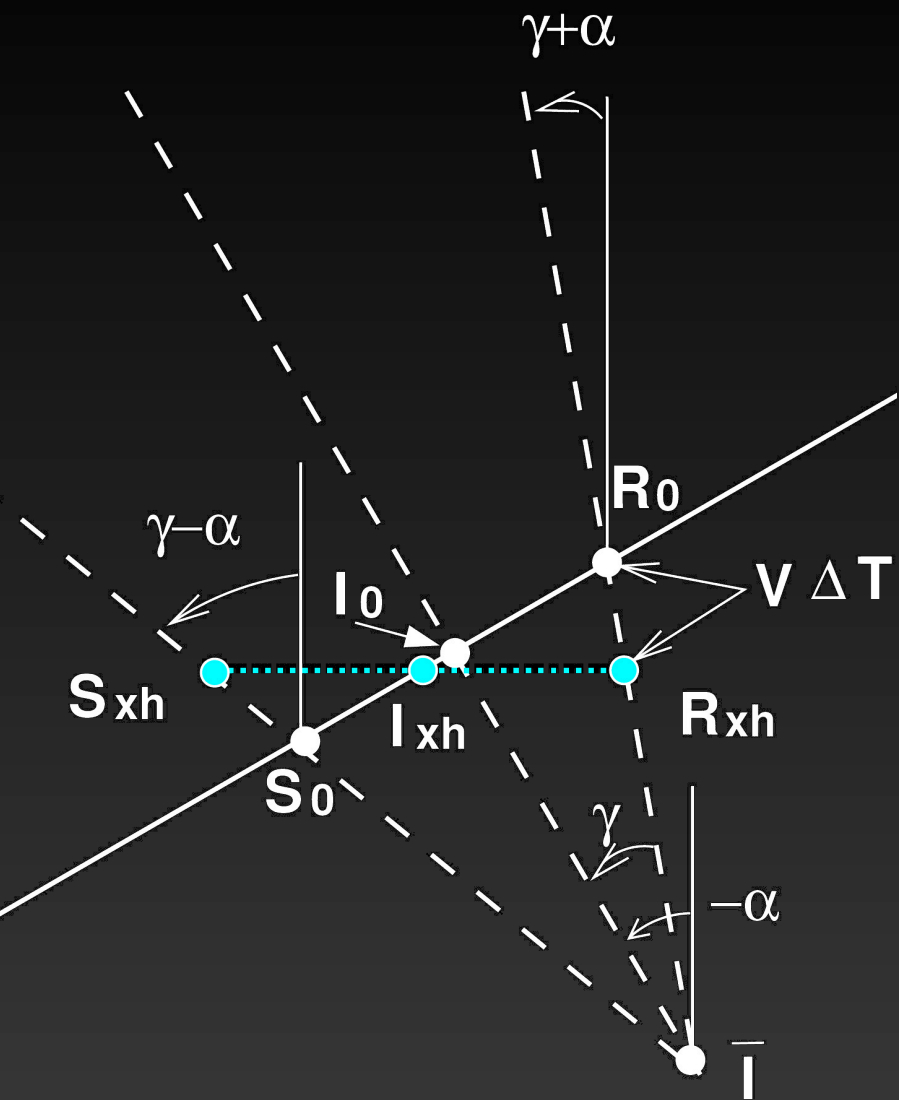
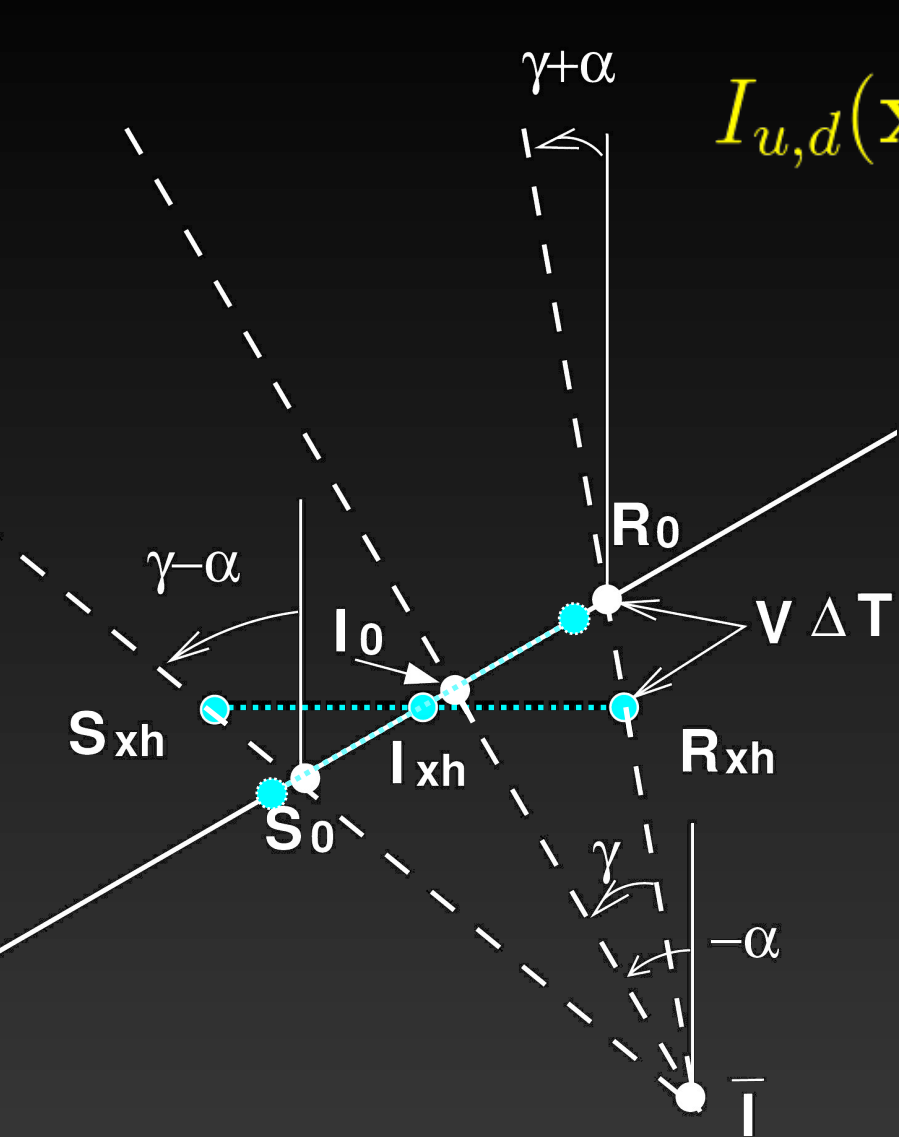


Image-space phase-encoded wavefields



$$I_{u,d}(\mathbf{x}, \mathbf{h}) = \iiint_{\alpha\gamma x'} \varrho I(\mathbf{x}, \mathbf{h}; x') dx' d\gamma d\alpha \Big|_{\zeta}$$

$$\zeta(\alpha, \gamma, \mathbf{h}, x') = z - htg(\gamma) - x'tg(\alpha) \pm htg(\gamma \pm \alpha)$$

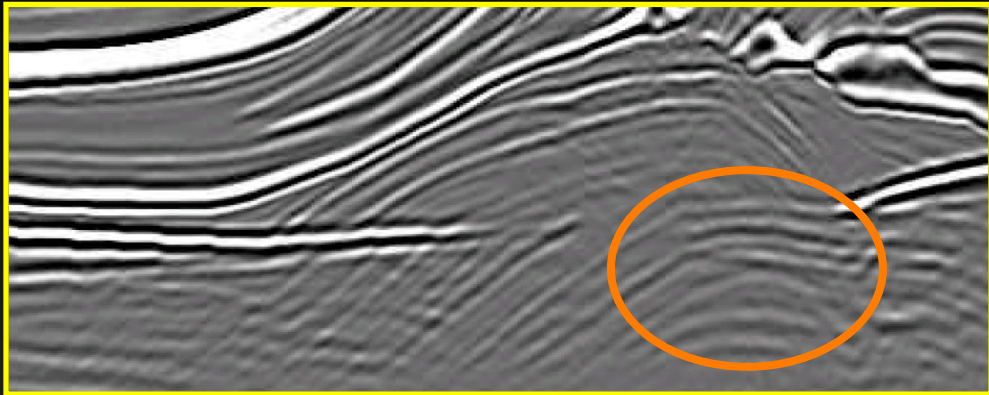
Motivation



Initial

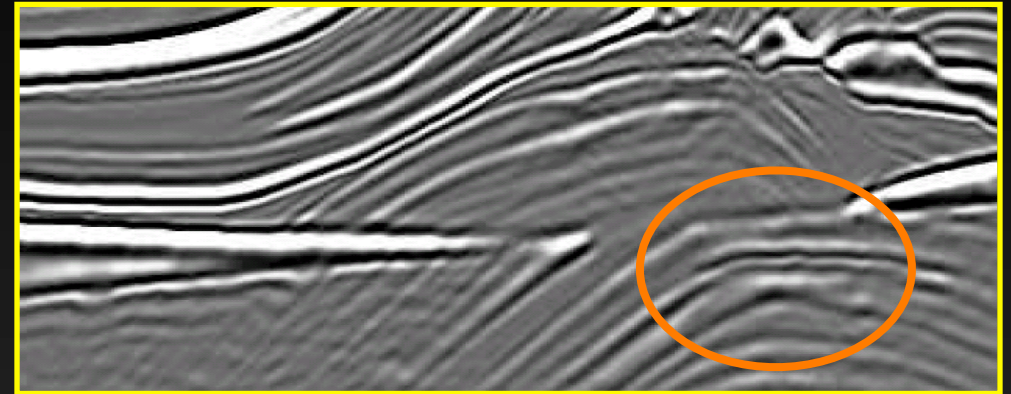
x

z



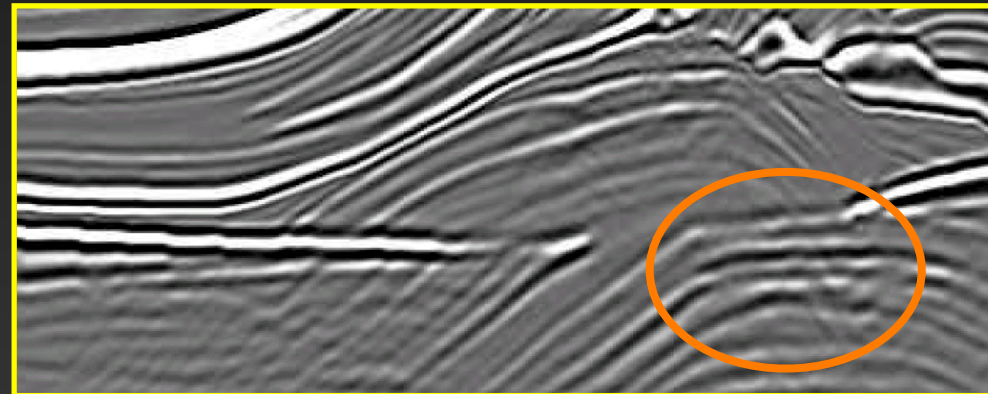
True

x



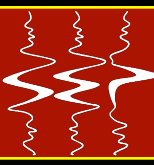
Optimized

z

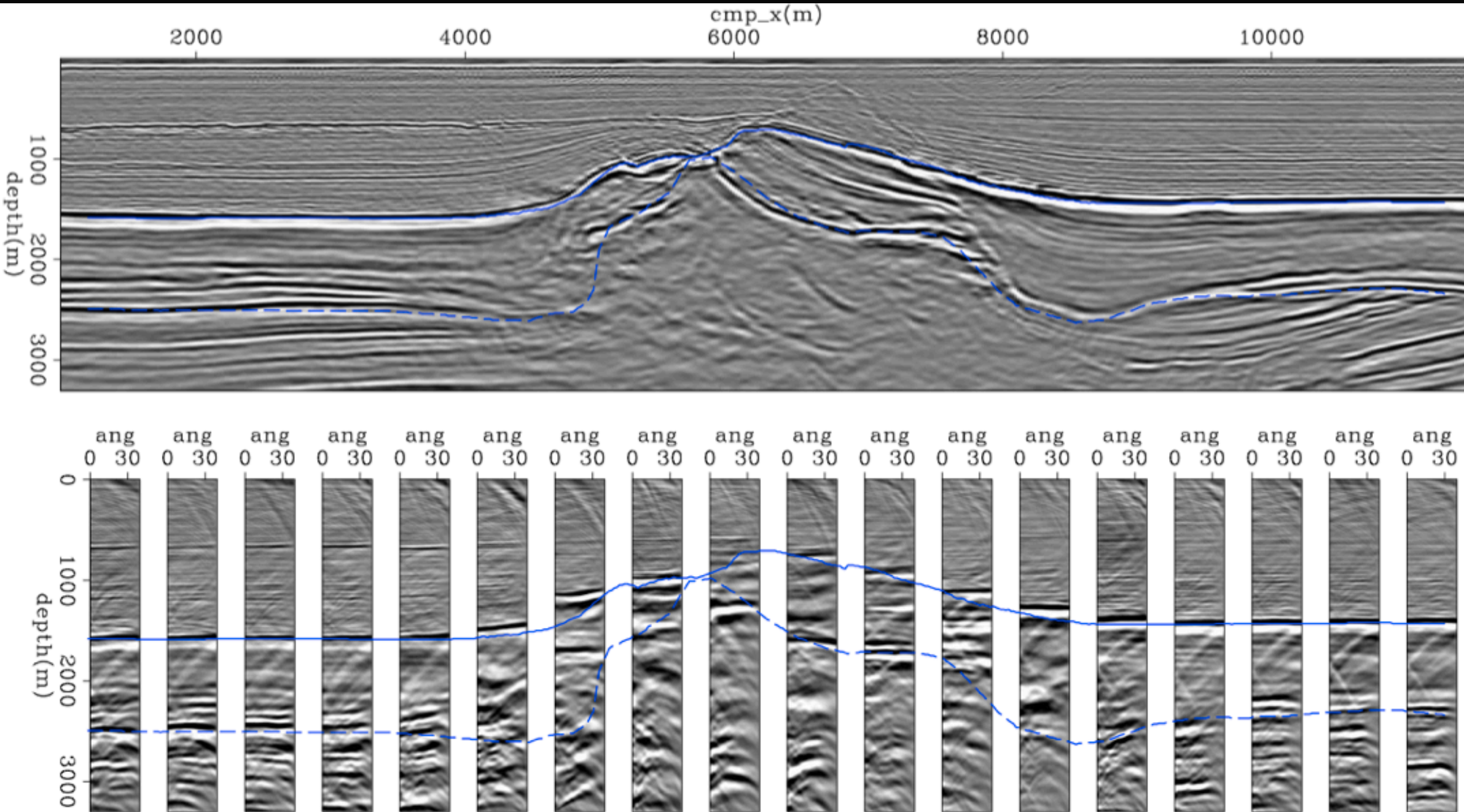


20x faster

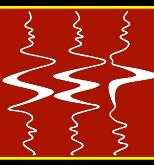
Comparisons: iline = 3200 m



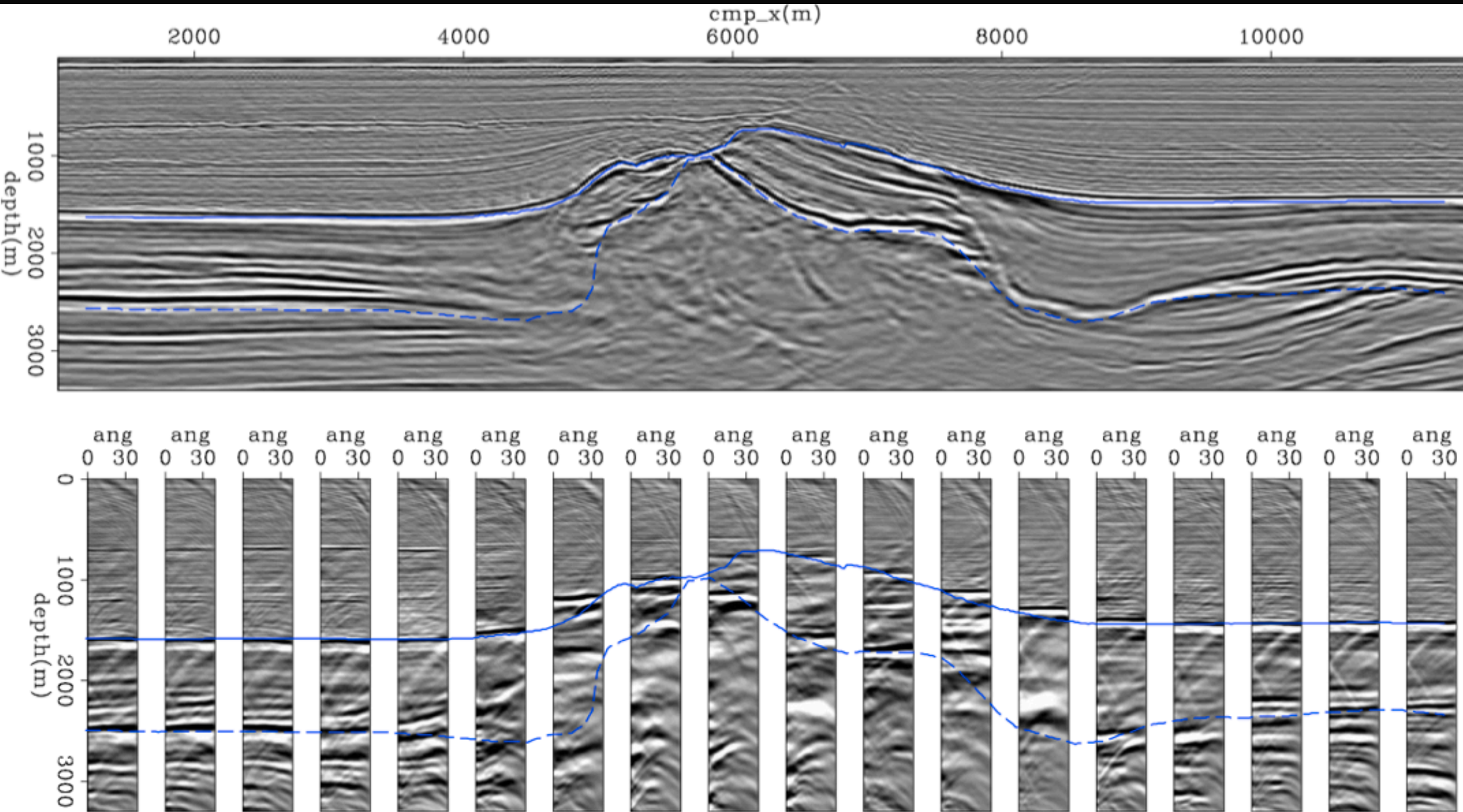
IFP



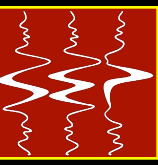
Comparisons: iline = 3200 m



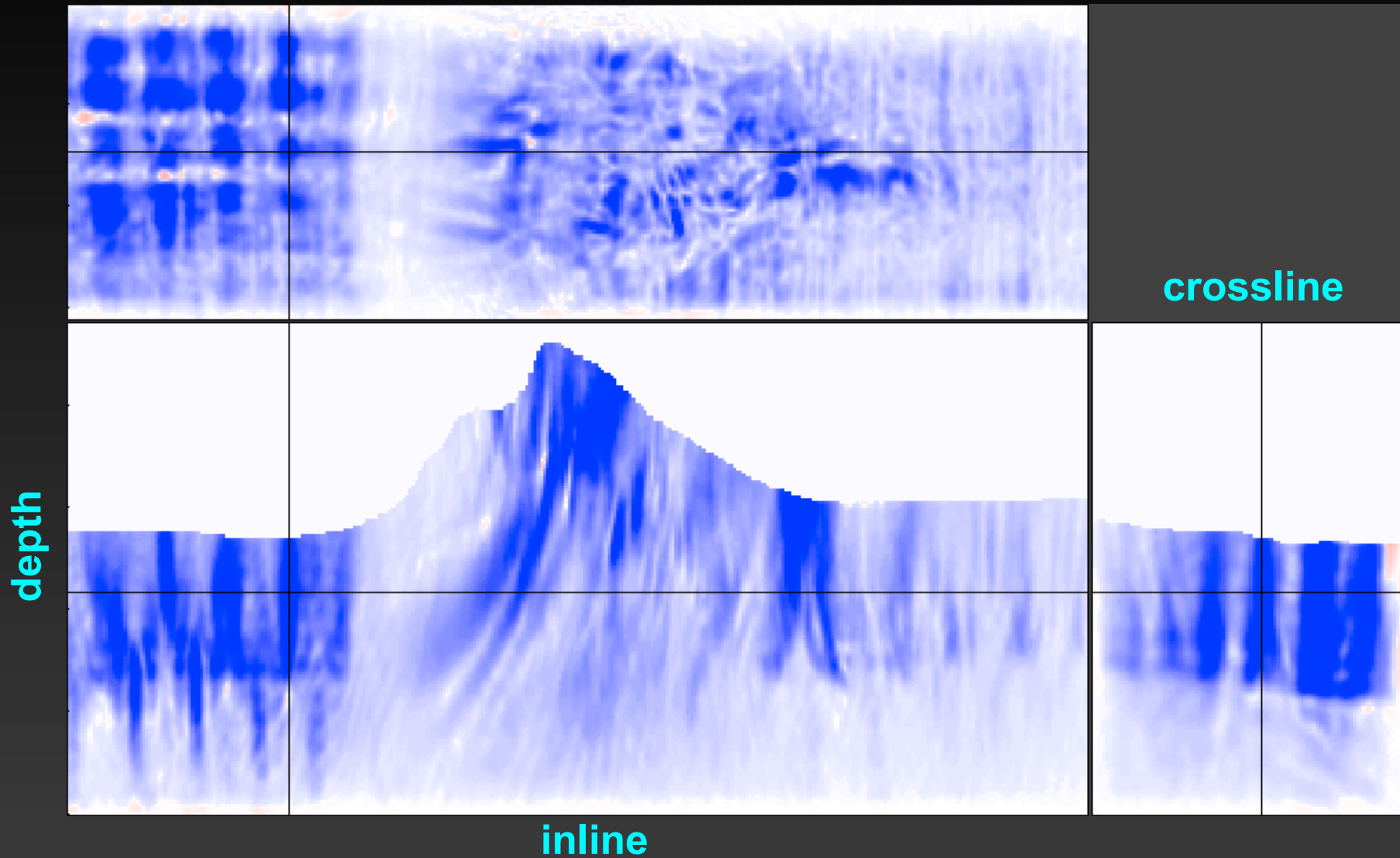
Chalk optimized velocity



Potential for grid-tomography



Gradient with 1 pair of ISPEW

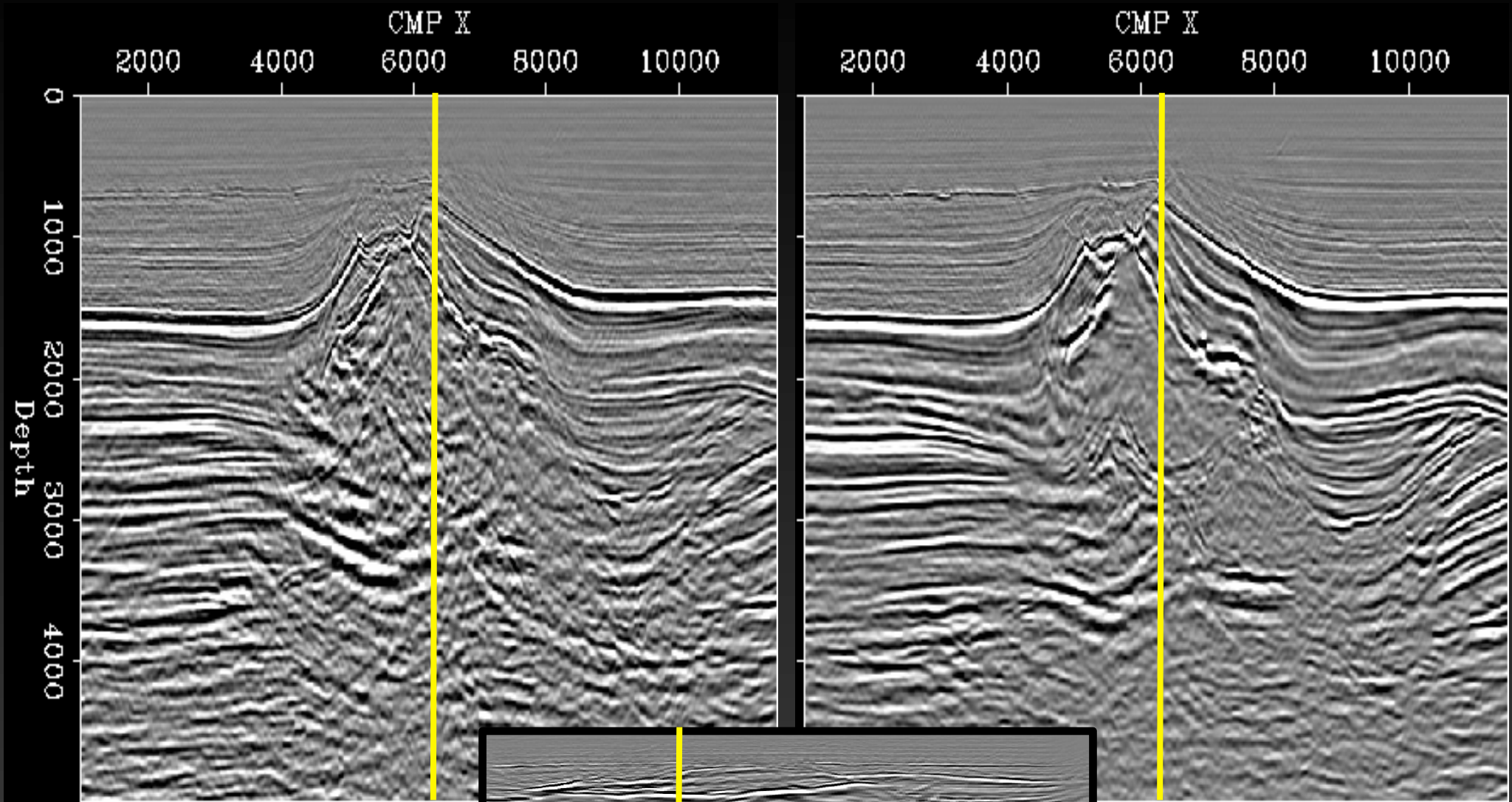


Comparisons: inline = 2900 m



Initial

After salt body

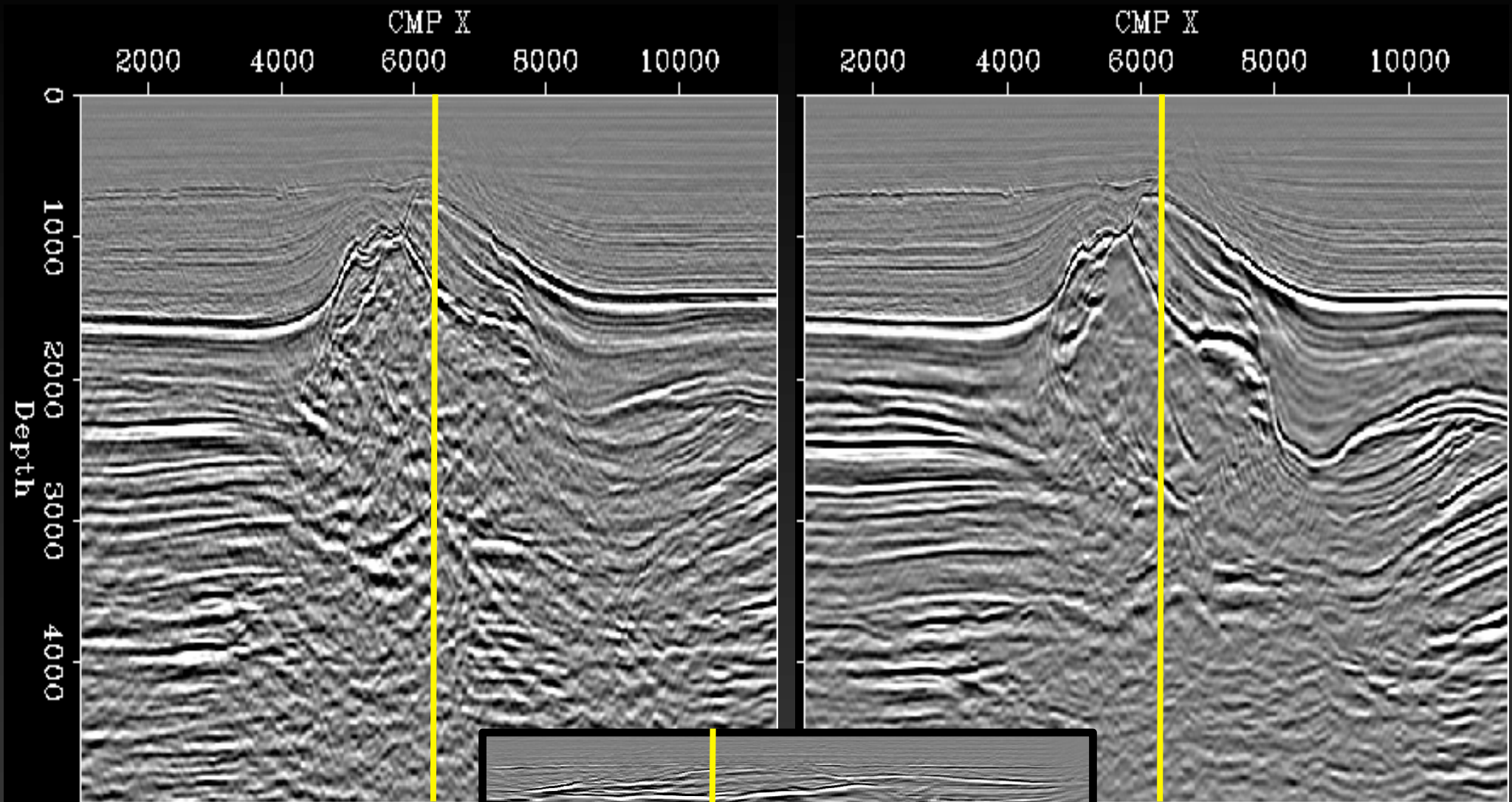


Comparisons: inline = 3200 m



Initial

After salt body

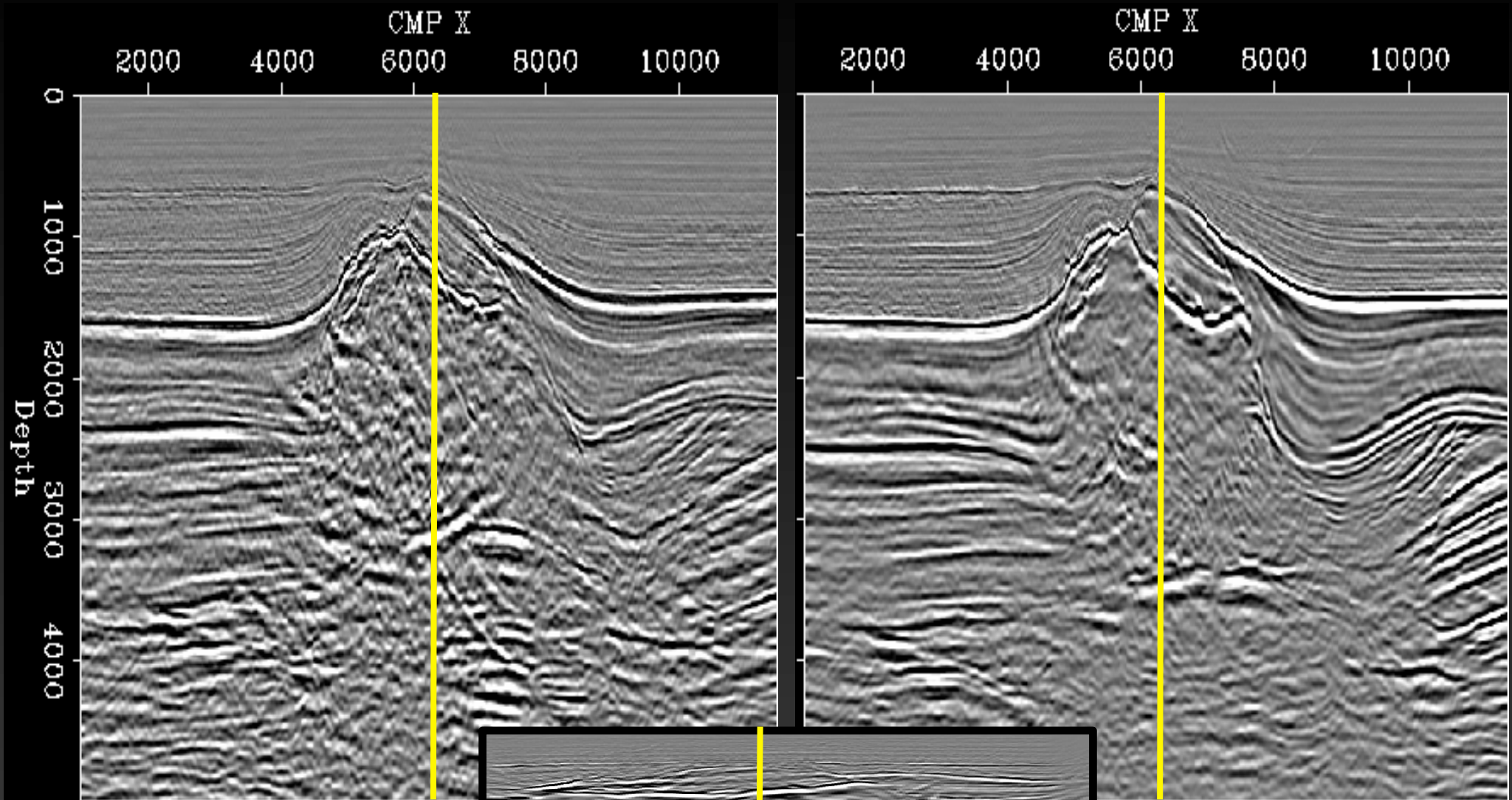


Comparisons: inline = 3500 m



Initial

After salt body

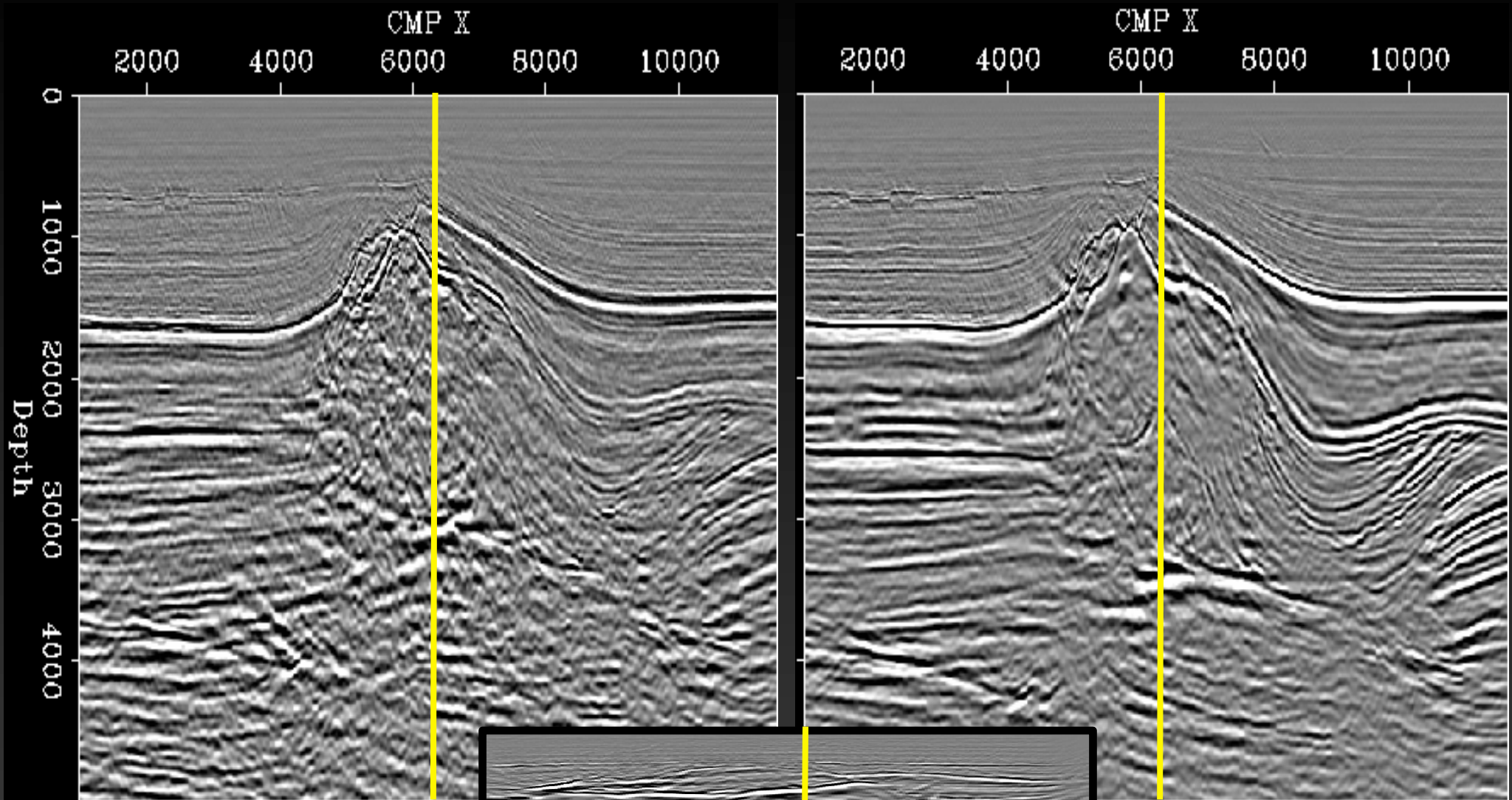


Comparisons: inline = 4000 m



Initial

After salt body

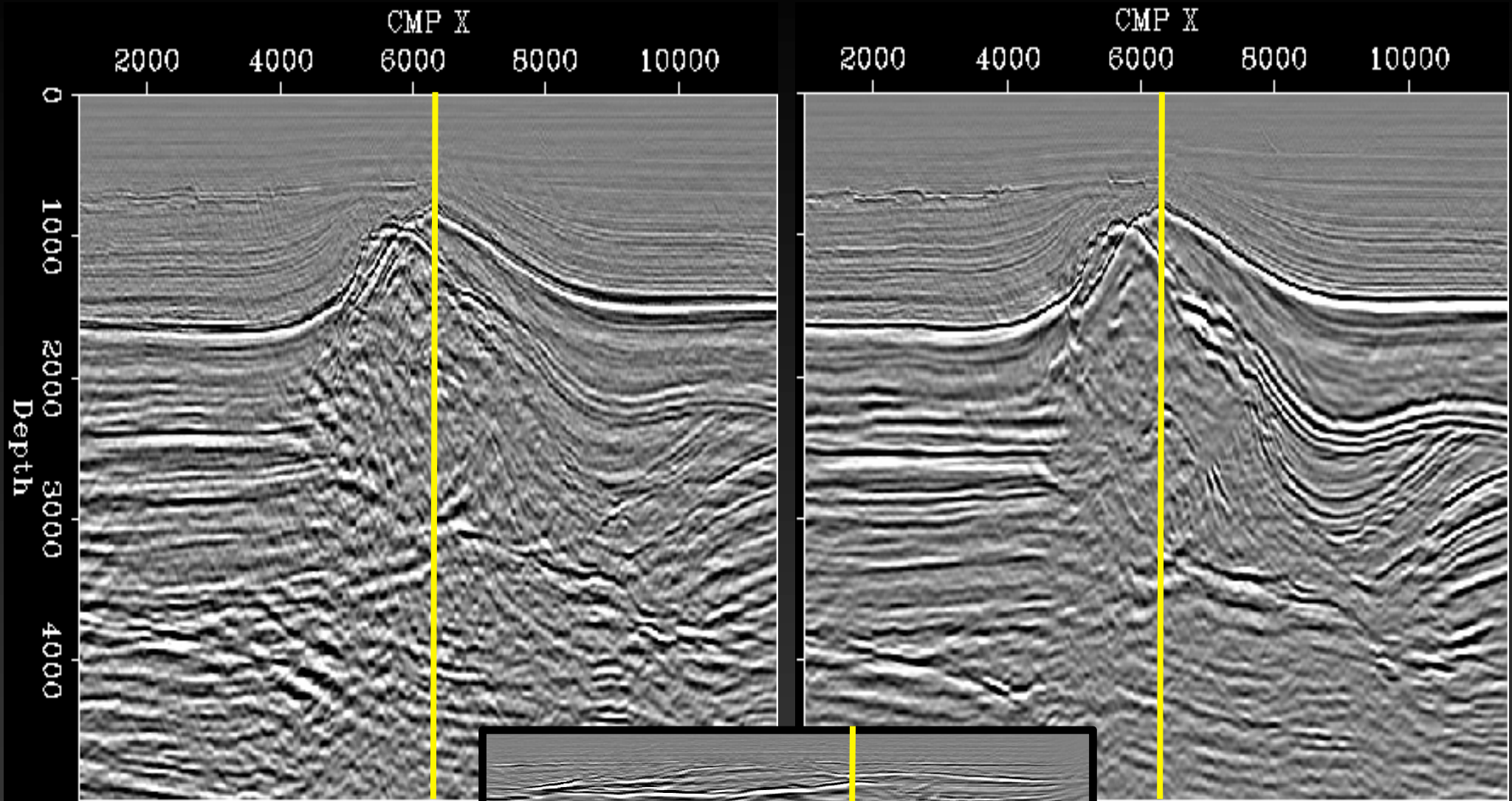


Comparisons: inline = 4200 m



Initial

After salt body

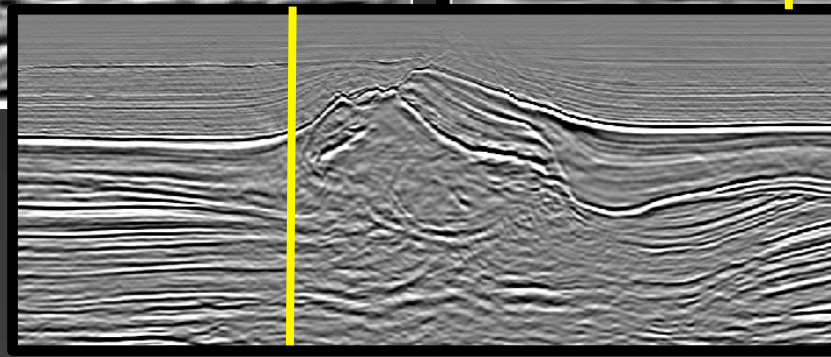
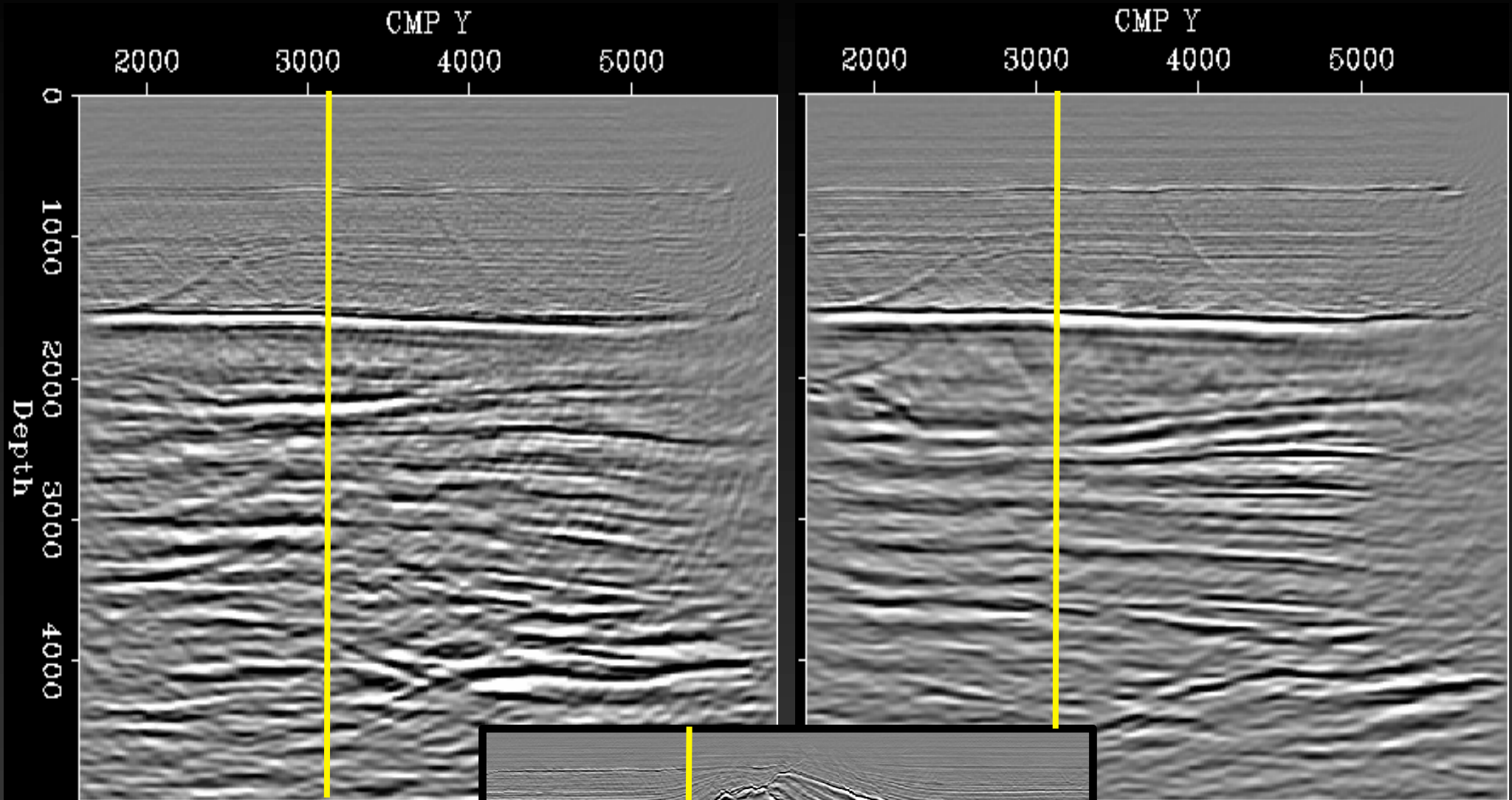


Comparisons: xline = 4400 m



Initial

After salt body

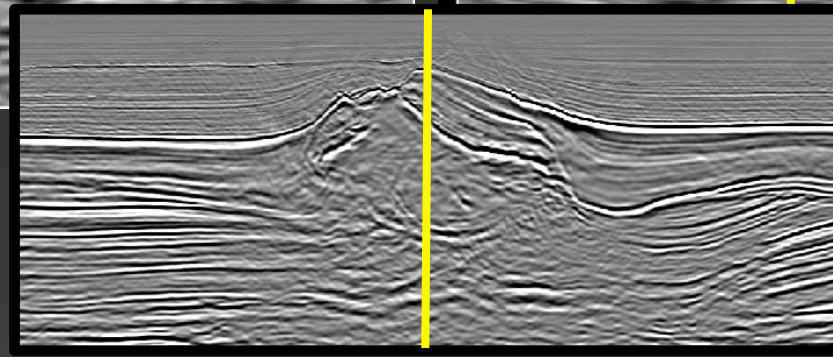
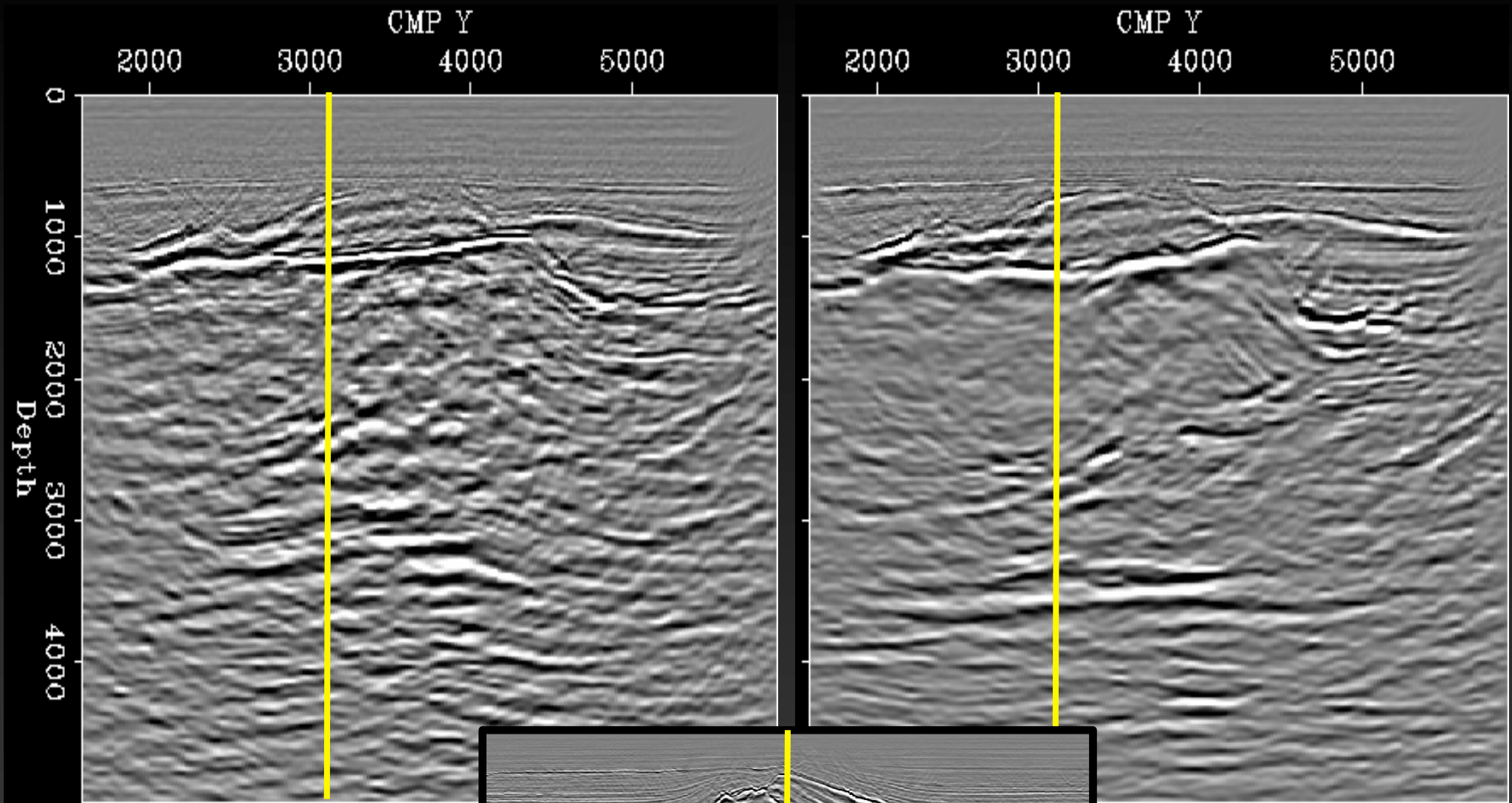


Comparisons: xline = 6100 m



Initial

After salt body

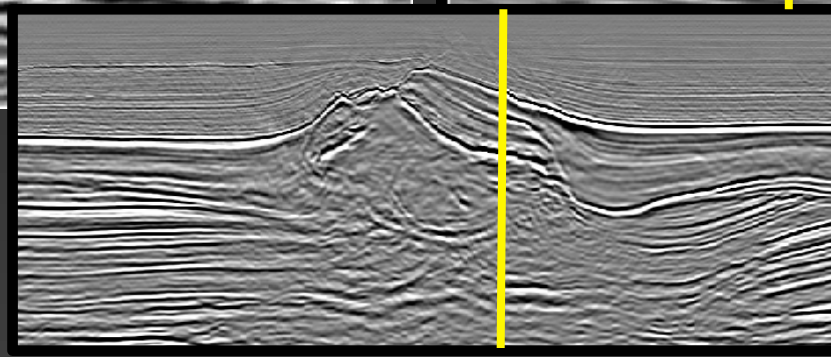
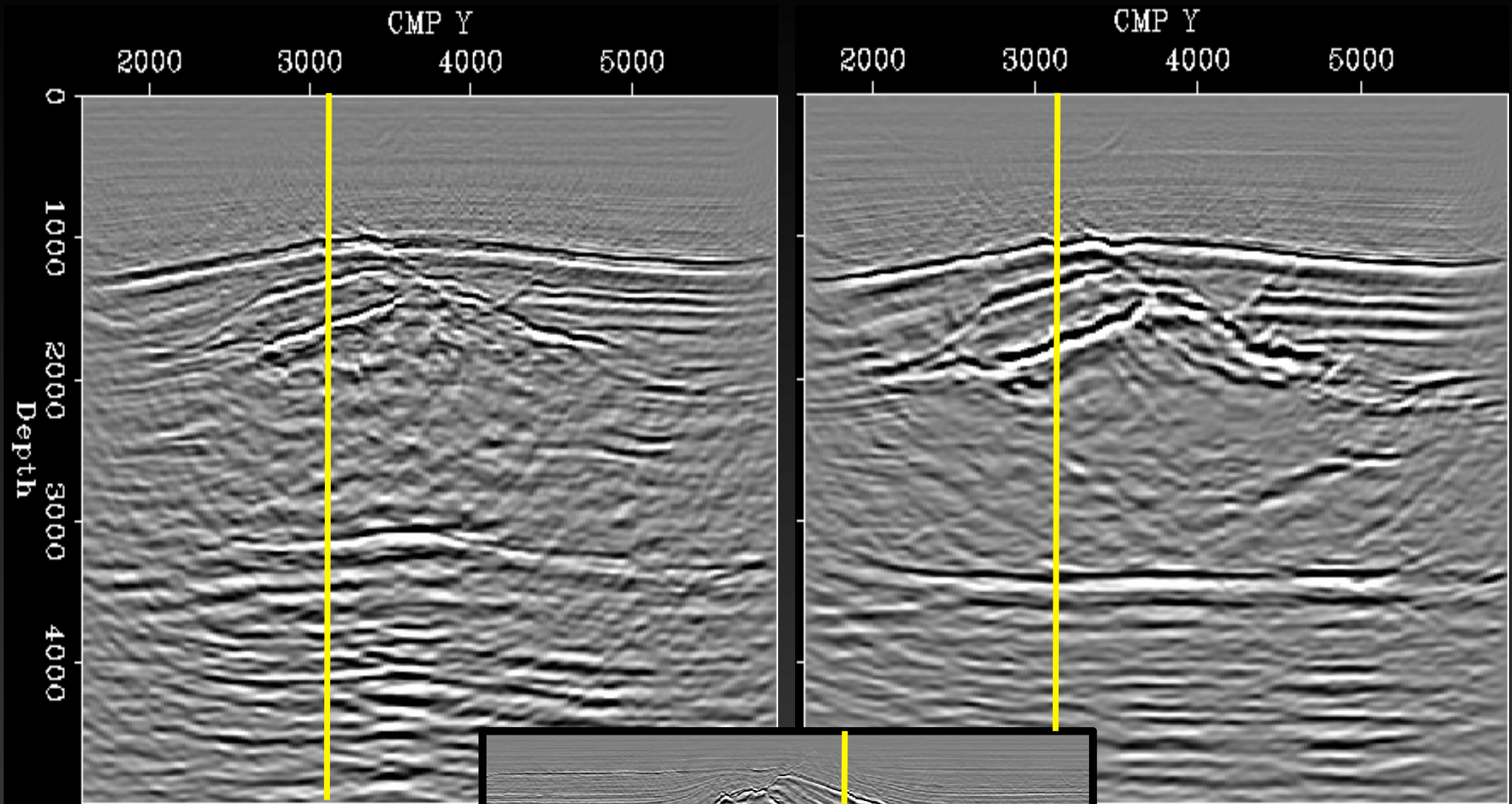


Comparisons: xline = 7300 m



Initial

After salt body

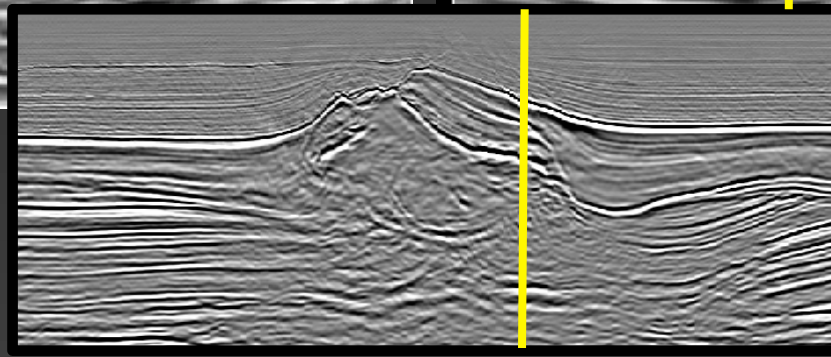
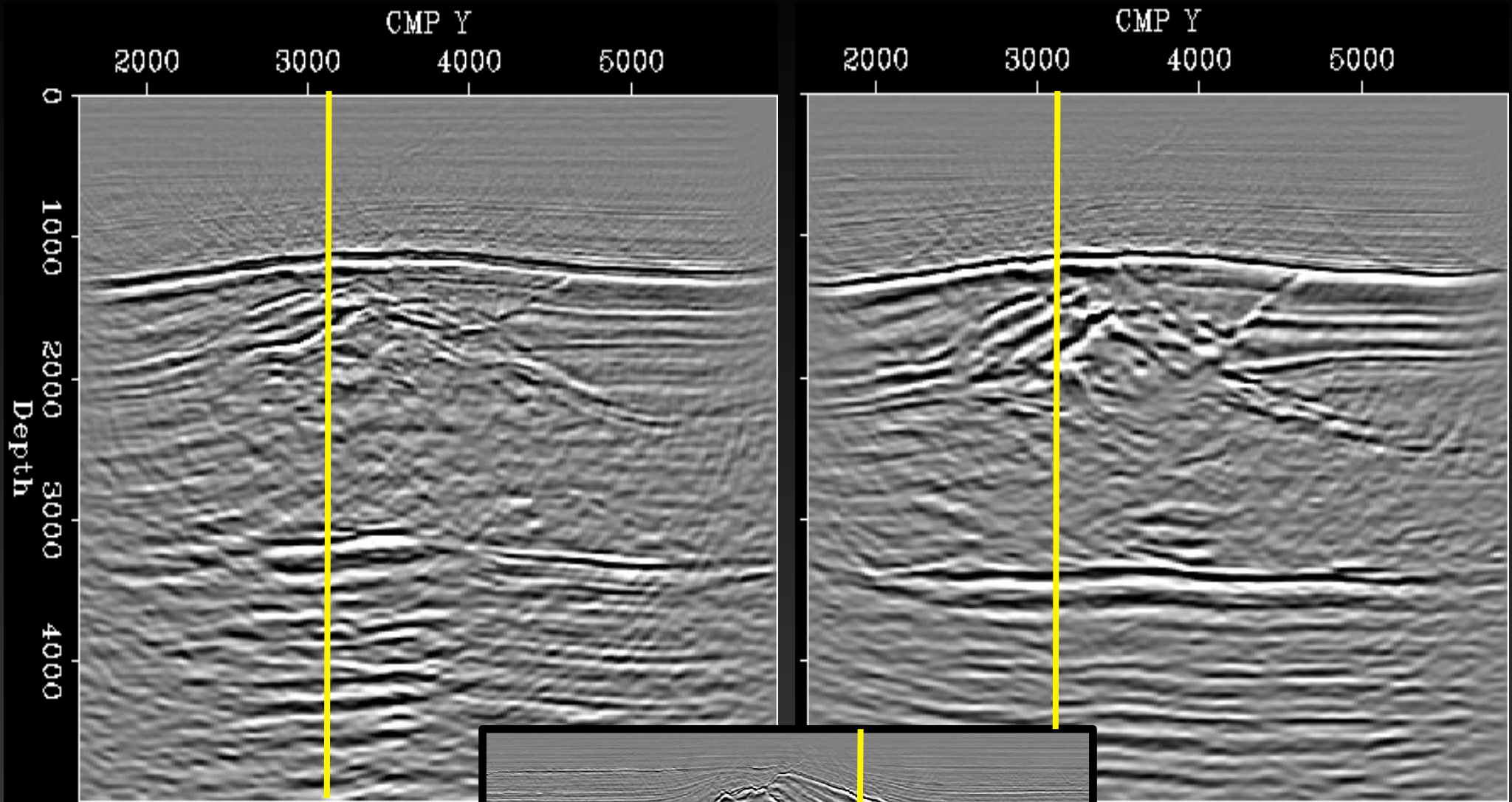


Comparisons: xline = 7600 m



Initial

After salt body

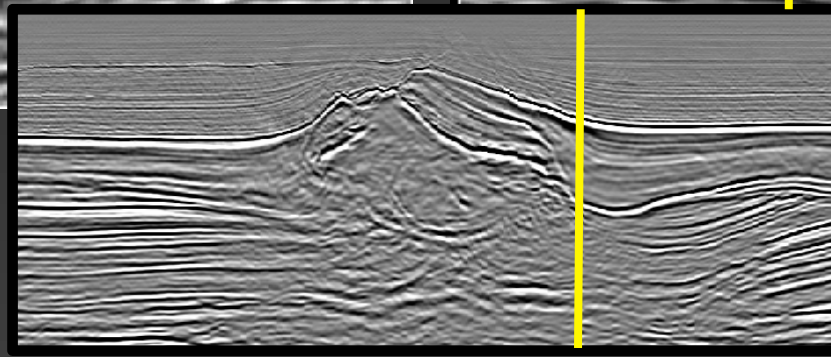
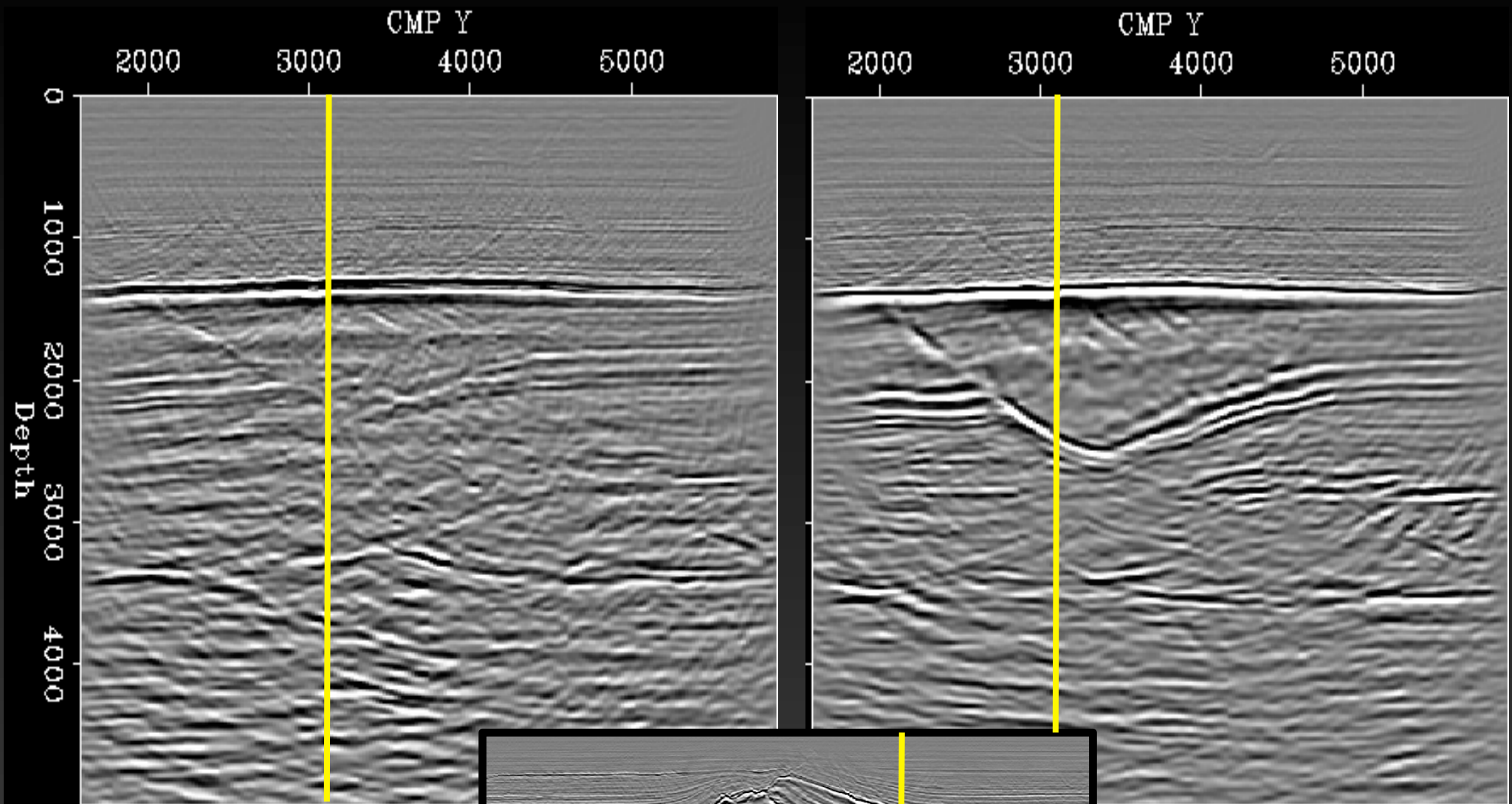


Comparisons: xline = 8200 m



Initial

After salt body

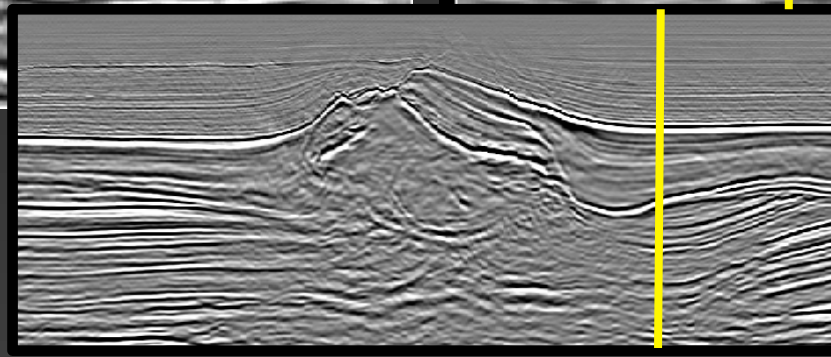
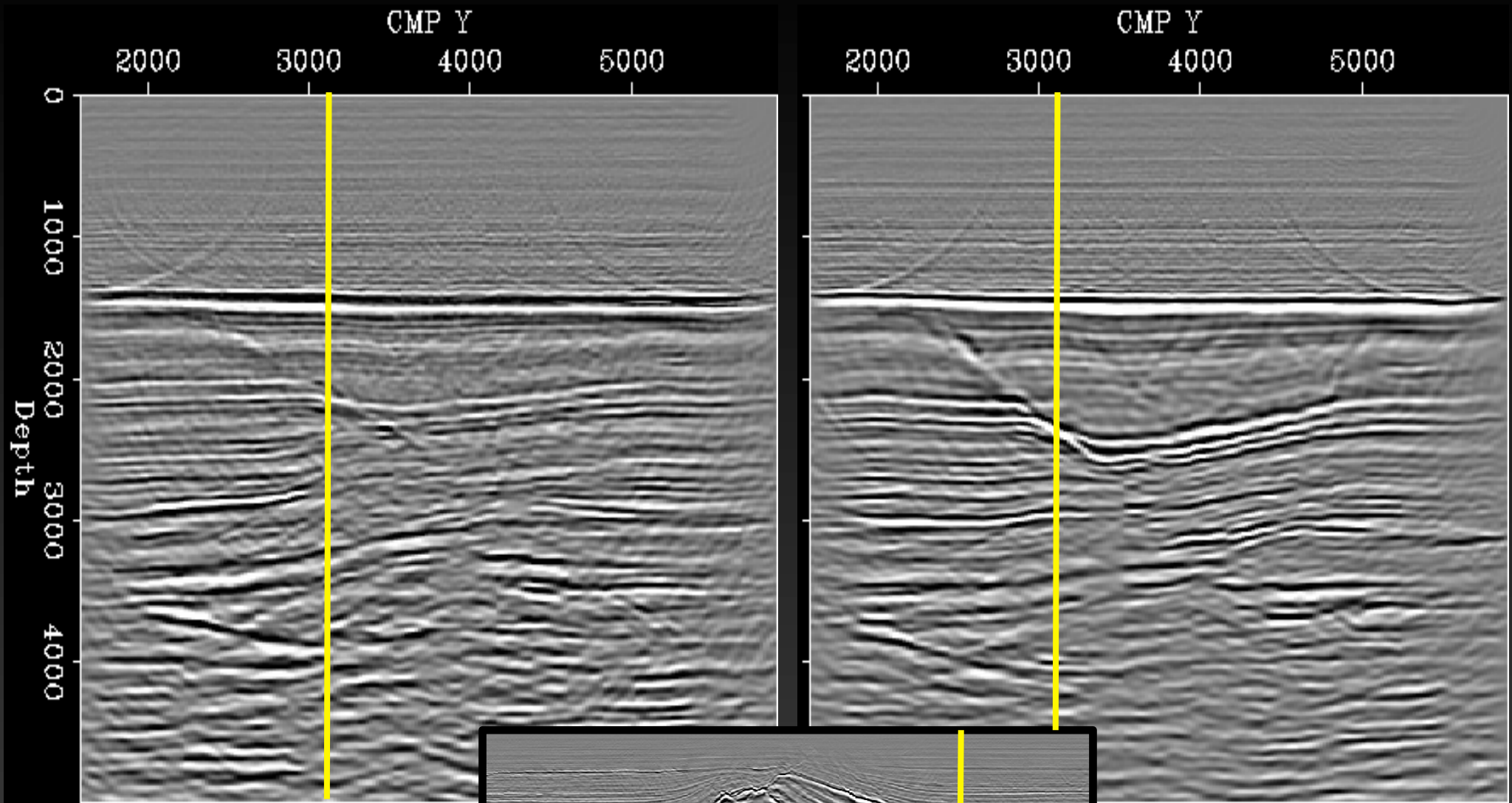


Comparisons: xline = 9300 m



Initial

After salt body

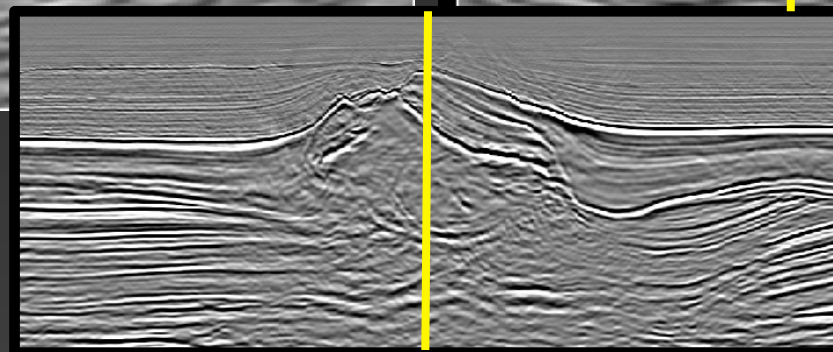
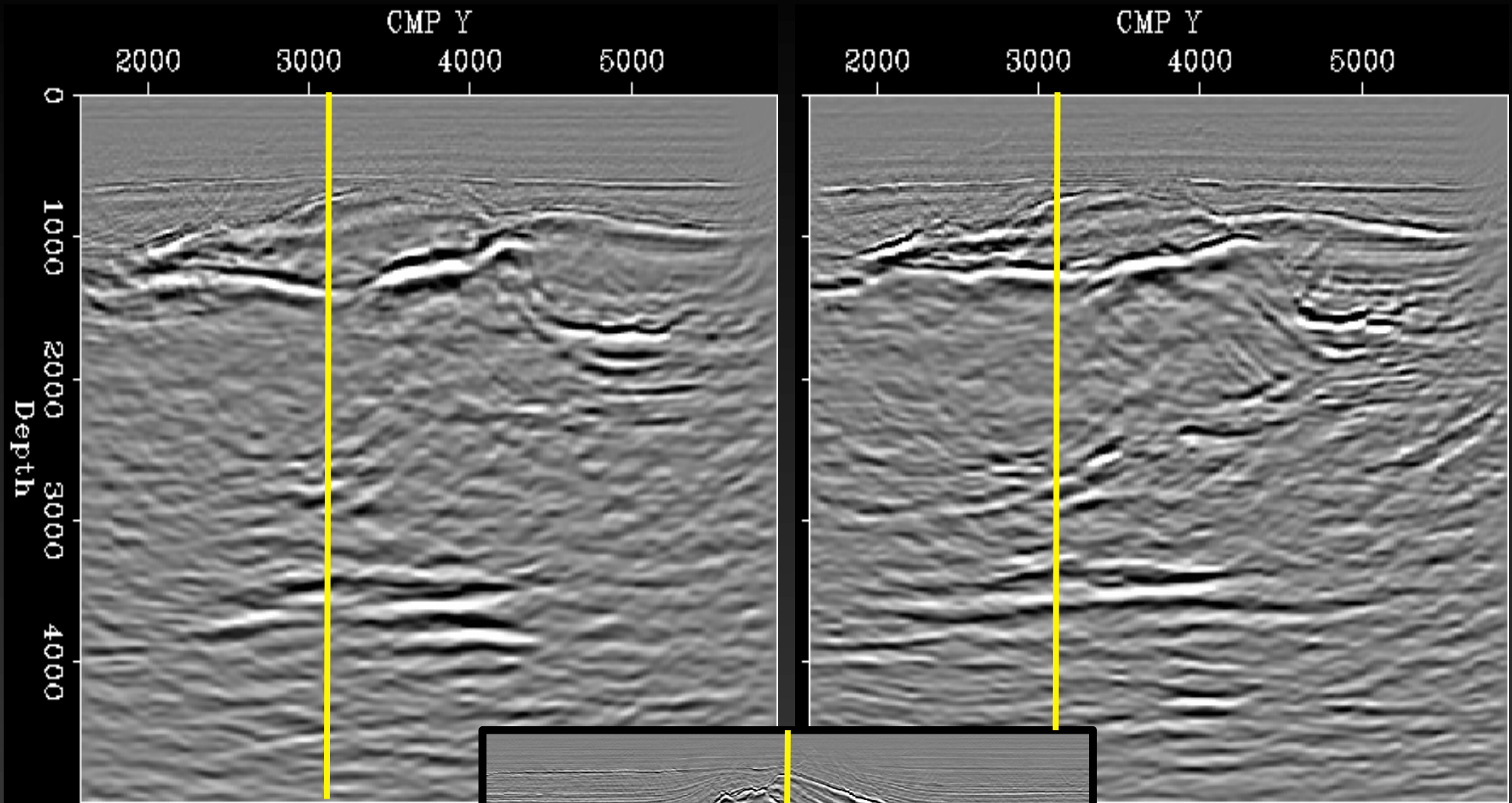


Comparisons: xline = 6100 m

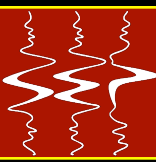


Original

After salt body

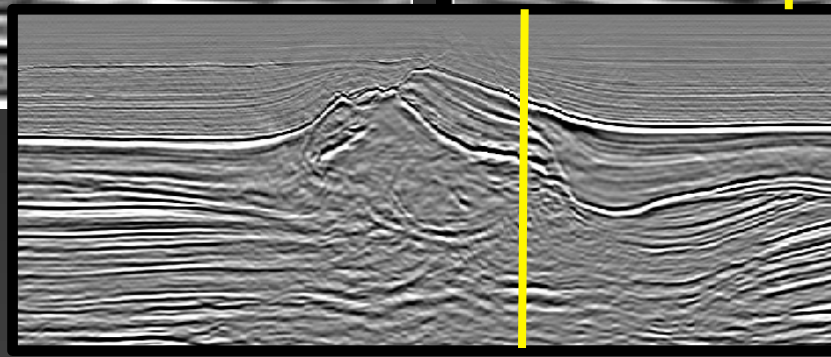
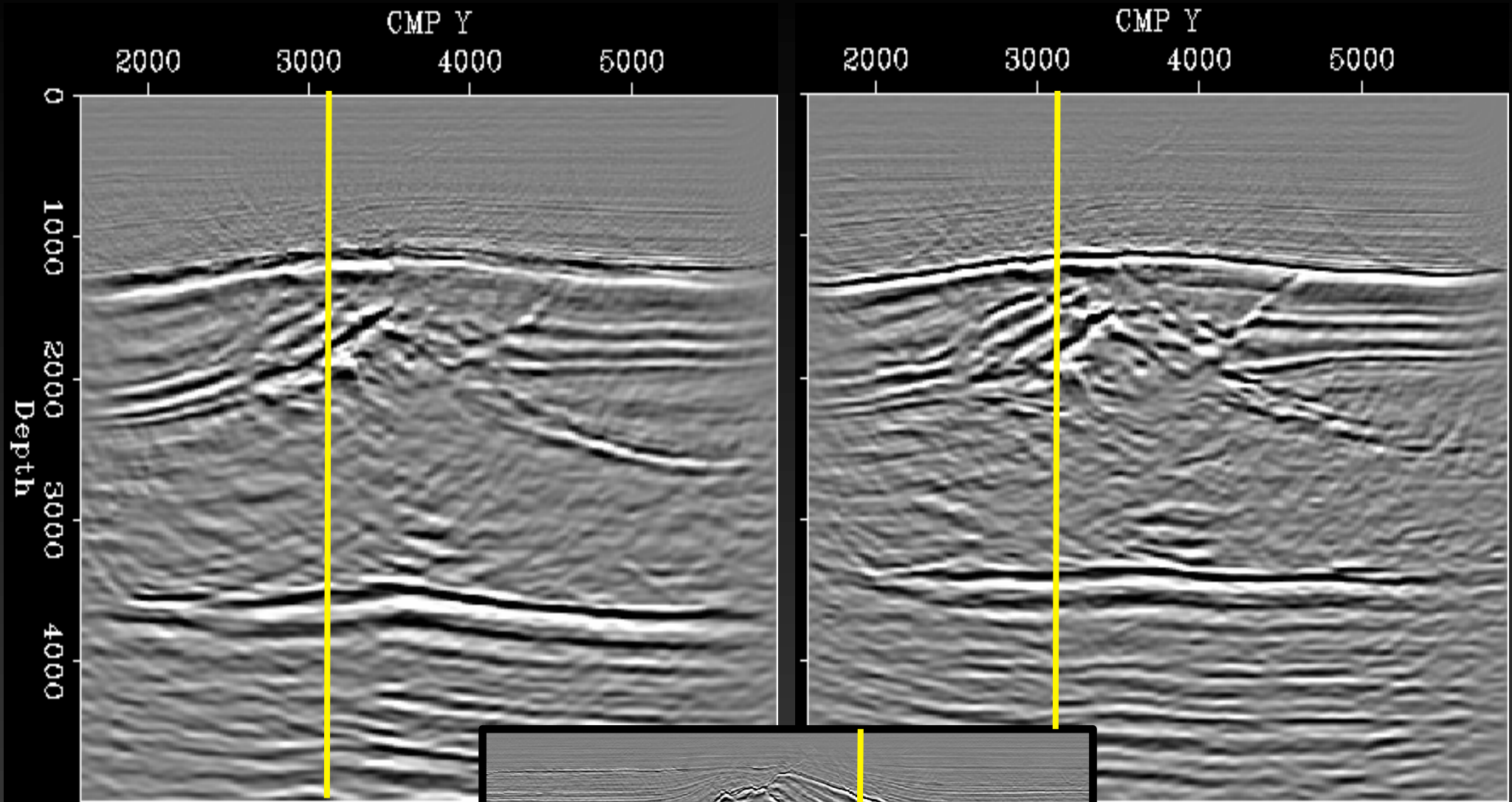


Comparisons: xline = 7600 m



Original

After salt body

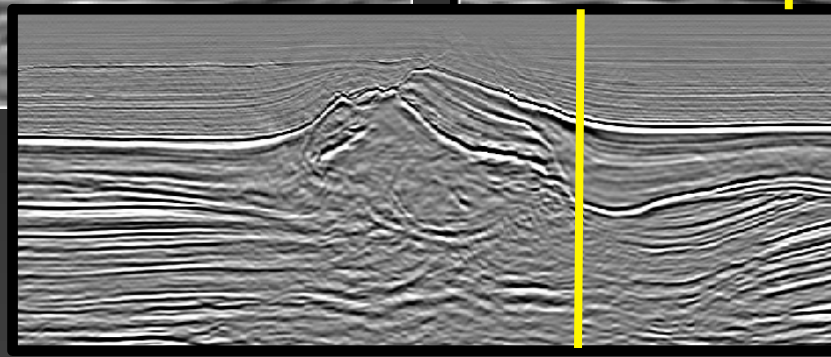
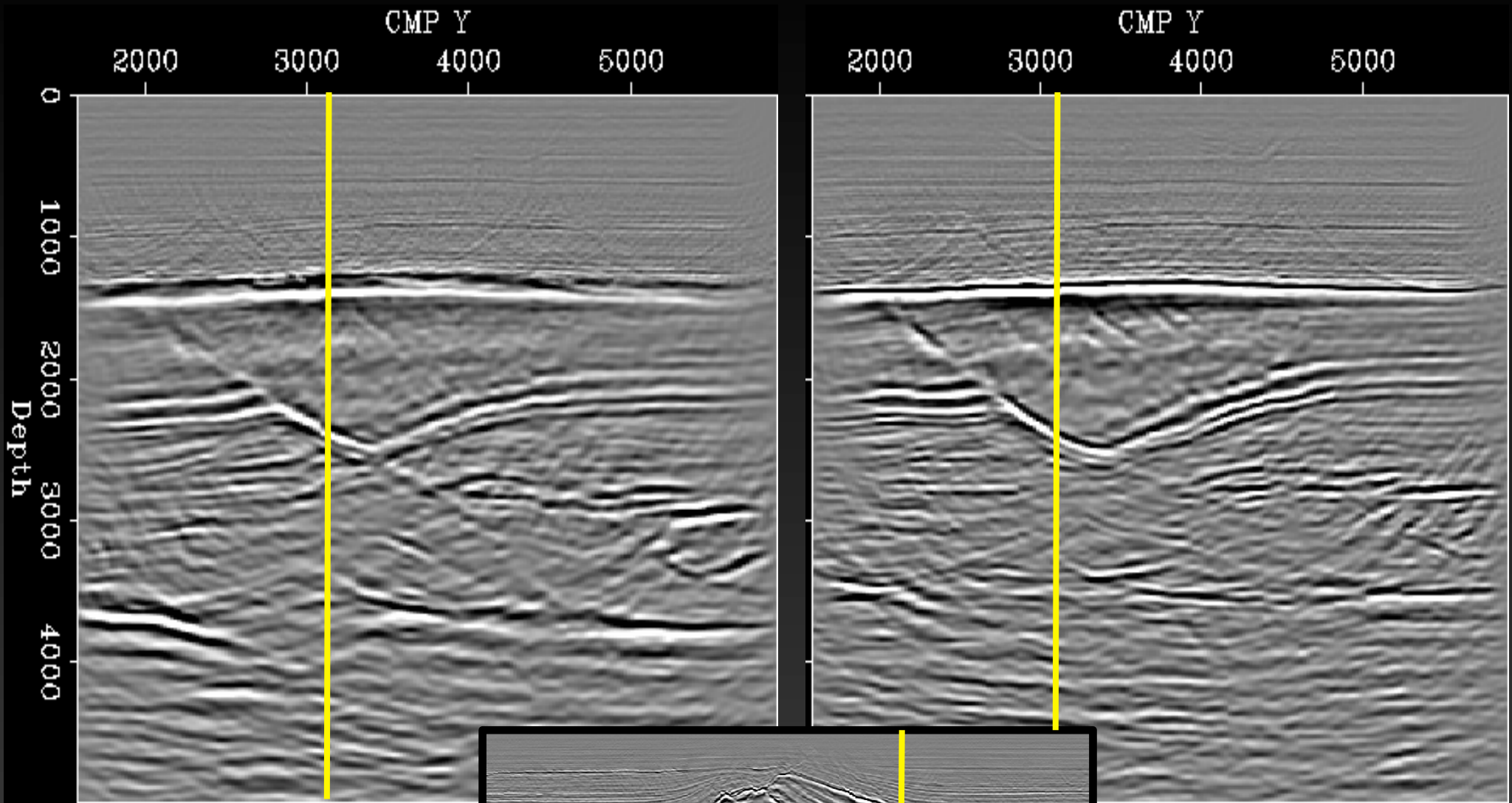


Comparisons: xline = 8200 m



Original

After salt body



Comparisons: xline = 9300 m



Original

After salt body

