# Fast velocity model evaluation with synthesized wavefields


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**SEP-147: p. 39**

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Stanford Exploration Project

# Motivation

- **Model-building is rarely straightforward**
  - **Many plausible scenarios, especially for salt interpretation**
- **Interpretation tools allow for fast generation of many possible models**
- **A way to quickly test these models without performing full migrations would be extremely useful**

# Goals

- Use velocity information from in initial image
- Synthesize new datasets with arbitrary acquisition parameters
- Quickly (quantitatively) evaluate relative accuracy of multiple possible models

# Outline

- **Method**
  - **Areal source generation [Guerra, SEP-141]**
  - **Born modeling/migration [Tang, SEP-144]**
- **Obtaining models**
  - **Image segmentation with interpreter discretion**
- **Synthetic examples**
  - **2D Sigsbee models**
- **Future work**
  - **3D model evaluation**

# Method overview

1) Start with subsurface offset gather(s)
2) After mapping procedure, upward continue to surface/datum to create areal source function
3) Use the source function and the initial image to generate a Born-modeled dataset
4) Resulting receiver wavefield can then be used to test multiple velocity models more efficiently

# Alternatives

- **Beam migration (Hill, 1990) widely used for fast, targeted imaging**
- **Also shown to be effective for updating images after changing salt interpretation (Wang et al., 2008)**
- **BUT:**
  - **Limited by assumptions of beam imaging**
  - **No prestack velocity information**

# Source generation

- Use as much information as possible from an initial image
- "Prestack exploding reflector" (Guerra, 2011)
- Using prestack information (subsurface offsets) allows us to identify and fix inaccuracies in the initial model

# Generalized Source

$$S(\mathbf{x}_s,\omega) = \sum_{\mathbf{x}'}\sum_{\mathbf{h}} G^*(\mathbf{x}'-\mathbf{h},\mathbf{x}_s,\omega)\,I(\mathbf{x}',\mathbf{h})$$

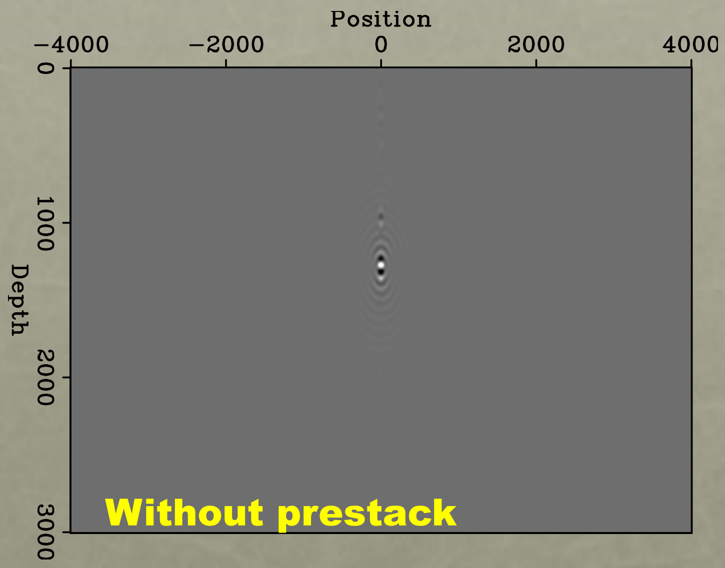
*Arbitrary (targeted) coordinates*

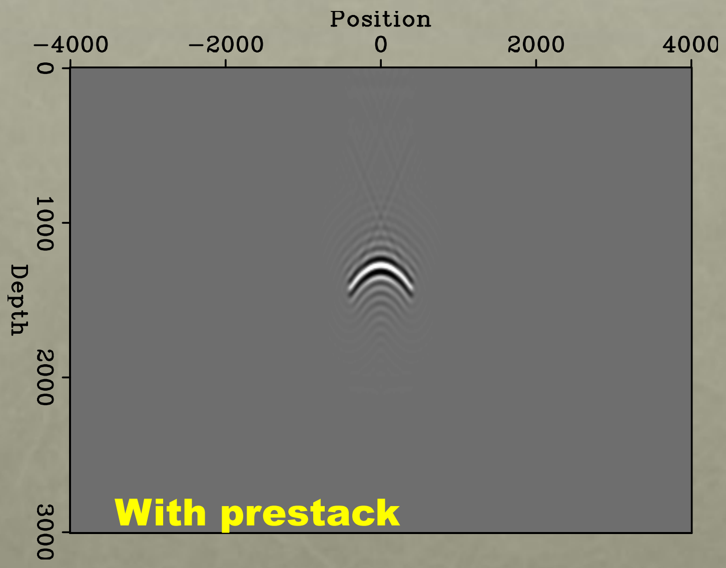
*Subsurface offset*

*Isolated locations along target reflector*

***Initial image:***

***Velocity too slow***



# Born wavefields

- **Tang (2011)**
- **Starting from an initial reflectivity model (image), synthesize a new, Born-modeled receiver wavefield**
- **Arbitrary acquisition geometry**
  - **Target-oriented imaging**
  - **Re-datuming**

# Born modeling

Reflectivity model (initial image)

$$d'(\mathbf{x}'_r,\mathbf{x}_s,\omega) = \sum_{\mathbf{x}'}\sum_{\mathbf{h}} S(\mathbf{x}_s)G(\mathbf{x}_s,\mathbf{x}'-\mathbf{h},\omega)G(\mathbf{x}'+\mathbf{h},\mathbf{x}'_r,\omega)I(\mathbf{x}',\mathbf{h})$$

*If computed using initial velocity model, the "recorded" data is kinematically invariant of that model*

***CROSSTALK artifacts avoided by using isolated locations from initial image***

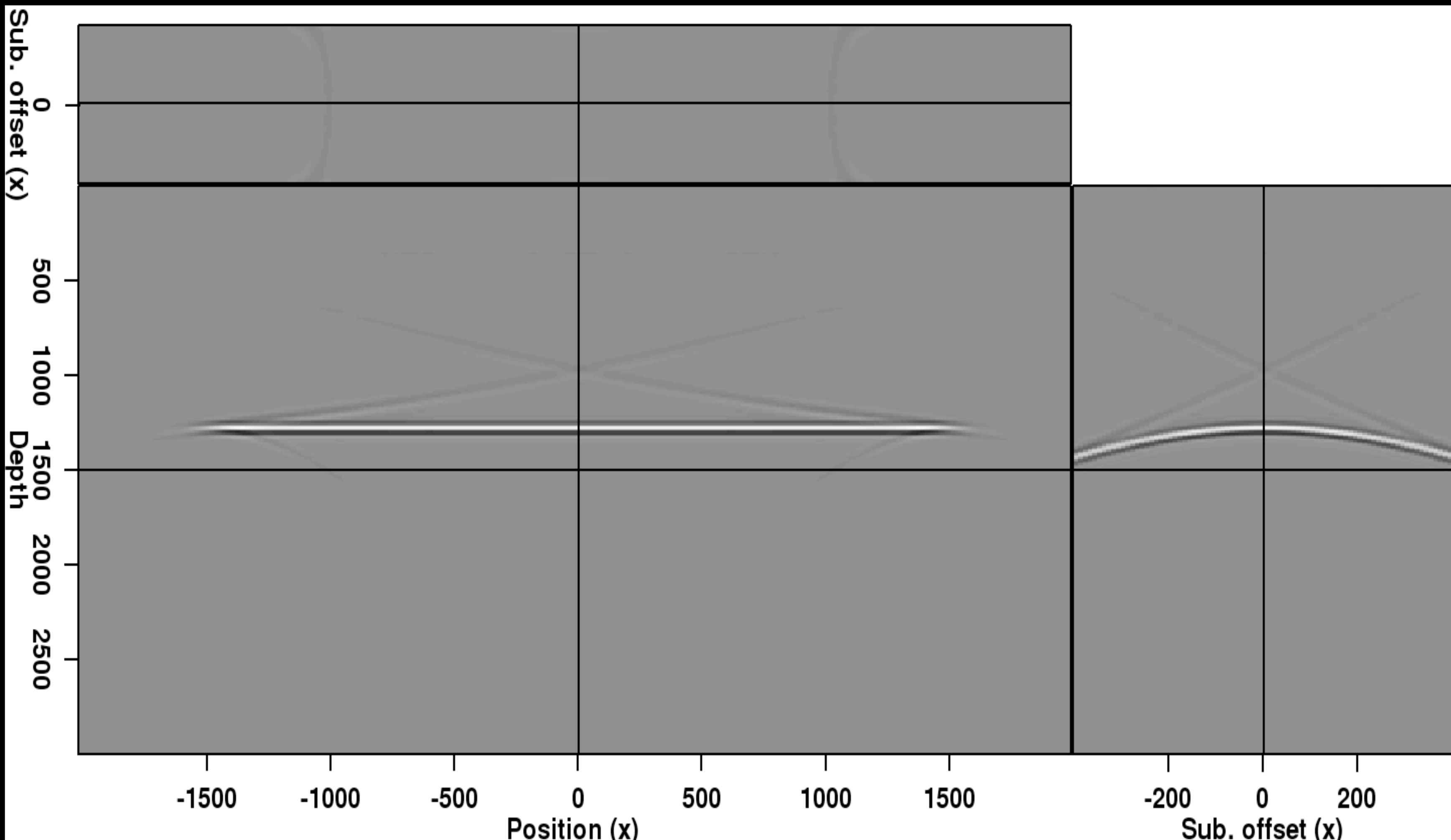
# Migration

$$m'(\mathbf{x}',\mathbf{h}) = \sum_{\omega} G^*(\mathbf{x}'-\mathbf{h},\omega) \sum_{\mathbf{x}'_r} G^*(\mathbf{x}'+\mathbf{h},\mathbf{x}'_r,\omega) d'(\mathbf{x}'_r,\omega)$$

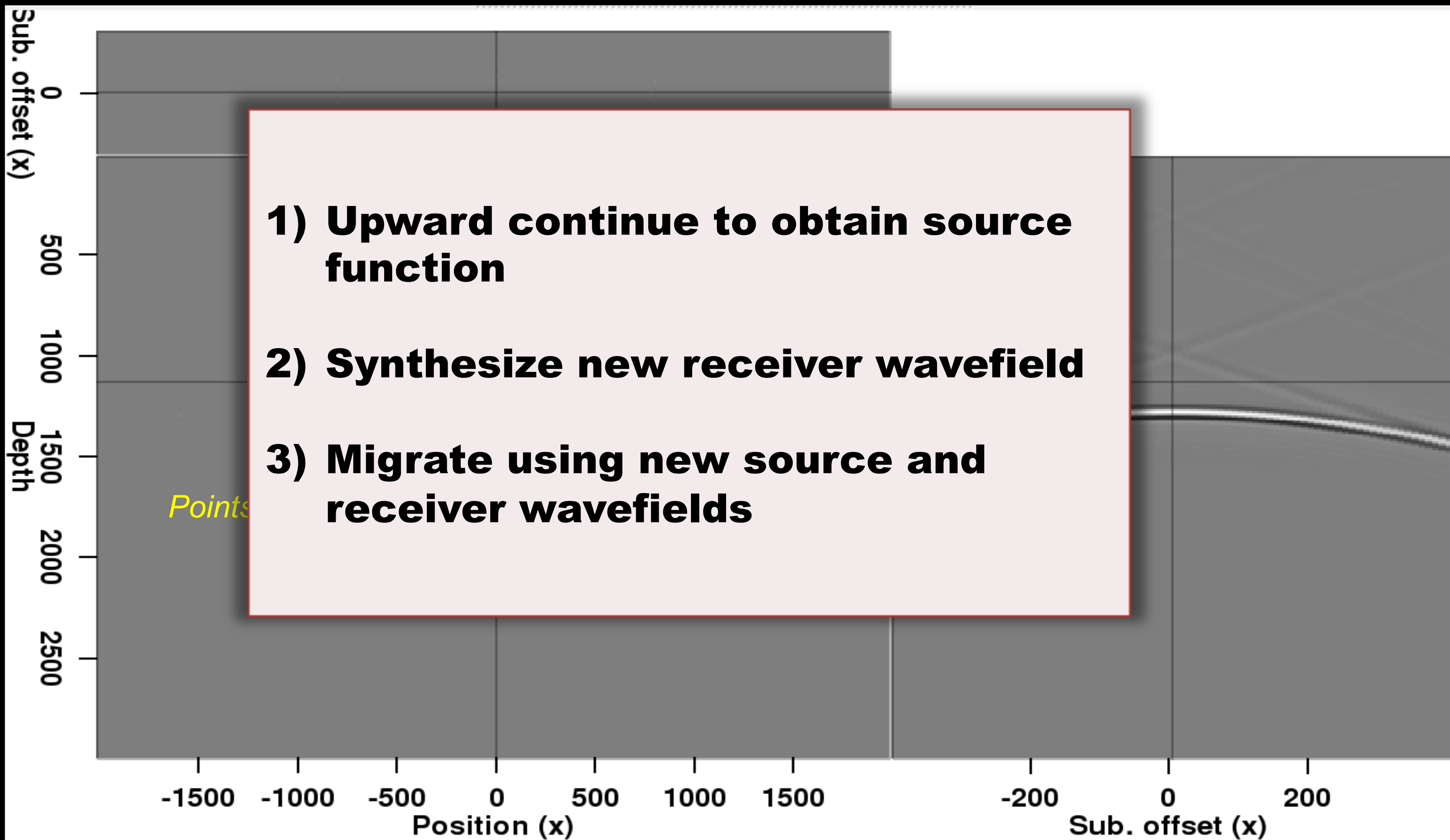
*Can be computed using any velocity model!*

**Targeted images can be computed by imaging a single shot in a fraction of the time required for migrating the full dataset**

# Initial image

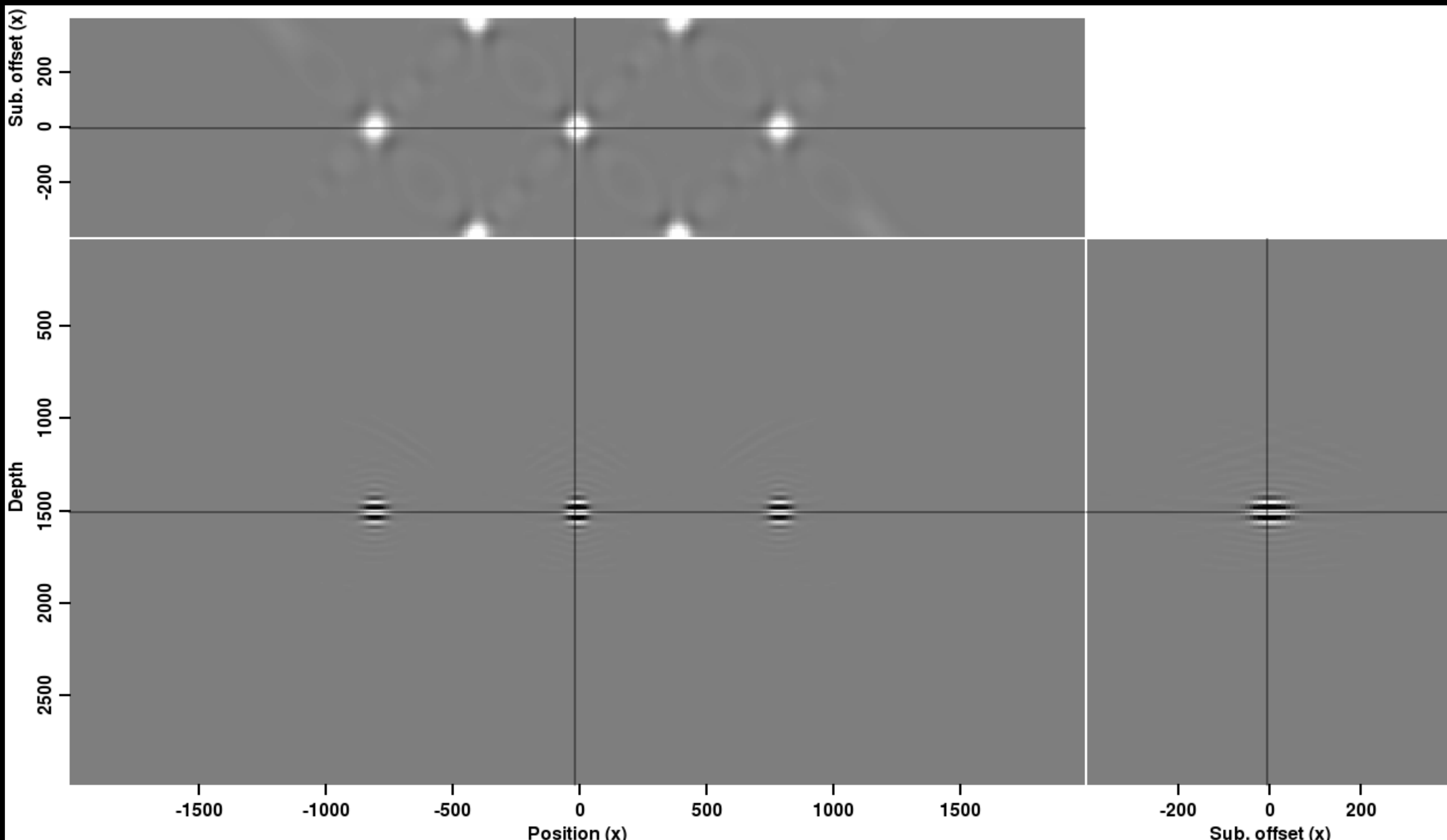


# Isolated points

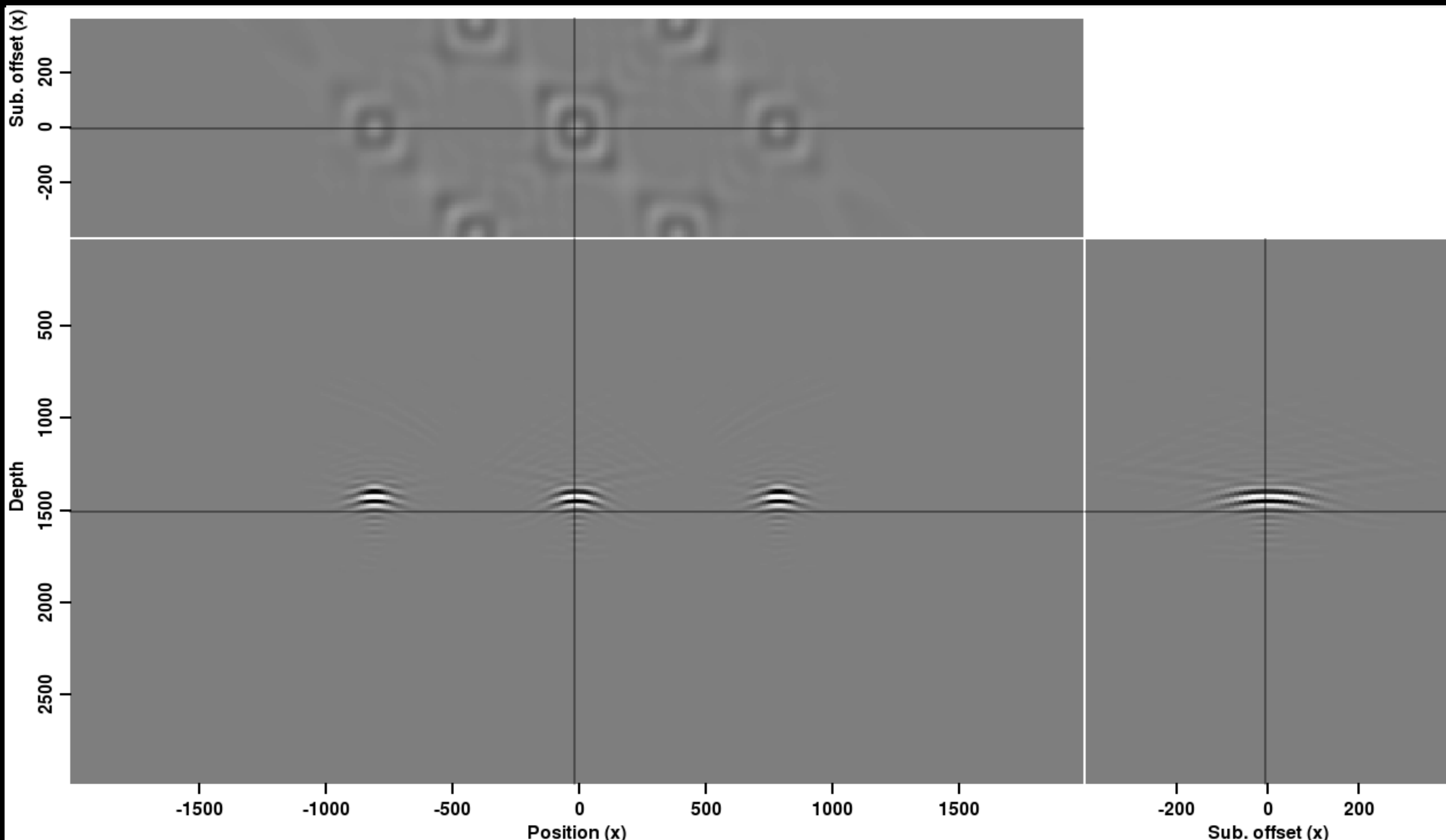



1) **Upward continue to obtain source function**
2) **Synthesize new receiver wavefield**
3) **Migrate using new source and receiver wavefields**

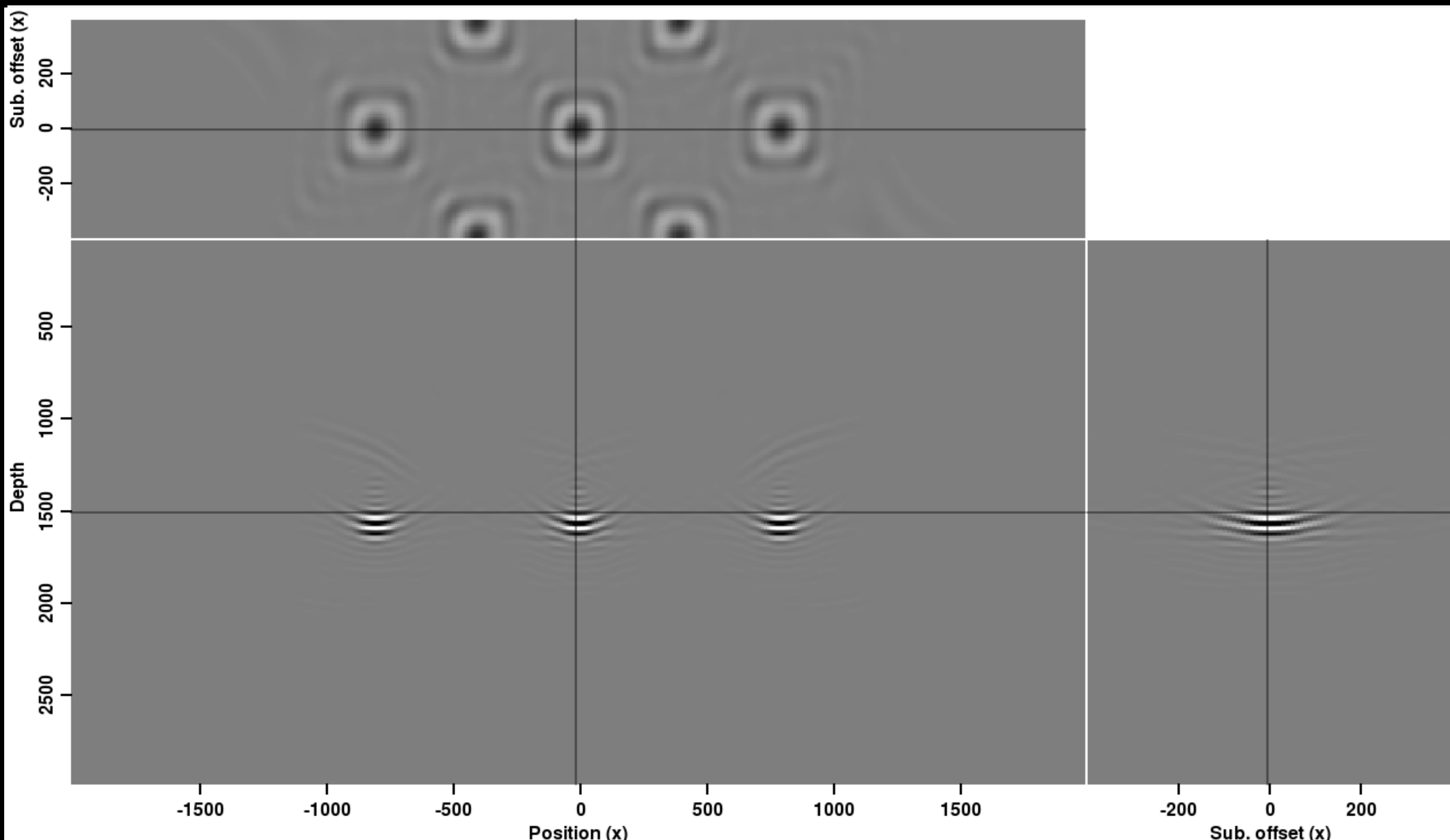
# Correct velocity



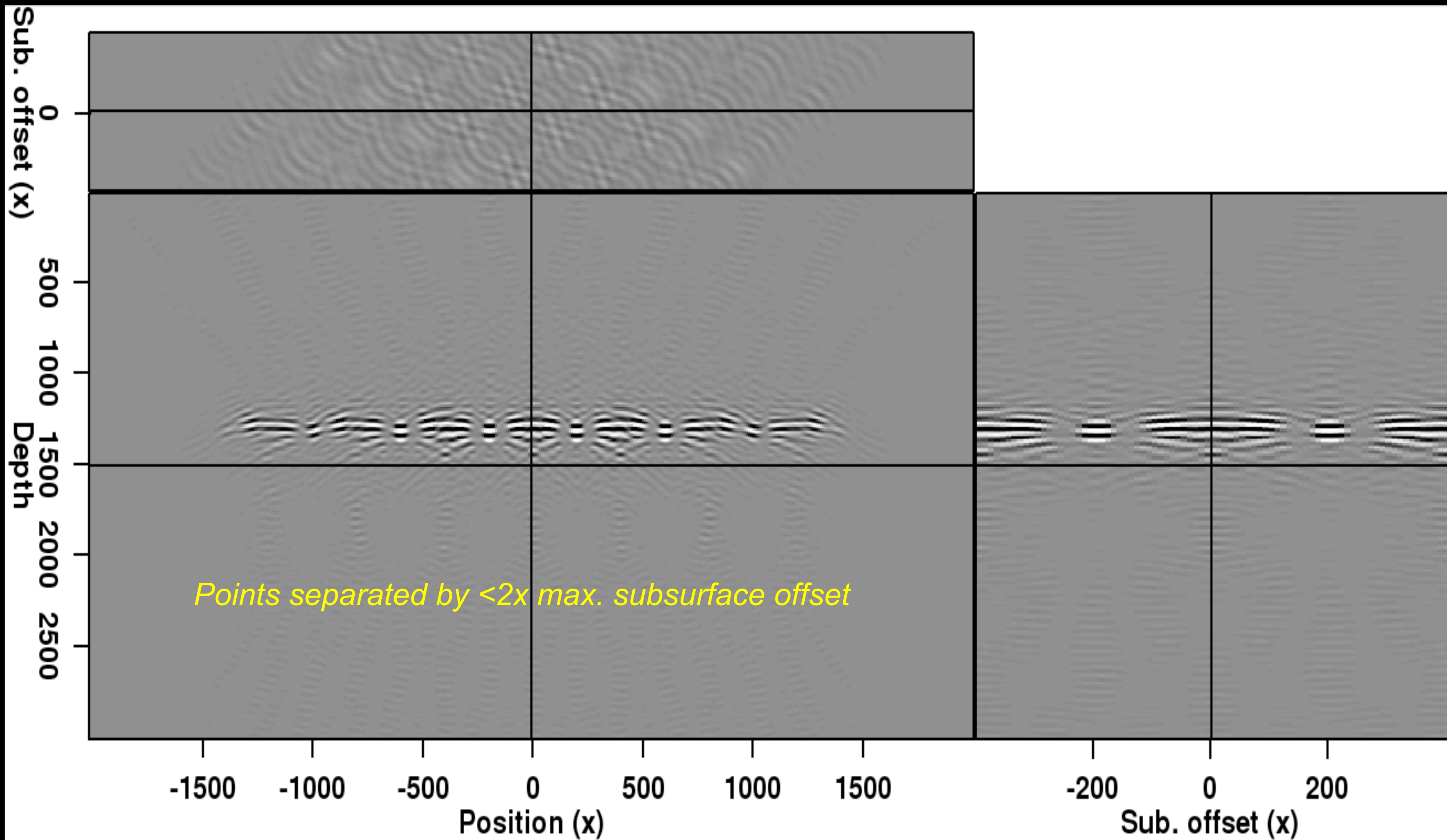
# 5% slow velocity



# 5% fast velocity



# Crosstalk



Sub. offset (x)
0
500
1000
1500
2000
2500
Depth
Points separated by <2x max. subsurface offset
-1500
-1000
-500
0
500
1000
1500
Position (x)
-200
0
200
Sub. offset (x)

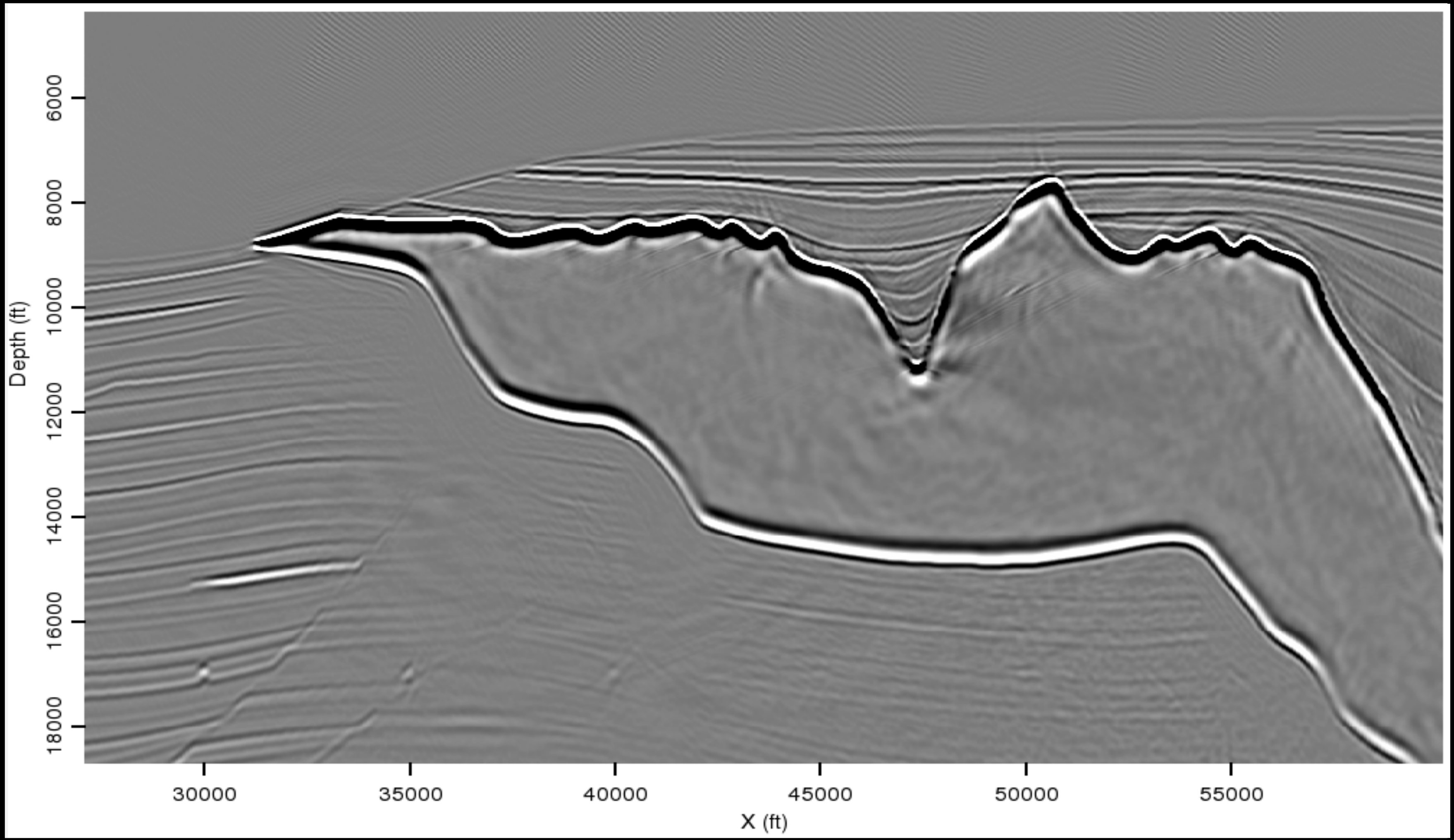
# Model building

- In many cases, salt interpretation is not straightforward
  - Many (discrete) possible scenarios
- Image segmentation is one tool that can quickly help generate these models
- Goal: test these models (almost) as quickly as they are generated
  - Alleviate the model-building bottleneck

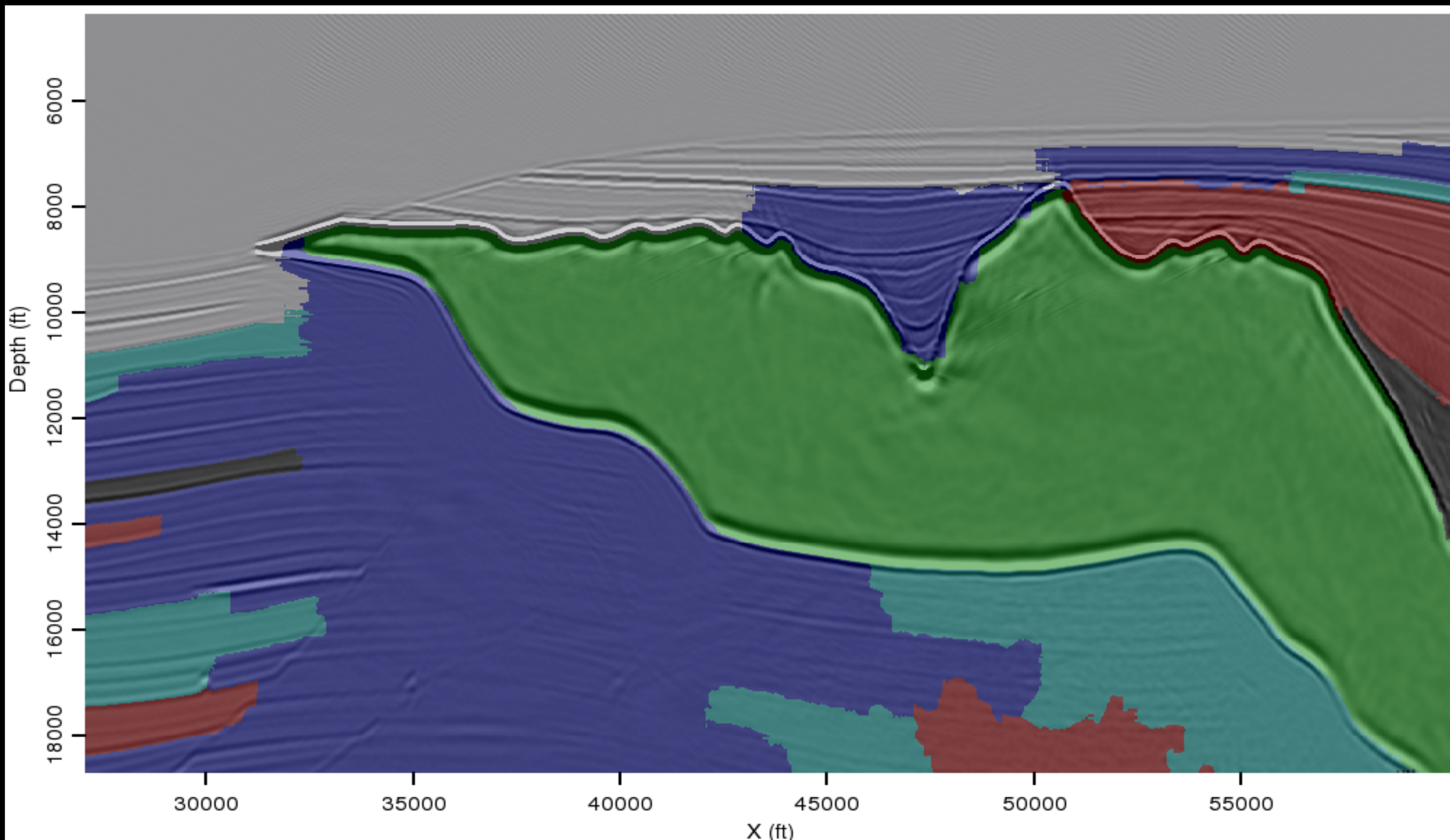
# Segmentation method

- **"Pairwise region comparison"**
- **Felzenszwalb and Huttenlocher (2004): *Efficient graph-based image segmentation***
  - **Seismic adaptation: Halpert et al. (2010)**
- **Presents an interpreter with well-defined regions within an image**
  - **Interpreter must decide which segments are salt**

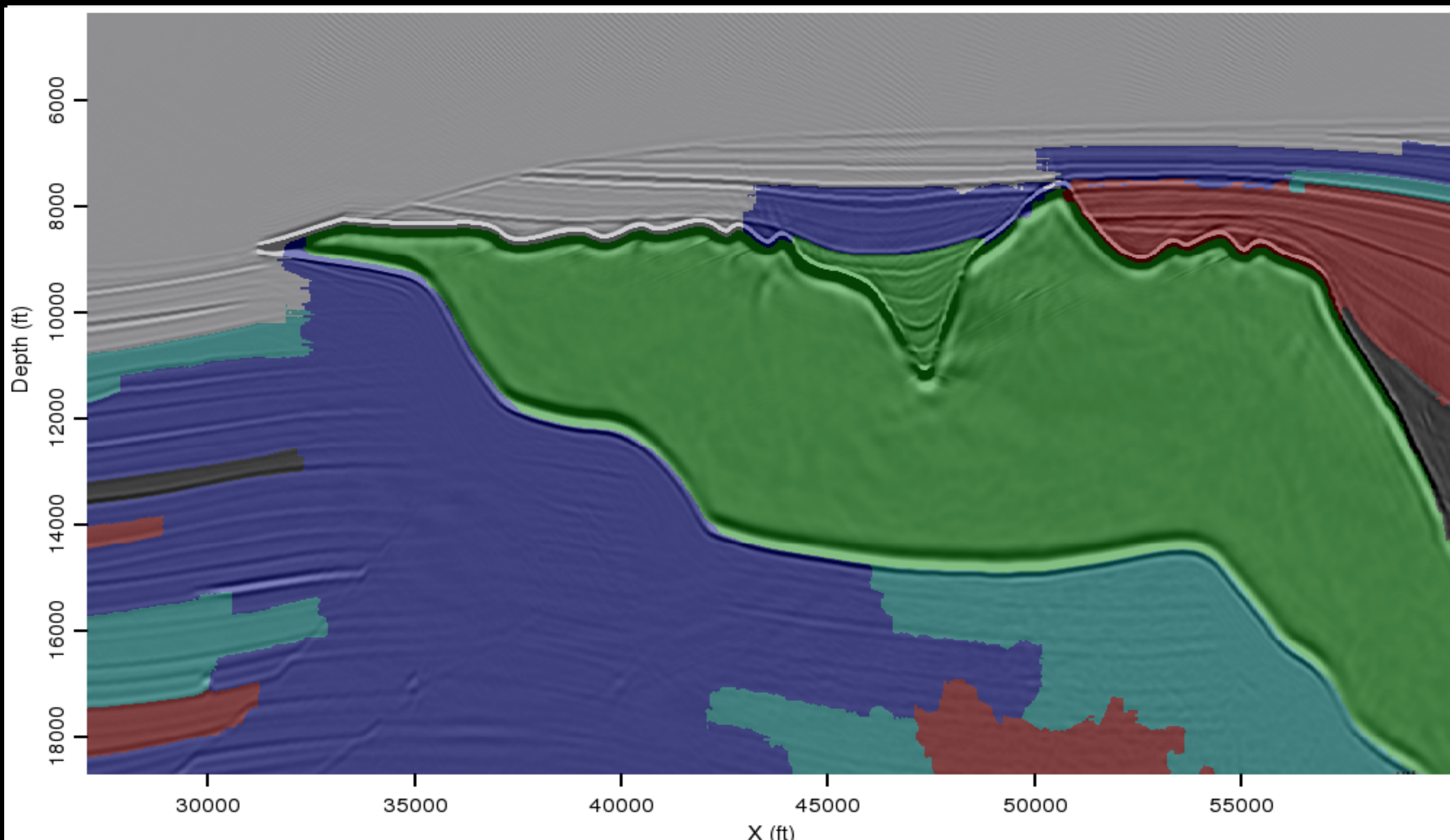
# Sigsbee example



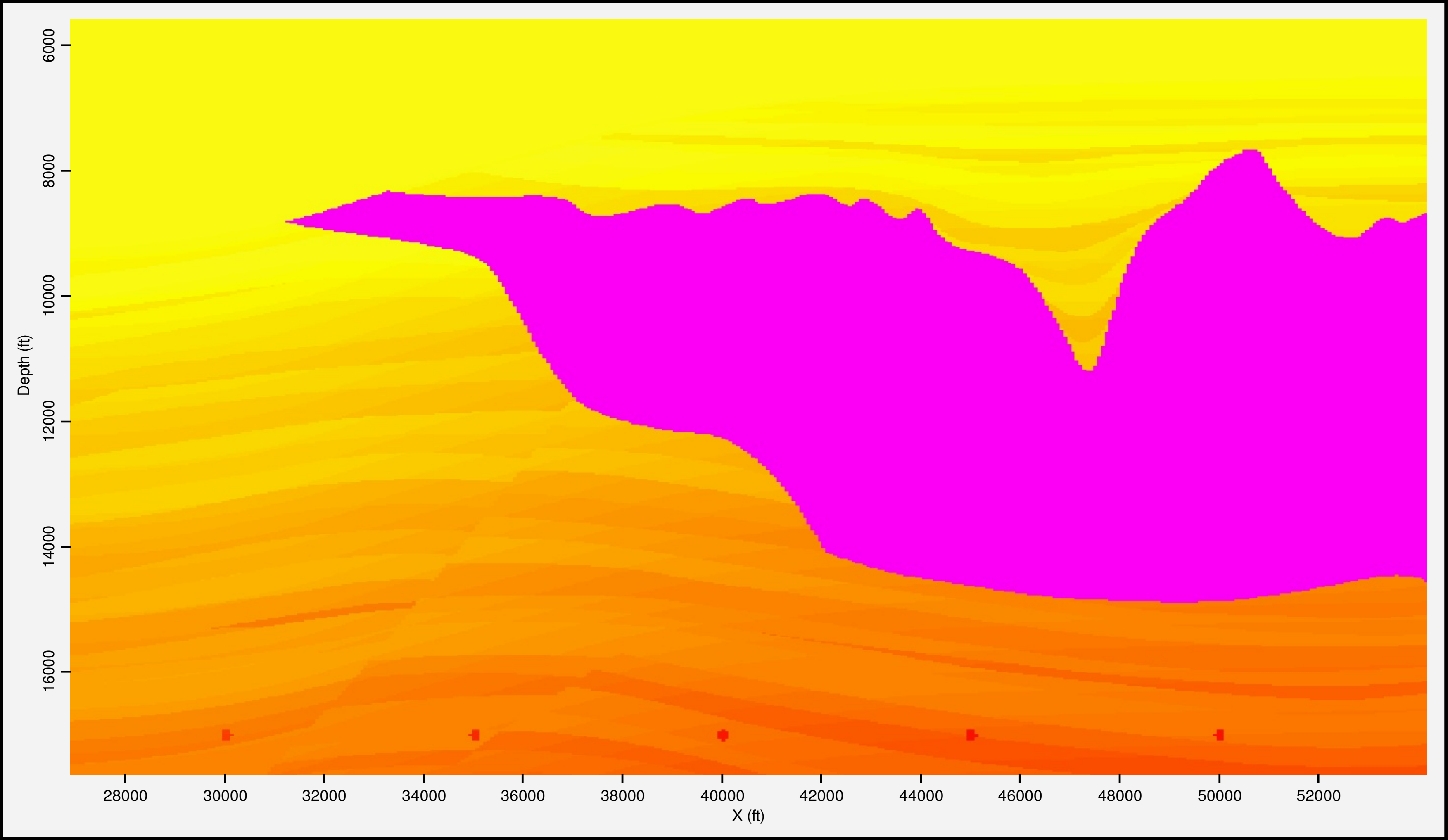
# Segmentation #1



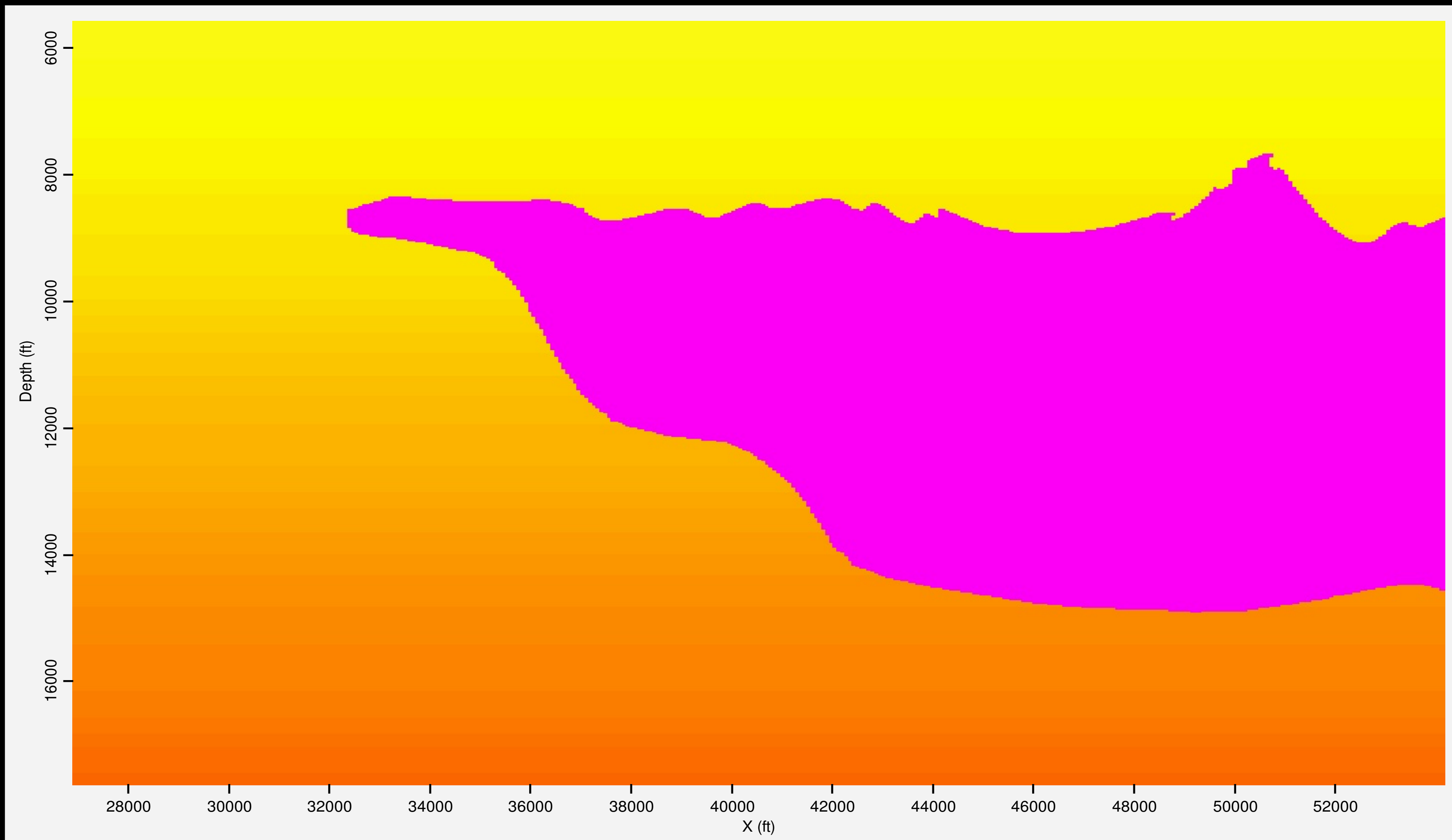
# Segmentation #2



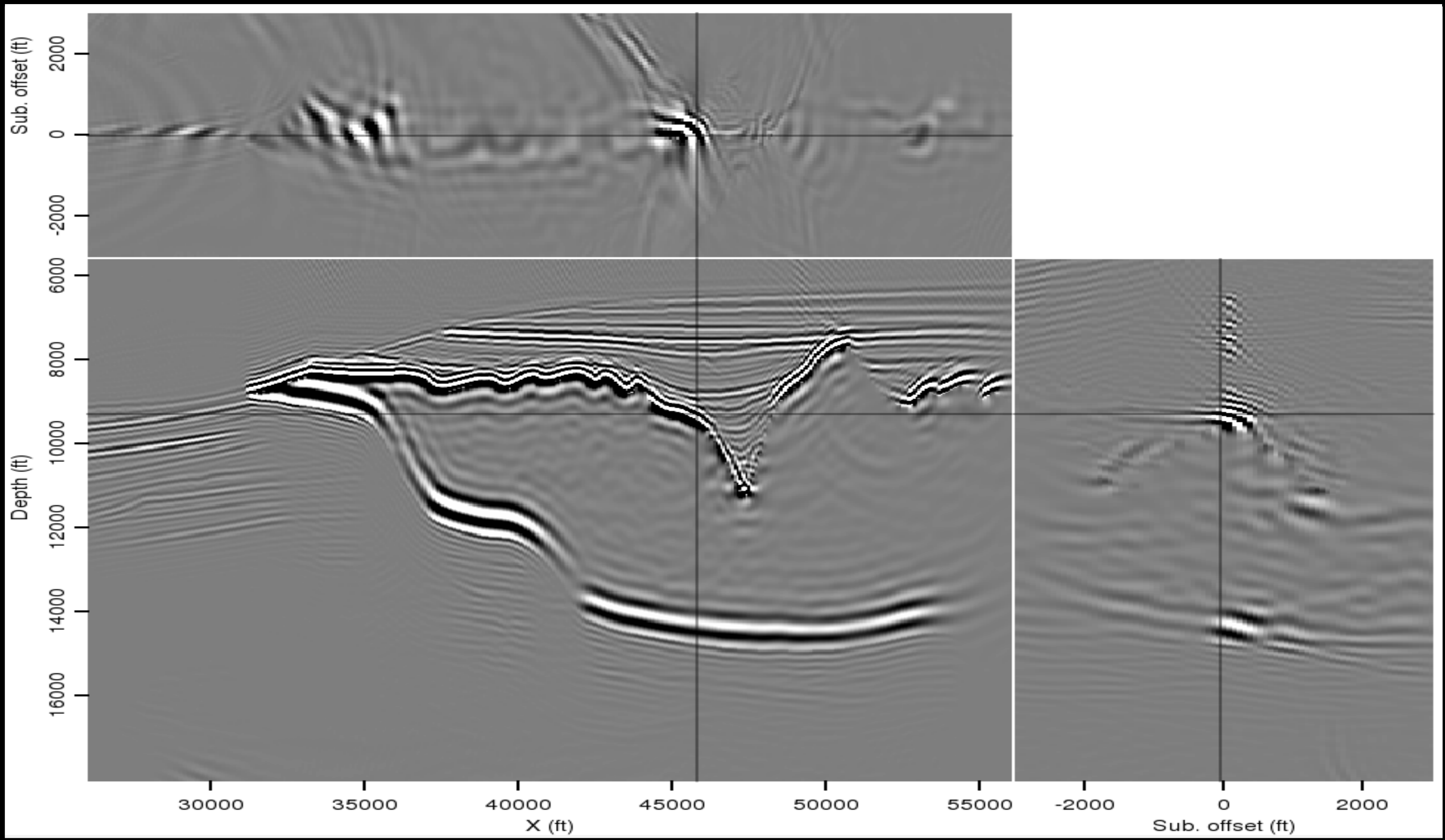
# True velocity



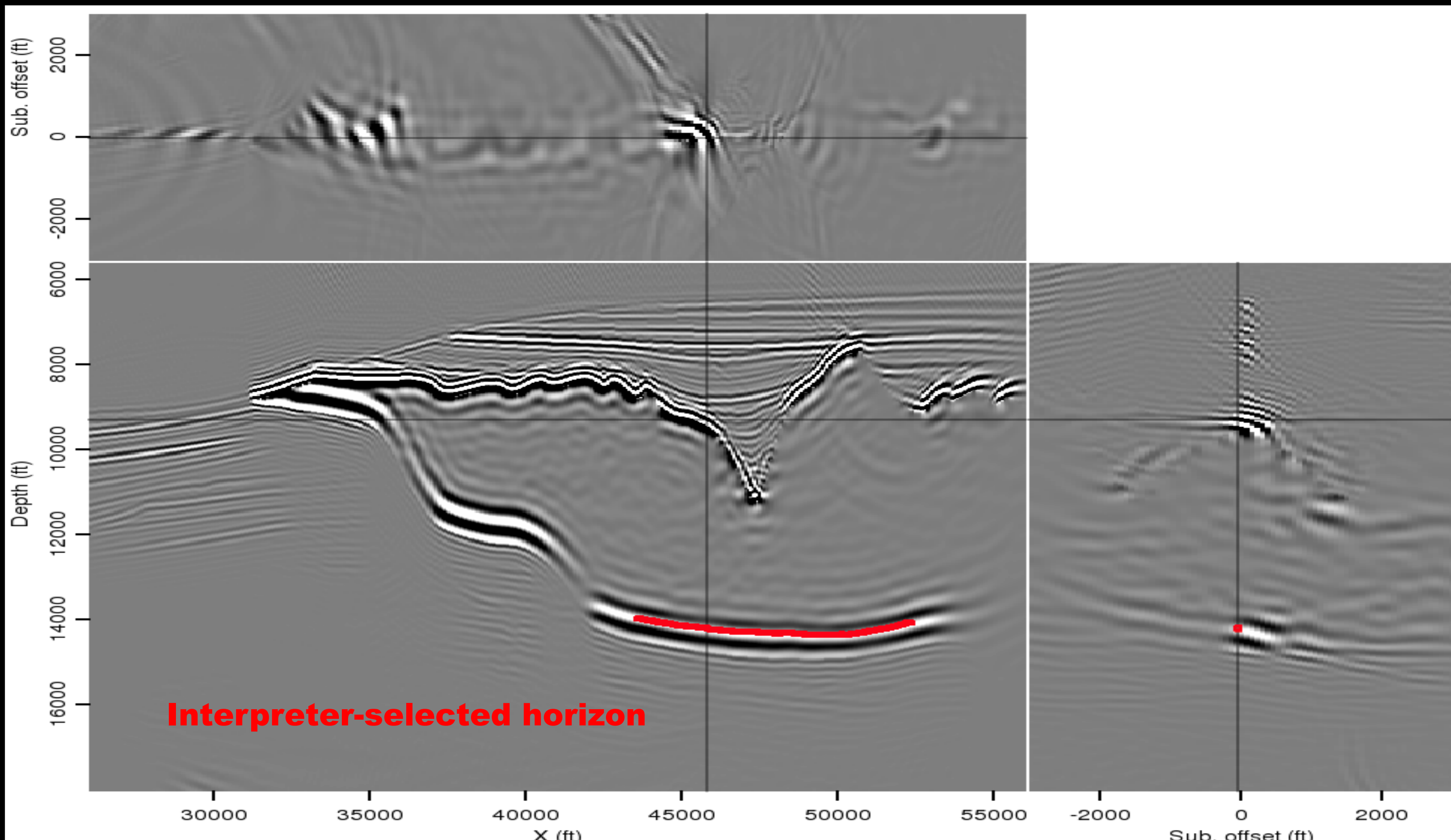
# Modified velocity



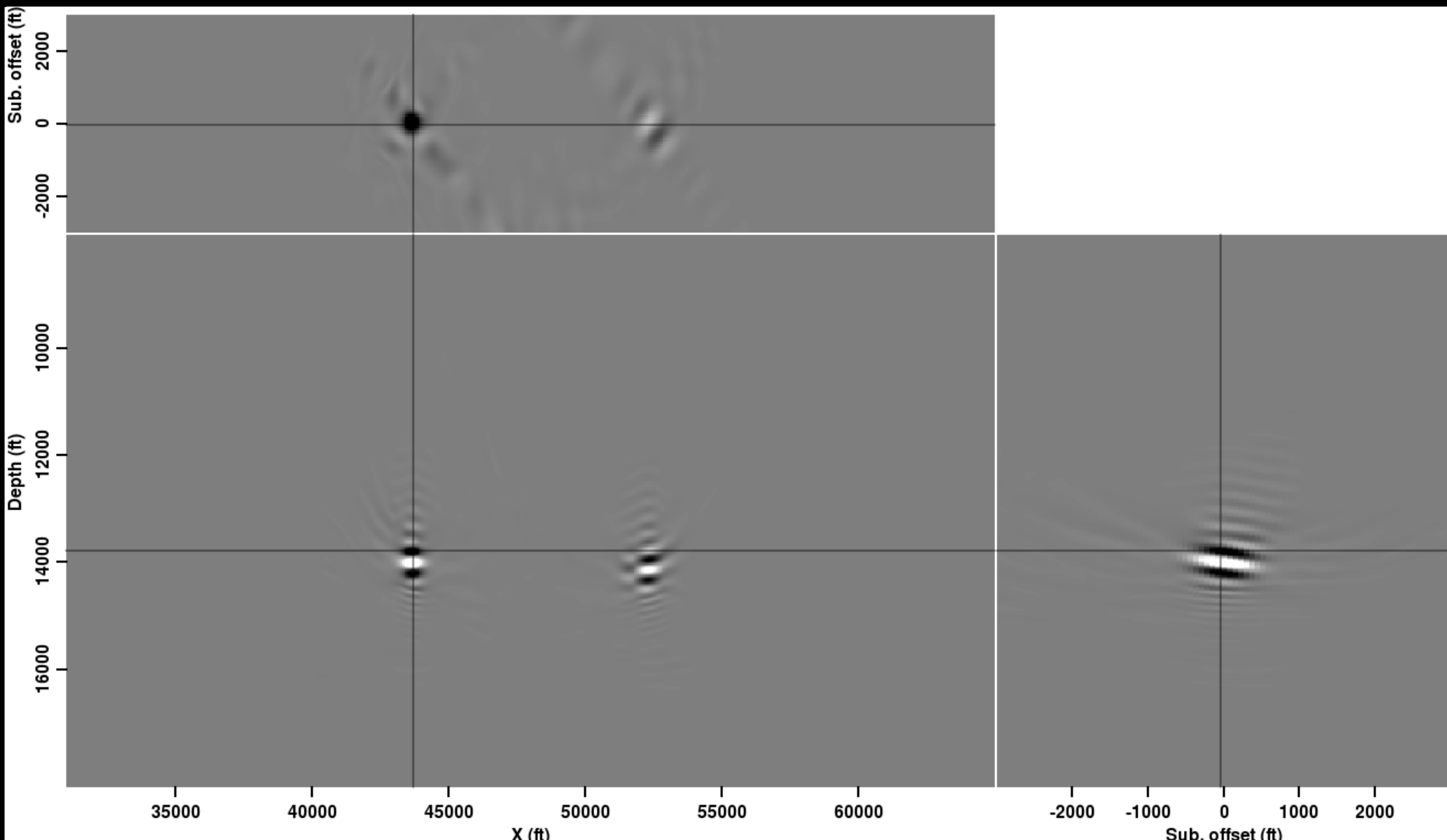
# Sigsbee example



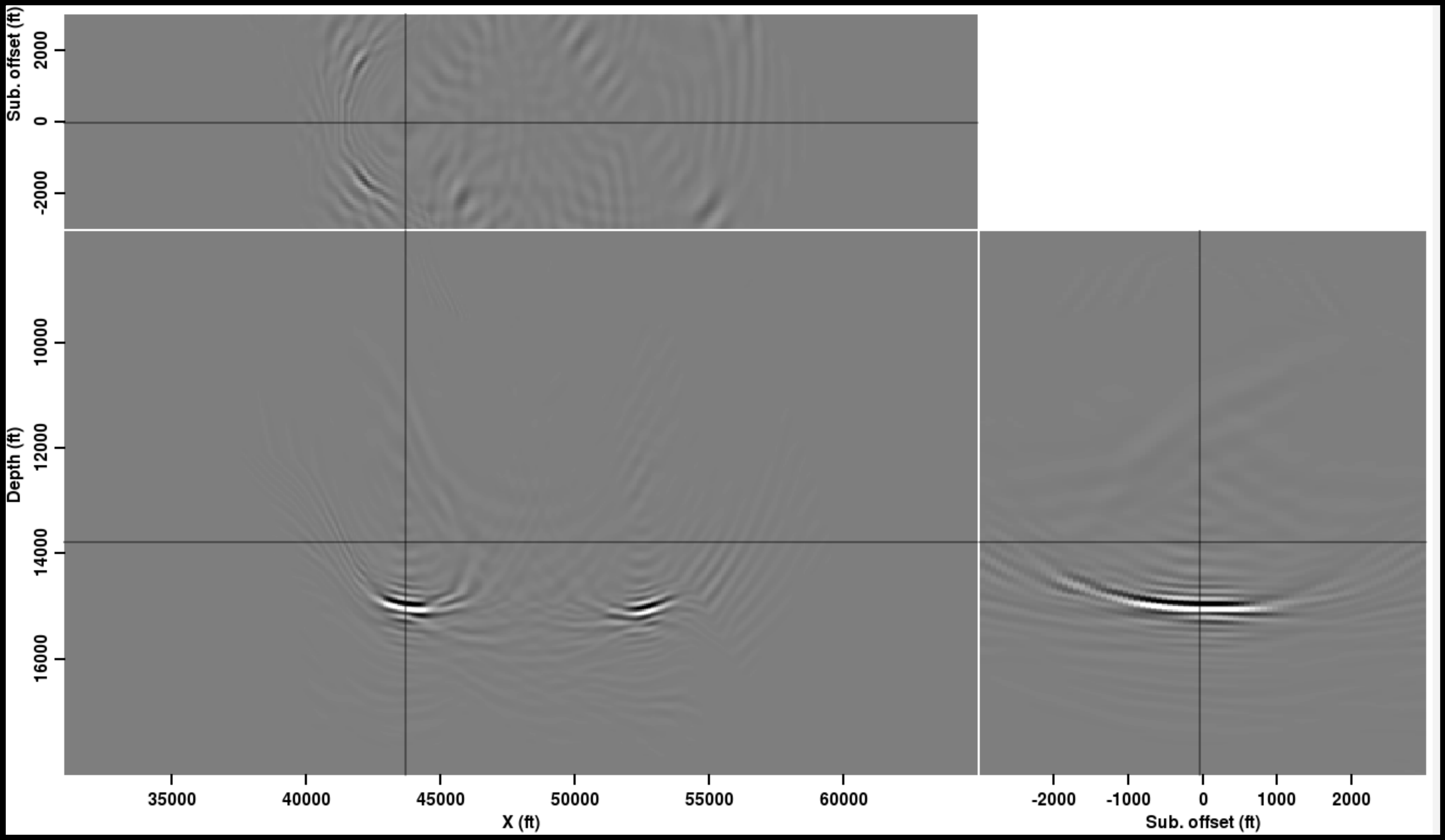
# Sigsbee example



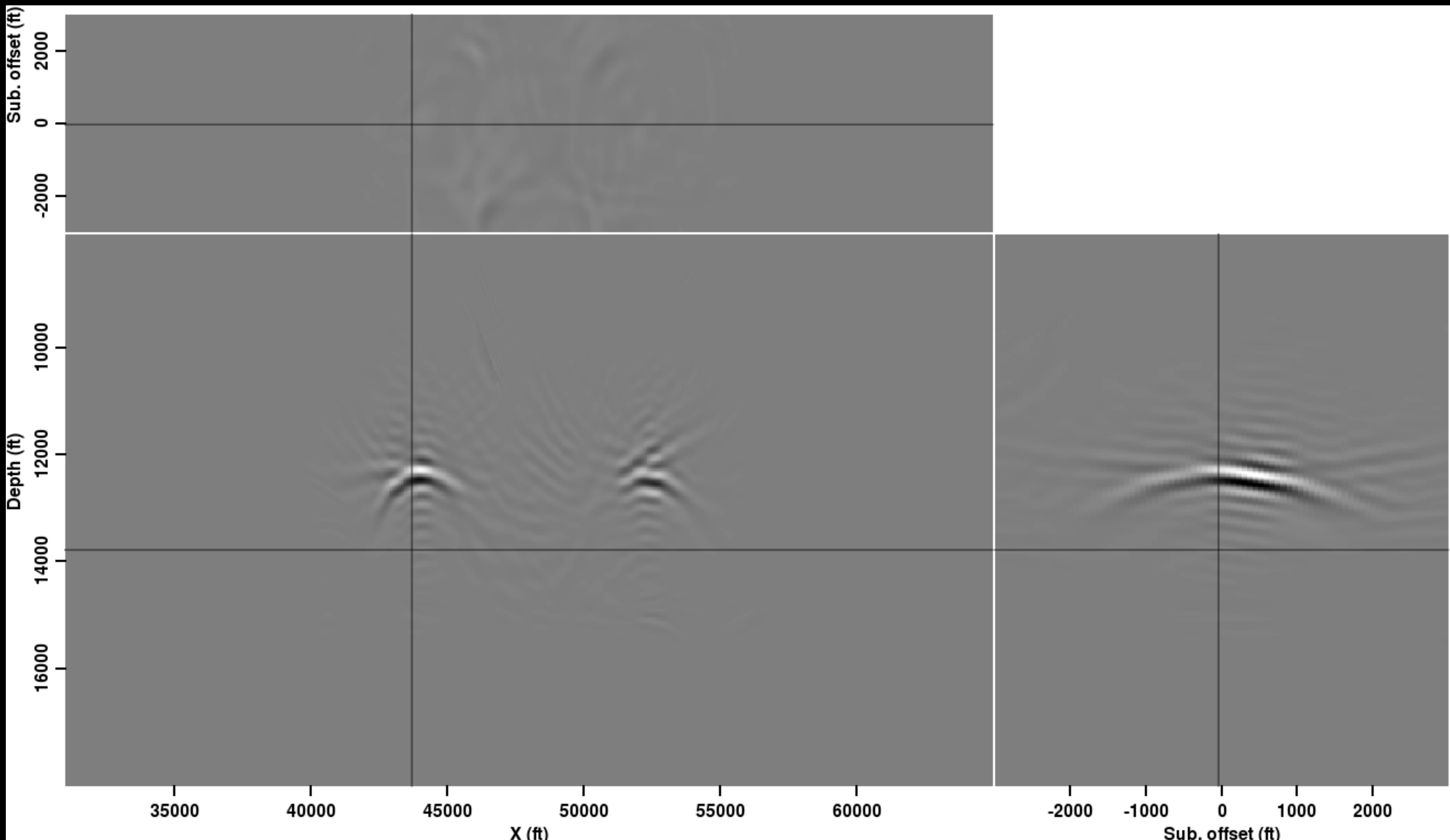
# True velocity result



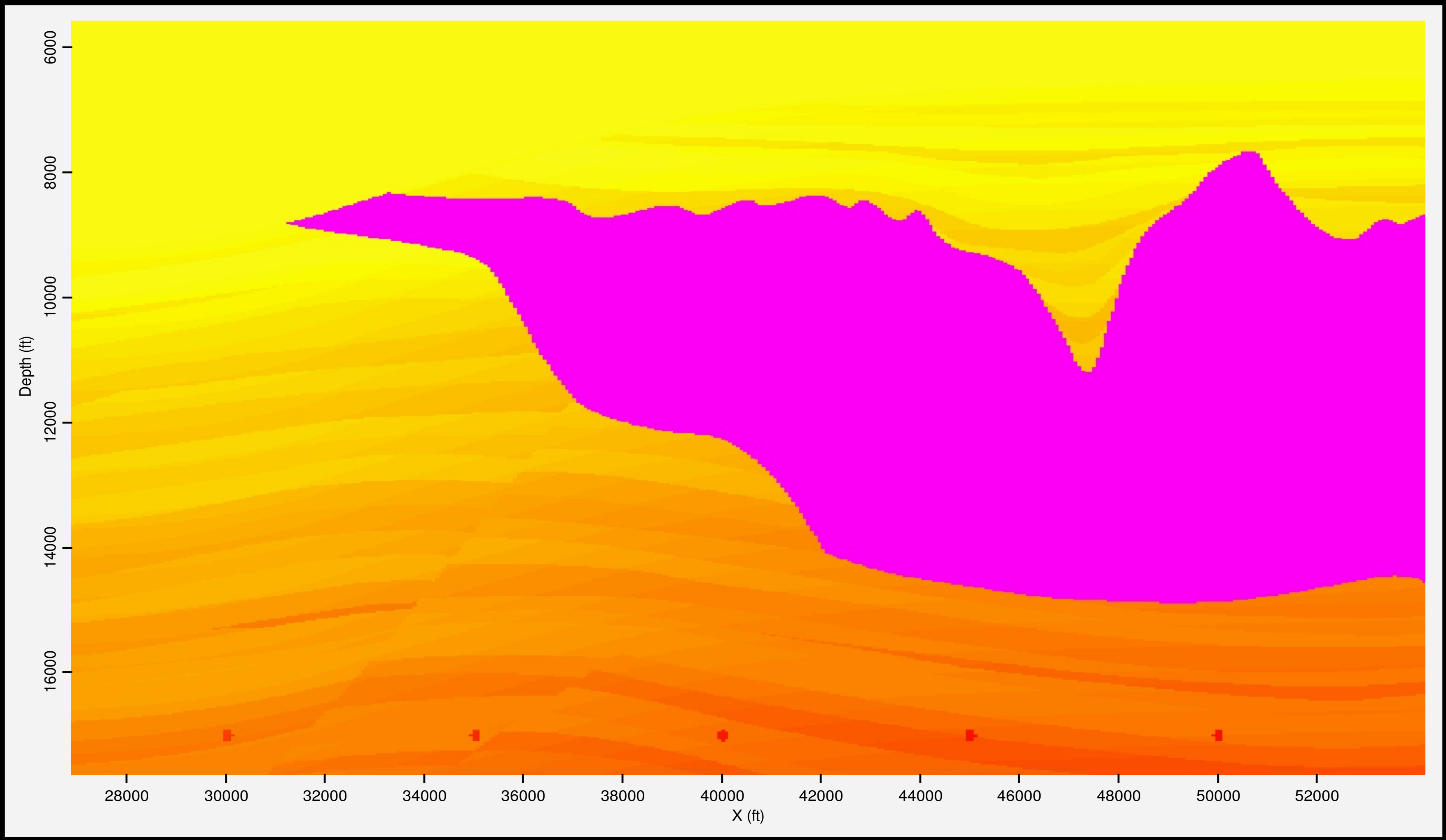
# 5% fast


Sub. offset (ft)
2000
0
-2000
Depth (ft)
10000
12000
14000
16000
35000
40000
45000
50000
55000
60000
X (ft)
-2000
-1000
0
1000
2000
Sub. offset (ft)

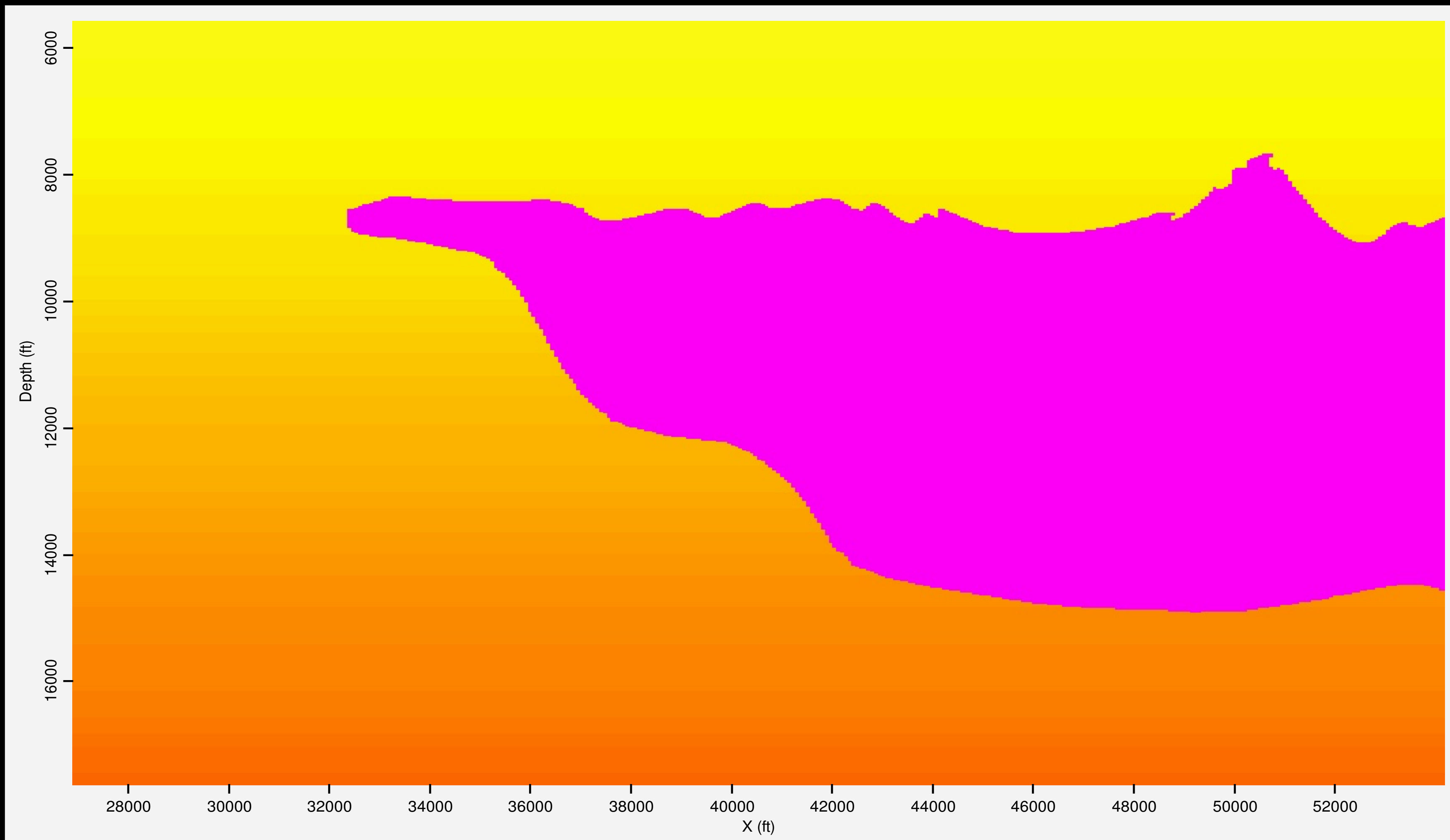
# 5% slow


Sub. offset (ft)
2000
0
-2000
Depth (ft)
10000
12000
14000
16000
35000
40000
45000
50000
55000
60000
X (ft)
-2000
-1000
0
1000
2000
Sub. offset (ft)

# True velocity



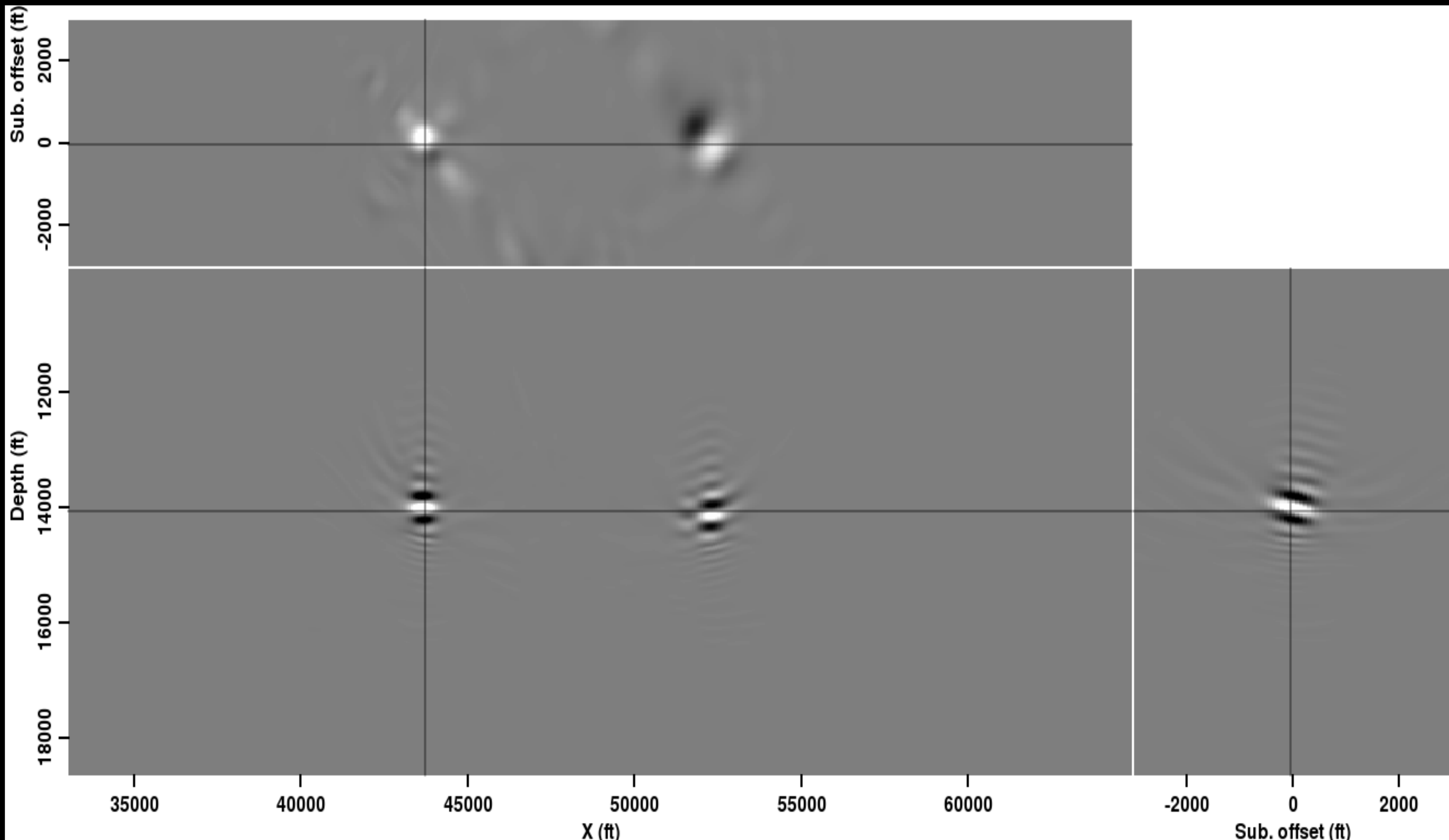
# Modified velocity



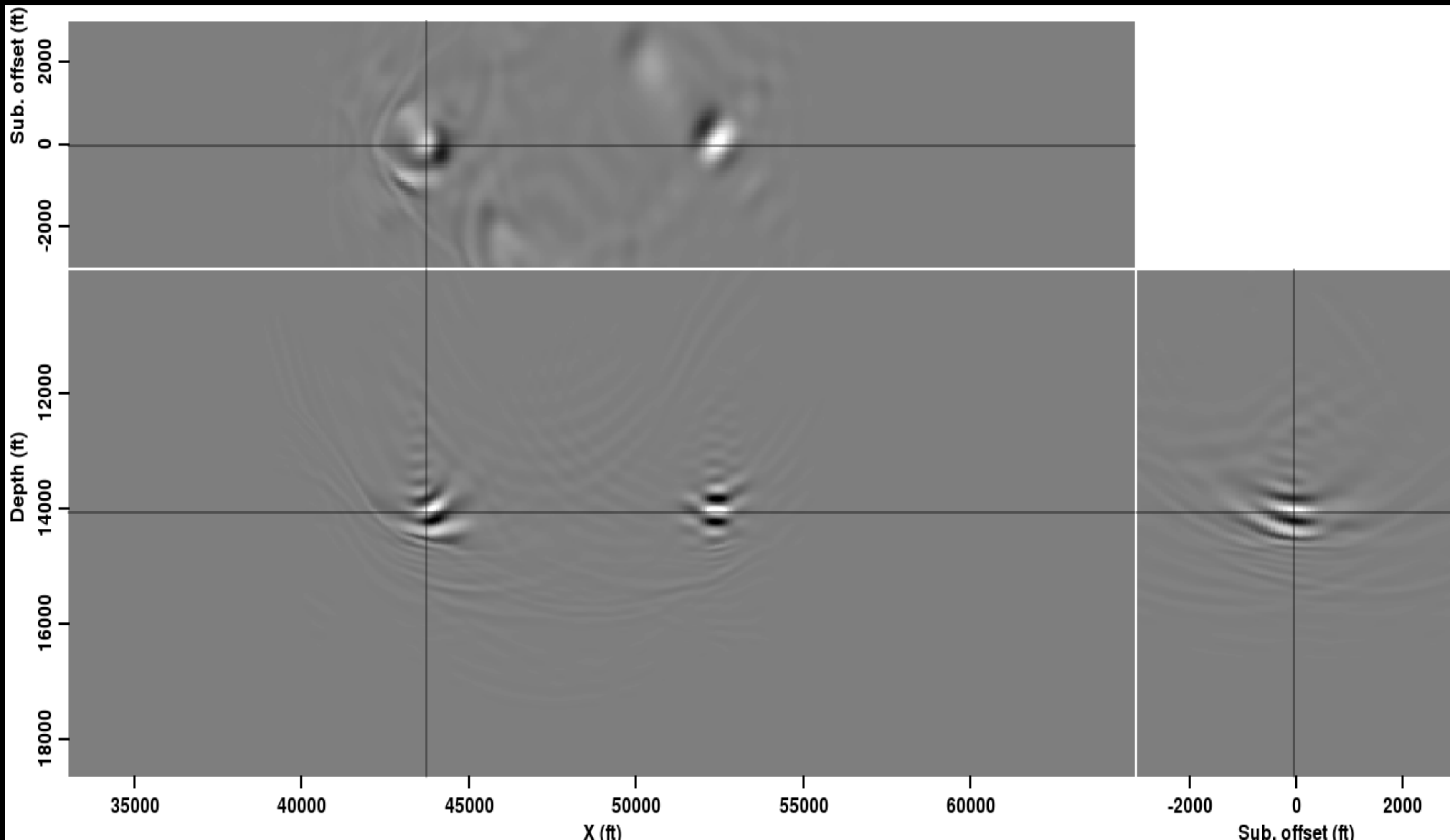
# Test #1

- **Initial image: true velocity**
  - **Source and receiver wavefields modeled with true velocity**
- **Migrate the synthesized wavefields with three different models**
  - **True velocity**
  - **Extra-salt model**
  - **"Slow-salt" model**

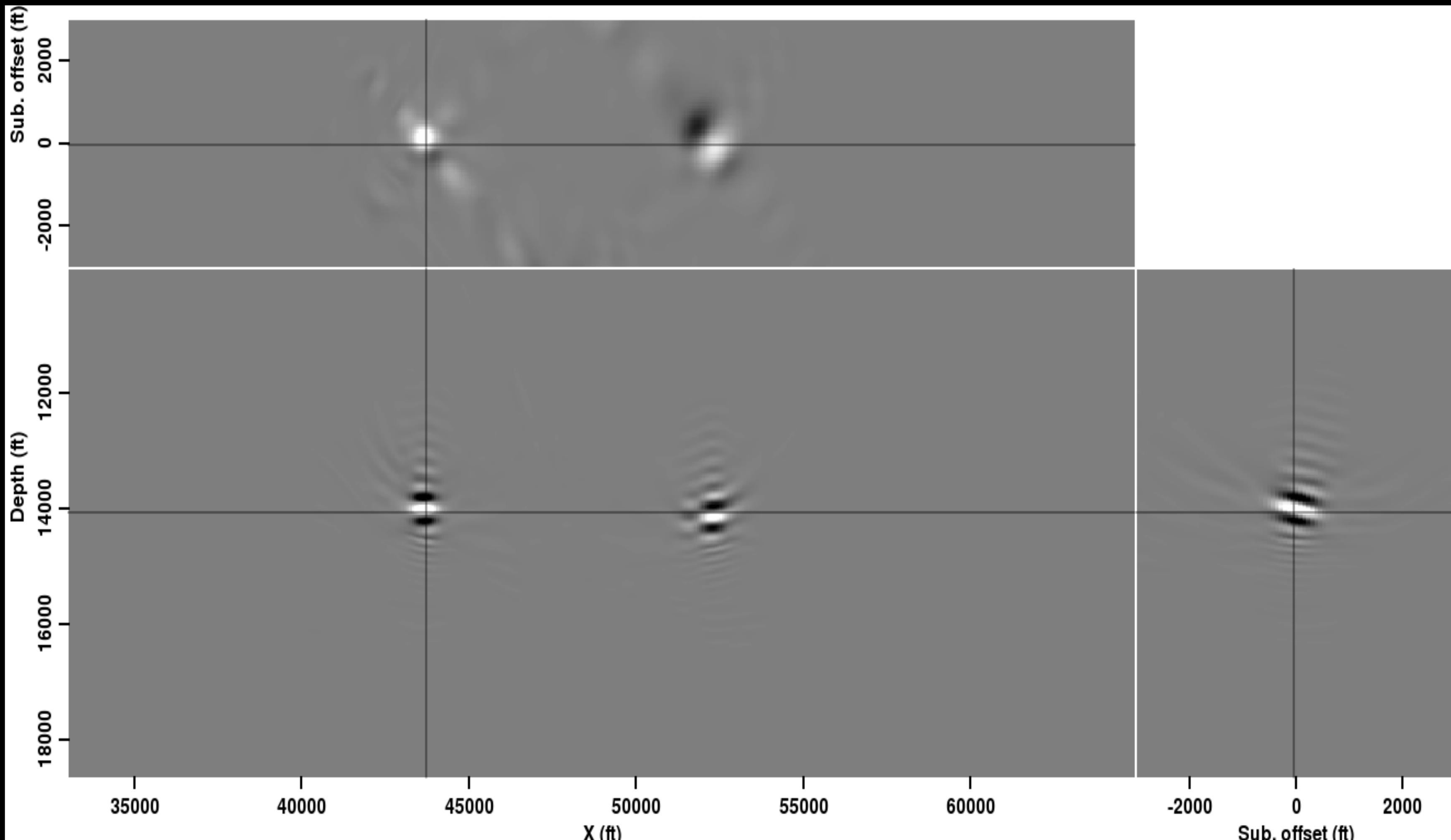
# True velocity



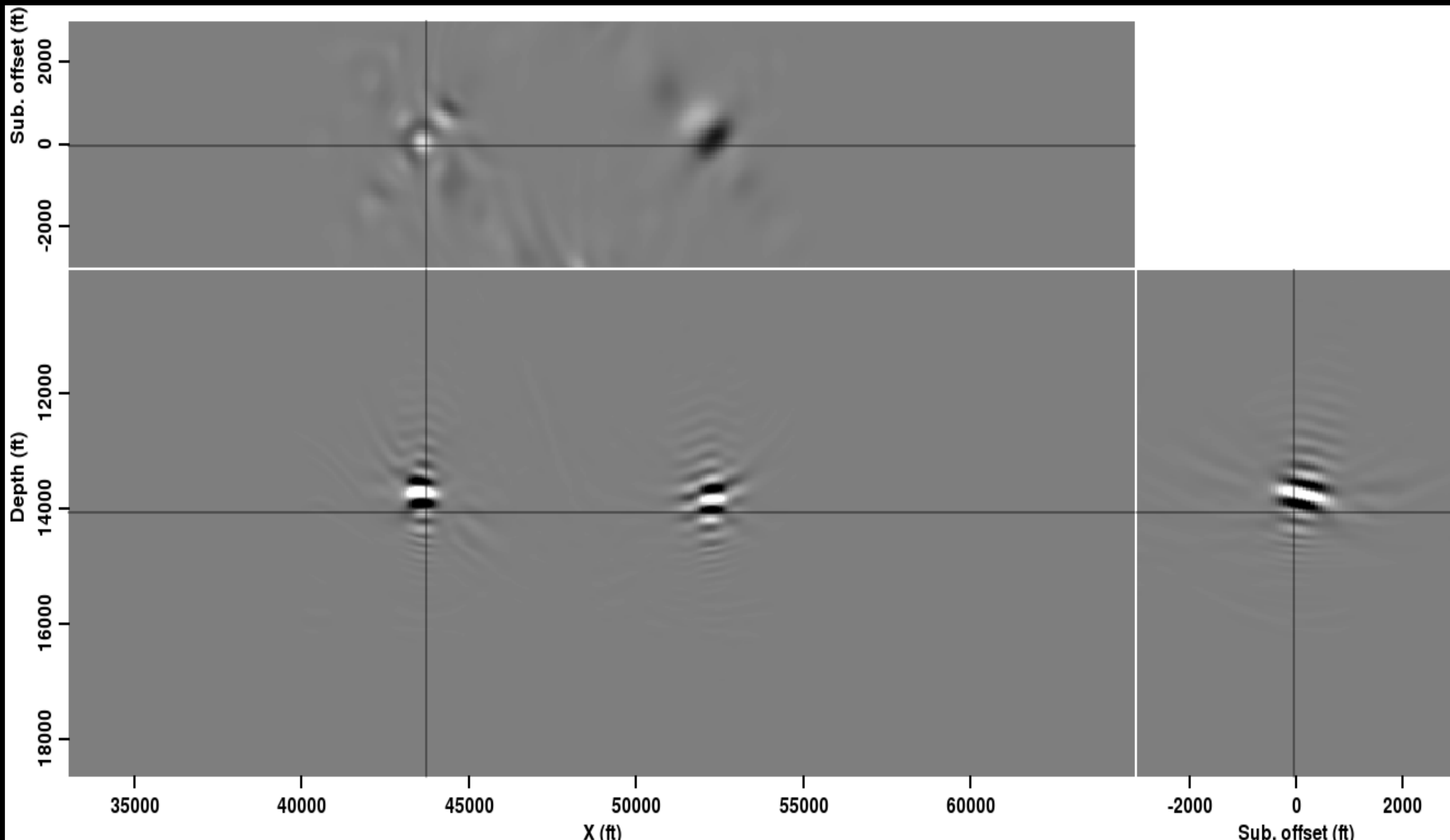
# Extra-salt velocity



# True velocity



# Slow salt velocity

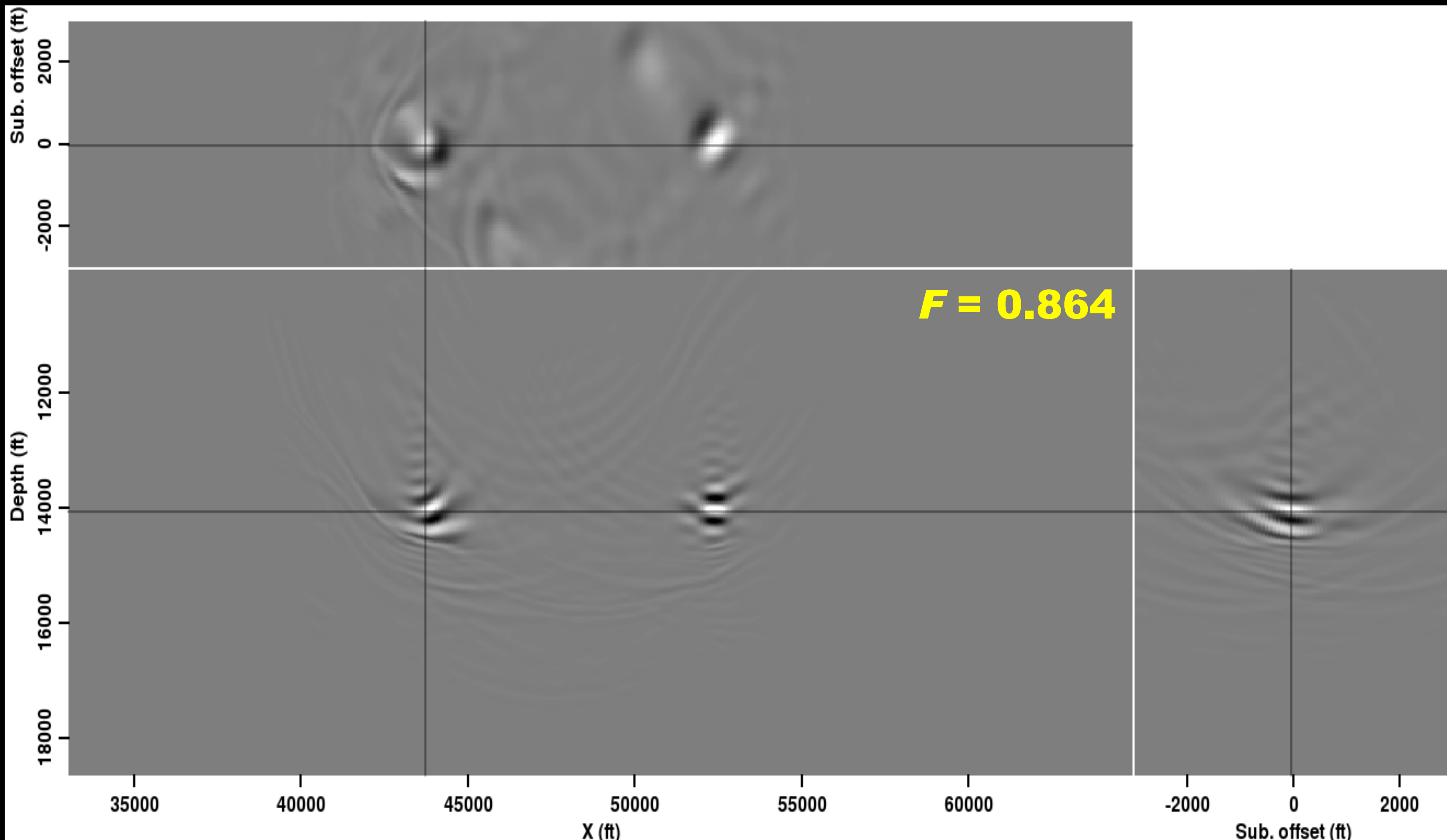


# Image focusing measure

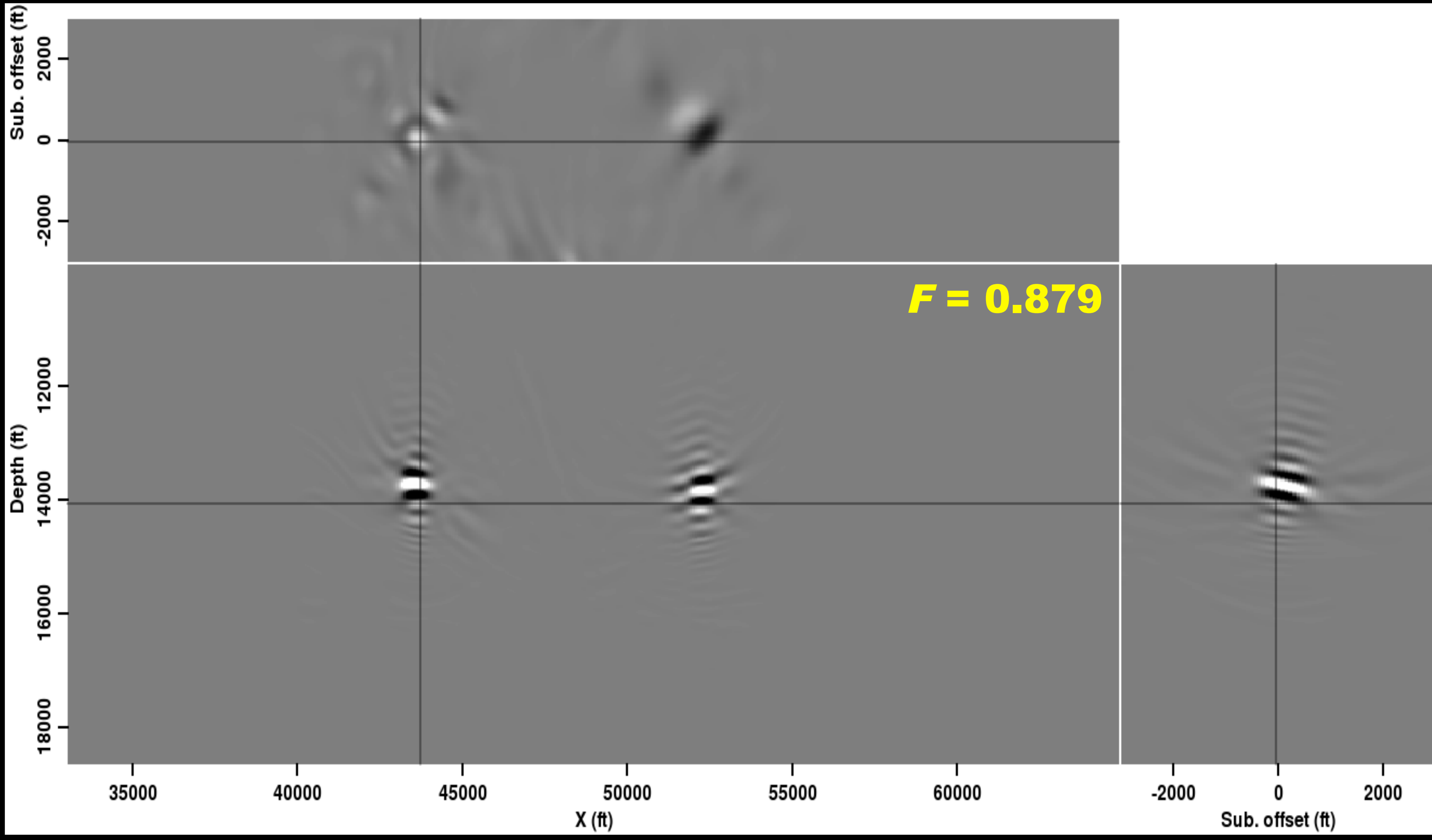
$$F = \frac{\sum_{i=\mathbf{p}} |A_i|}{\sum_{i=\mathbf{p}} |A_i| \exp\left(\alpha \frac{|h_i|}{h_{\max}}\right)}$$

**p = set of all image points**
**A = amplitude/energy**
**α = optional weight**

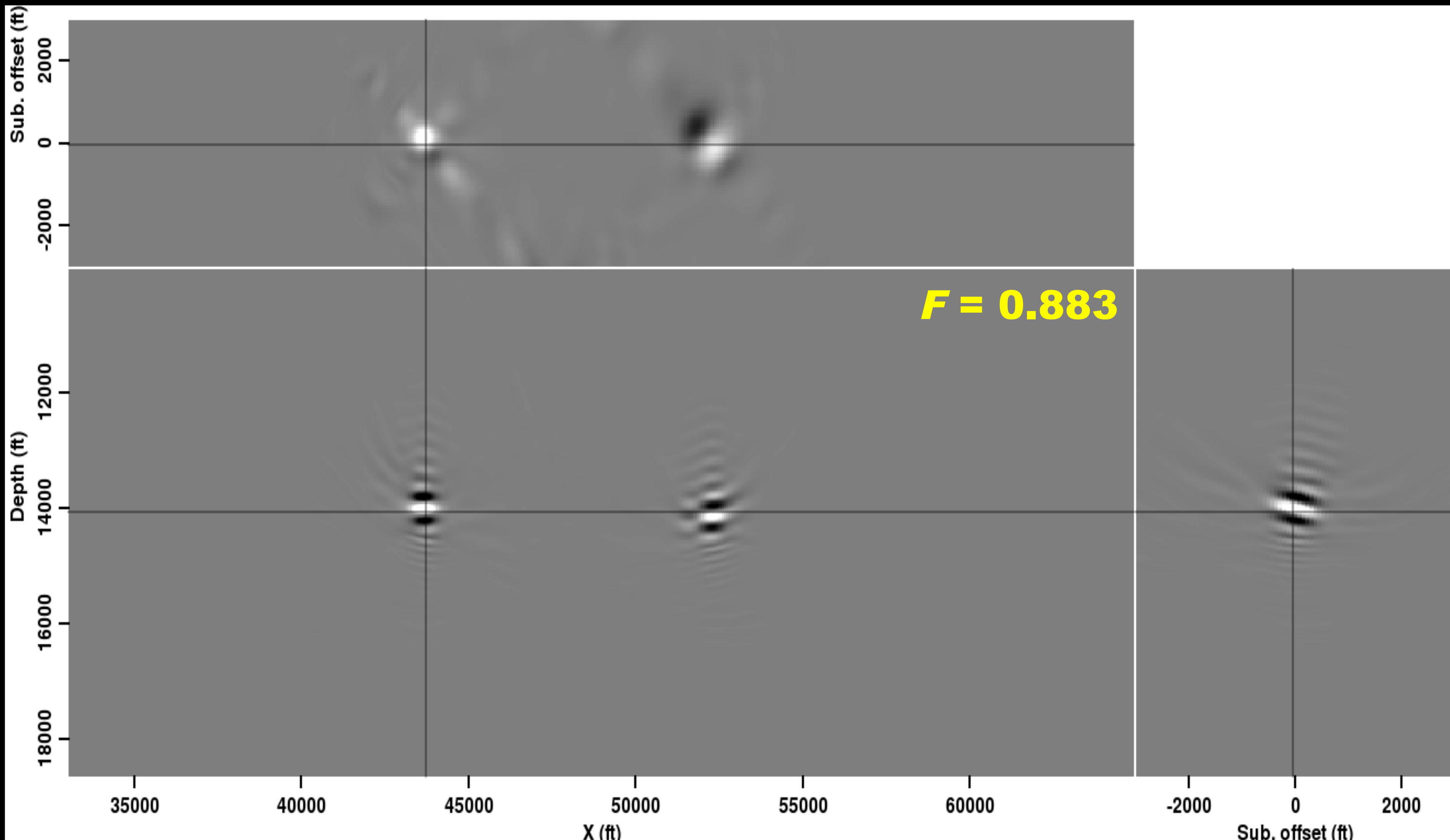
# Extra-salt velocity



# Slow salt velocity



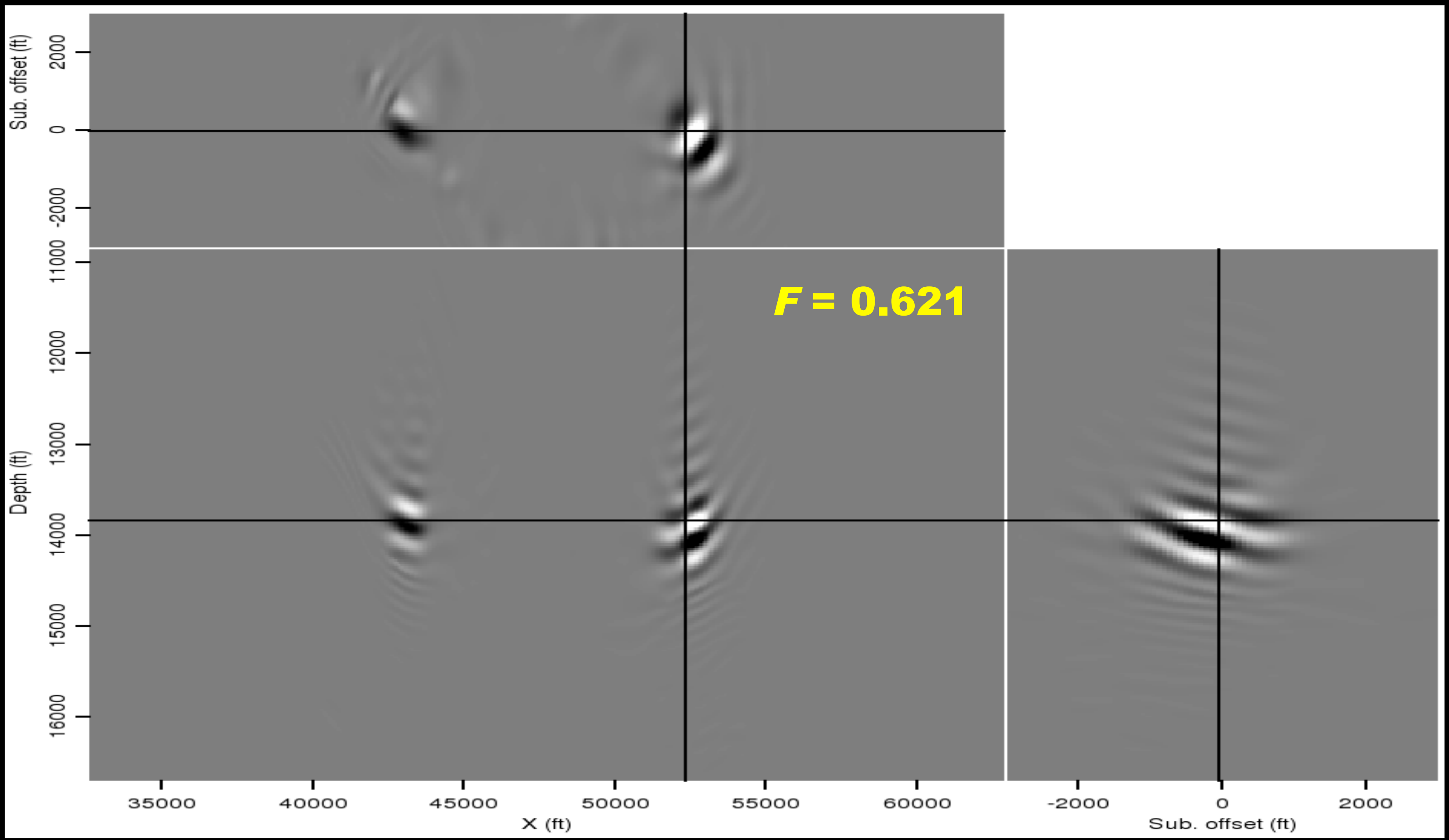
# True velocity



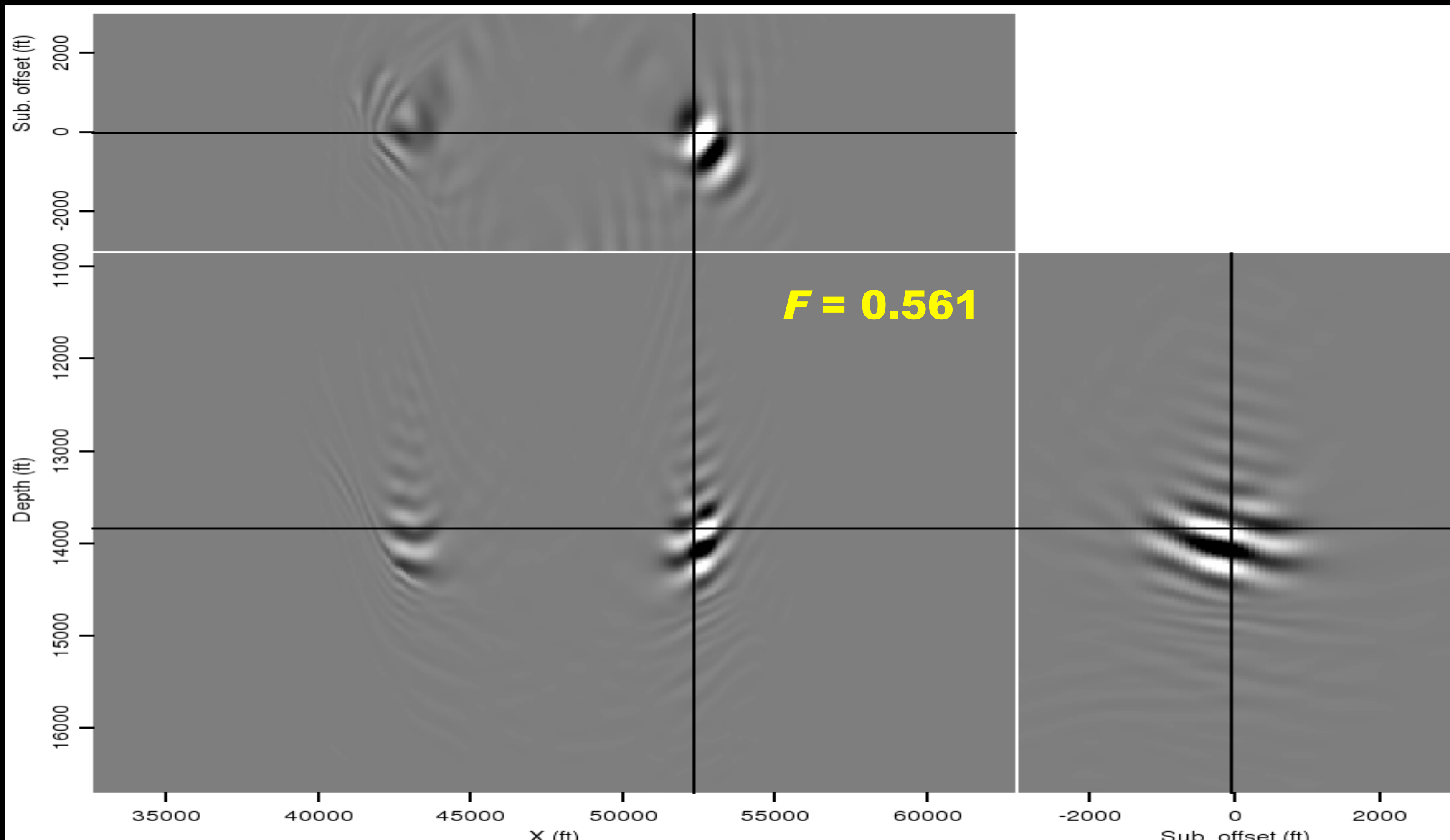
# Test #2

- **Initial image: "Slow-salt" velocity**
  - **Source and receiver wavefields modeled with slow-salt velocity**
- **Migrate the synthesized wavefields with three different models**
  - **True velocity**
  - **Extra-salt model**
  - **"Slow-salt" model**

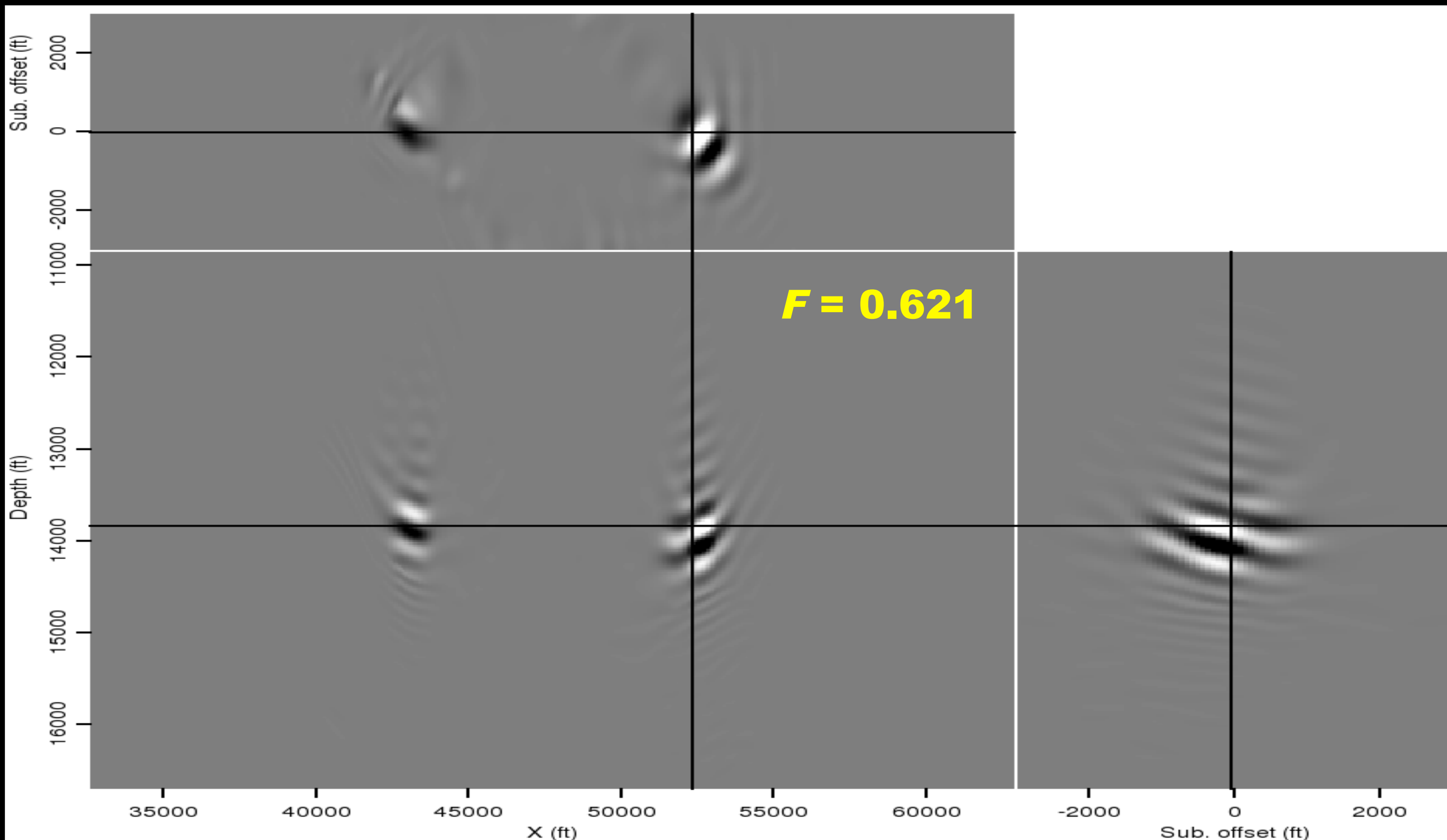
# True velocity



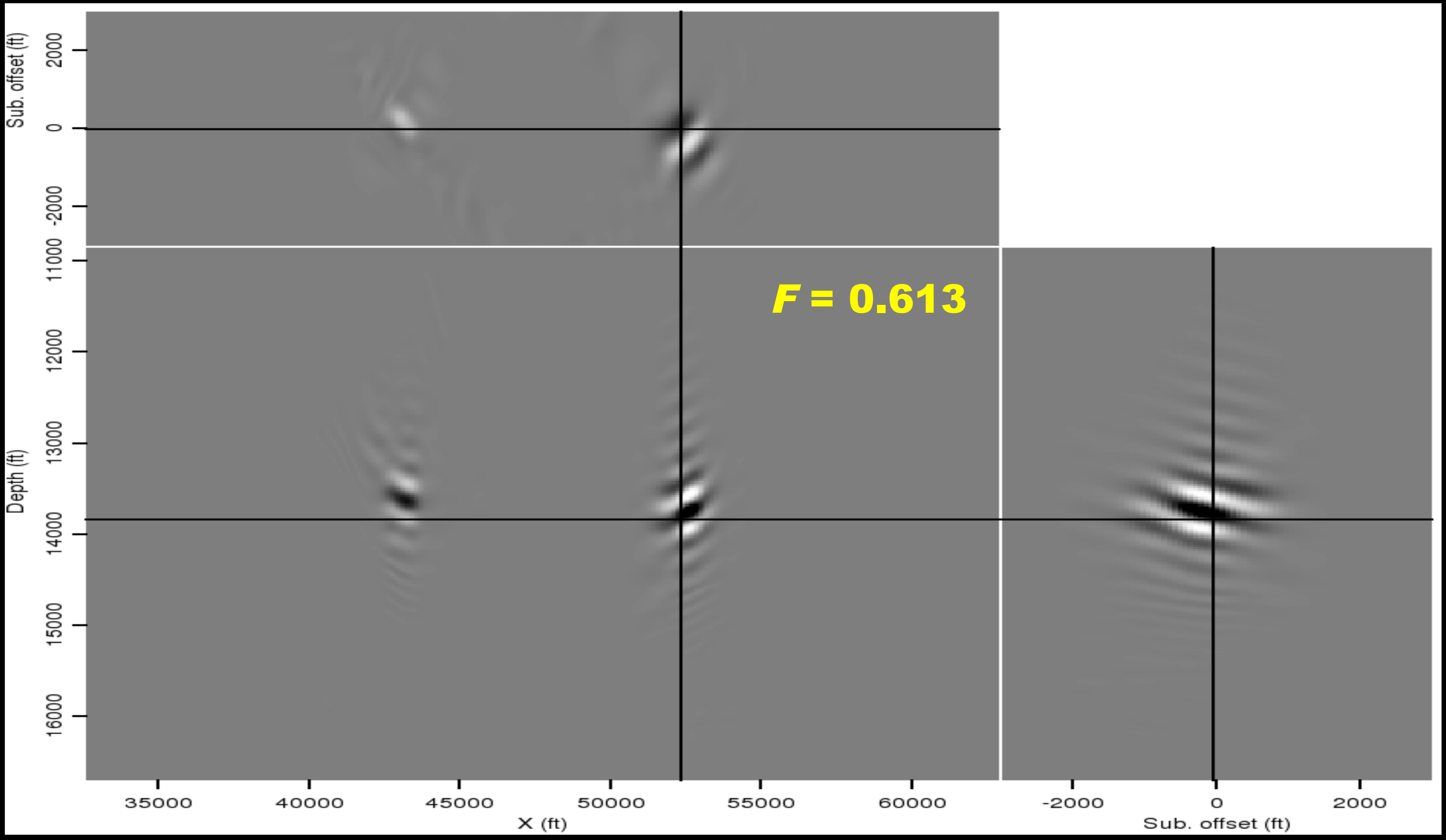
# Extra-salt velocity



# True velocity



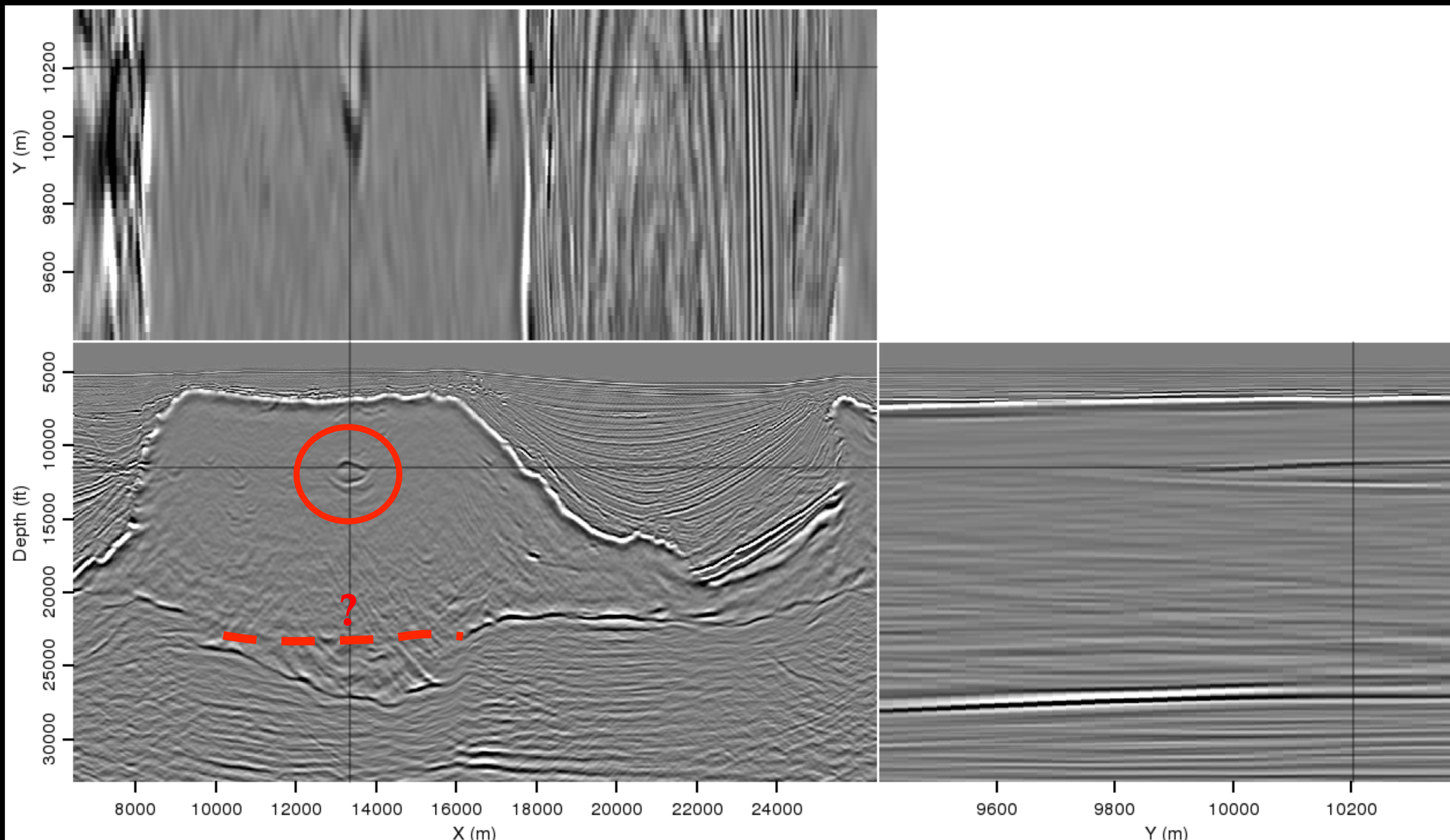
# Slow salt velocity



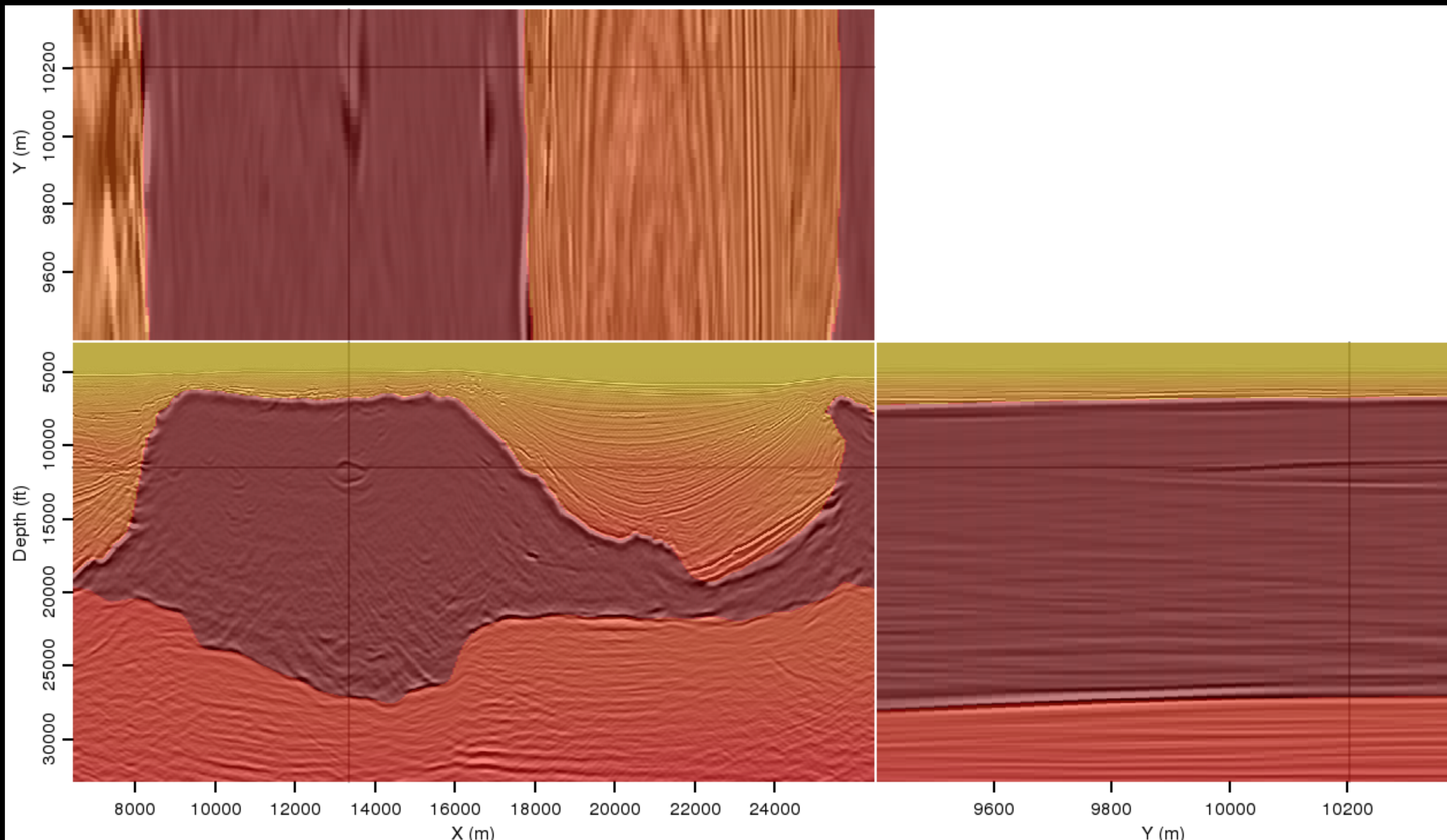
# Upcoming research

- **Extend and test all interpretation, modeling and migration tools to 3D**
- **For a 3D field dataset:**
  - **Generate an initial image**
  - **Use image segmentation to obtain several alternative models**
  - **Test the models via synthesized wavefields**
  - **Re-migrate to obtain a new (improved?) image**

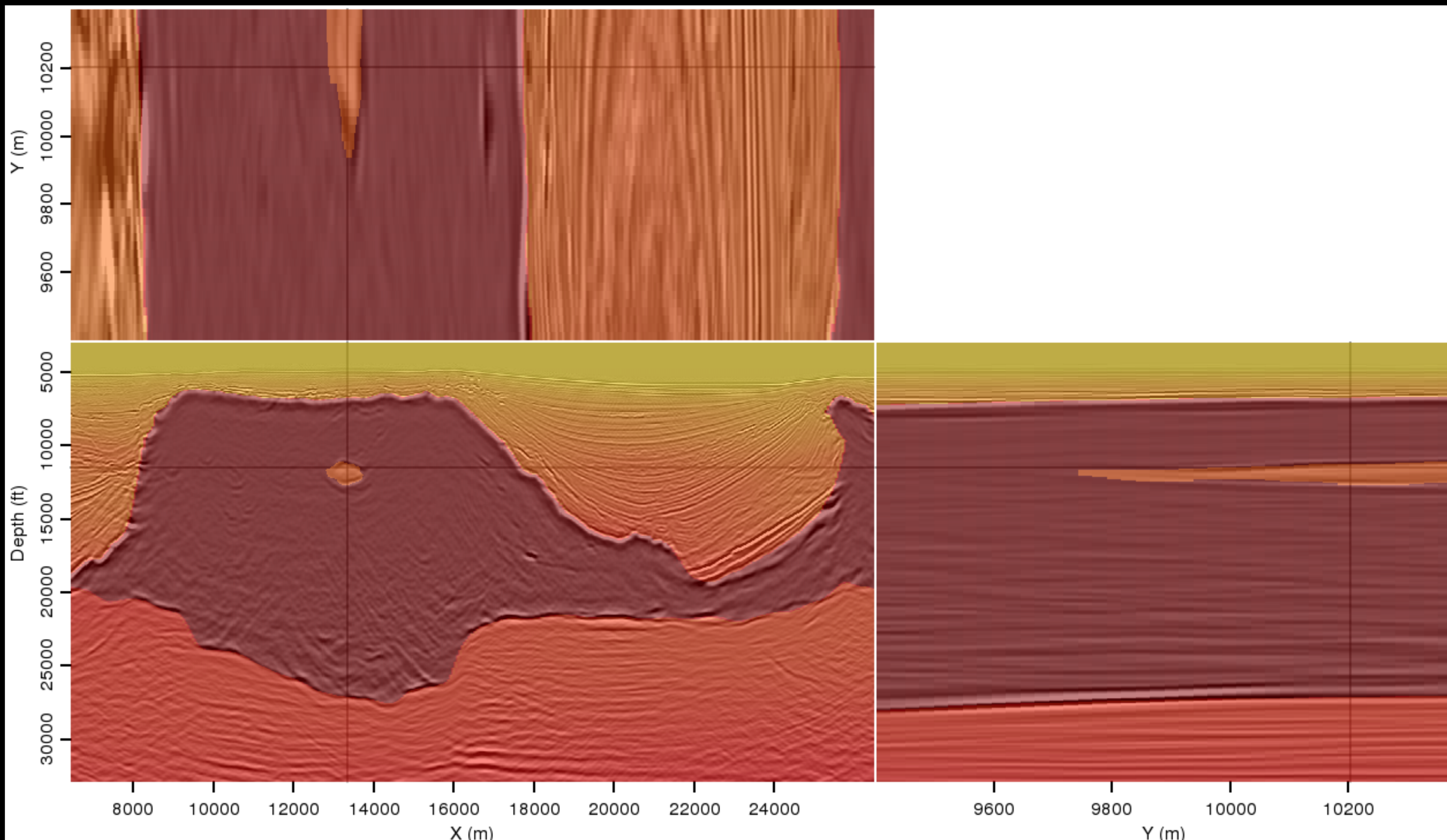
# 3D field image



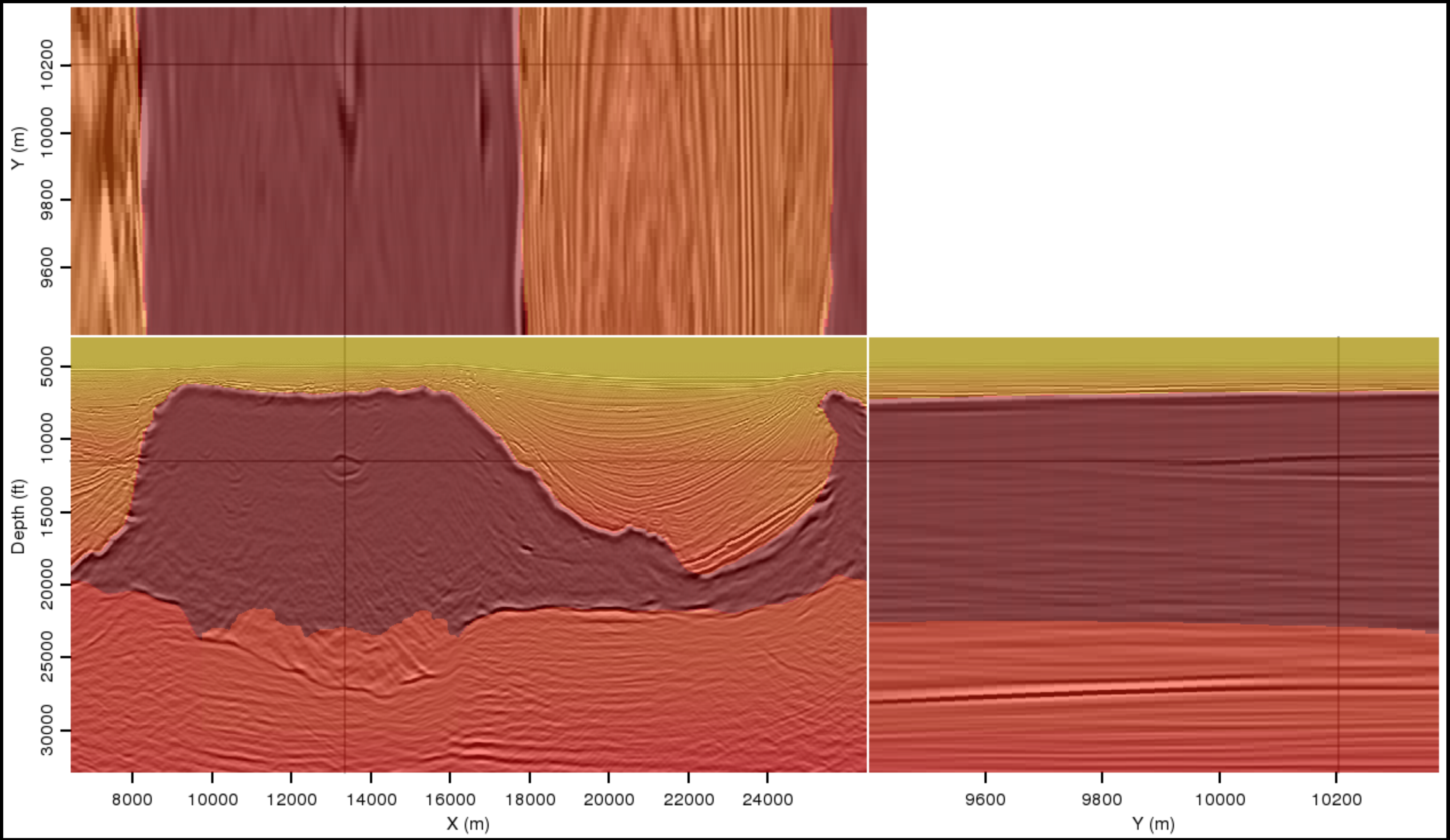
# Original velocity



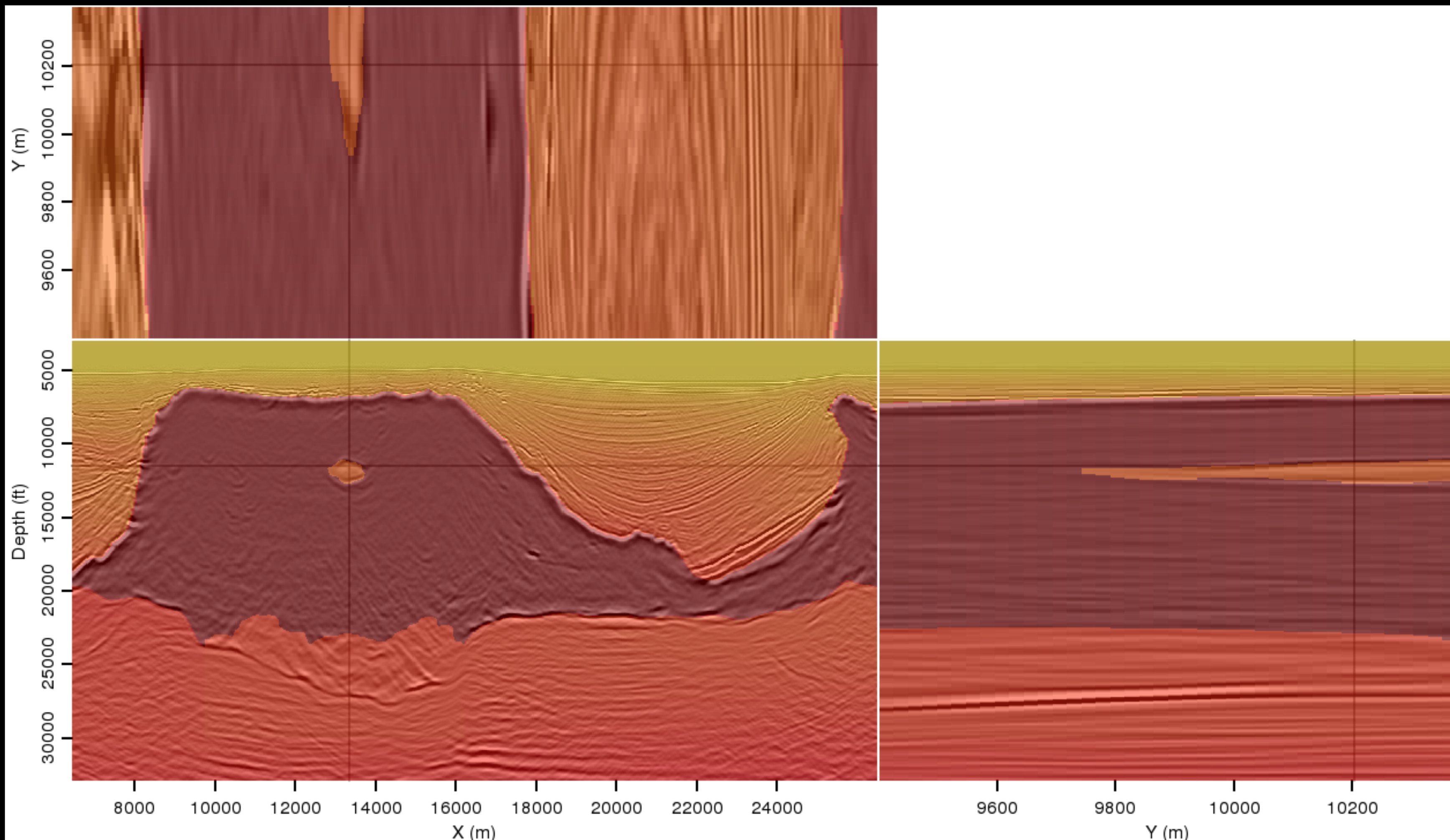
# Alternative model #1



# Alternative model #2



# Alternative model #3



# Conclusions

- **A fast Born modeling and migration scheme can allow for efficient, quantitative evaluation of many possible velocity models**
- **Inclusion of prestack velocity information when synthesizing both source and receiver wavefields helps to identify and correct errors in the initial model**
- **Along with interpretation tools such as image segmentation, this method has the potential to help interpreters build more accurate models more efficiently**

# Acknowledgments

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