Fast velocity model evaluation with synthesized wavefields

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SEP-149: p. 129

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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 an initial image
- Synthesize new datasets with arbitrary acquisition parameters
- Quickly (quantitatively) evaluate relative accuracy of multiple possible models
- Today: show that these goals are achievable on a 3D field dataset

Outline

- **Method**
  - **Areal source generation [Guerra, SEP-141]**
  - **Born modeling/migration [Tang, SEP-144]**
  - **Quantitative model evaluation**
- **2D field example**
- **3D field example**
- **Future work and conclusions**

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**

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

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

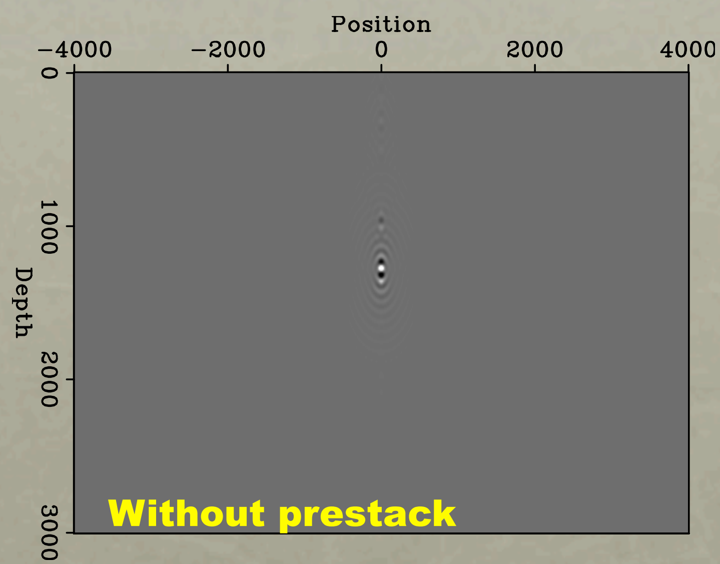
Arbitrary (targeted) coordinates ($\mathbf{x}'$)

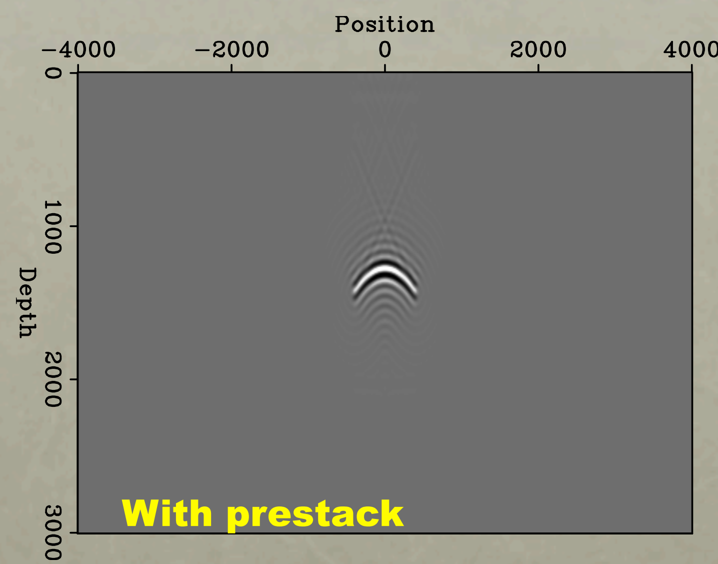
Subsurface offset ($\mathbf{h}$)

Isolated locations along target reflector ($I(\mathbf{x}',\mathbf{h})$)

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

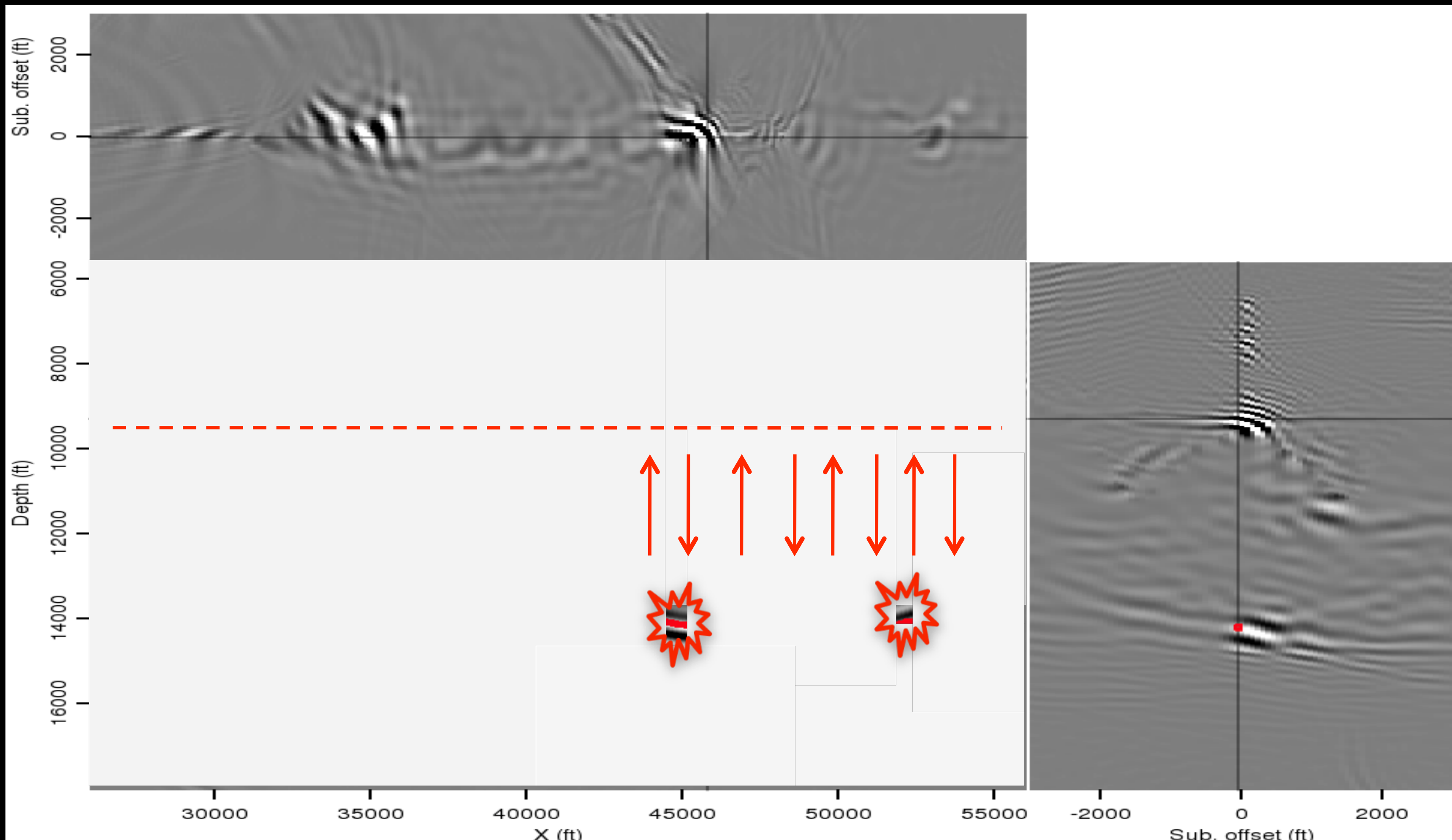
Reflectivity model (initial image)

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

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

Last year: synthetic example



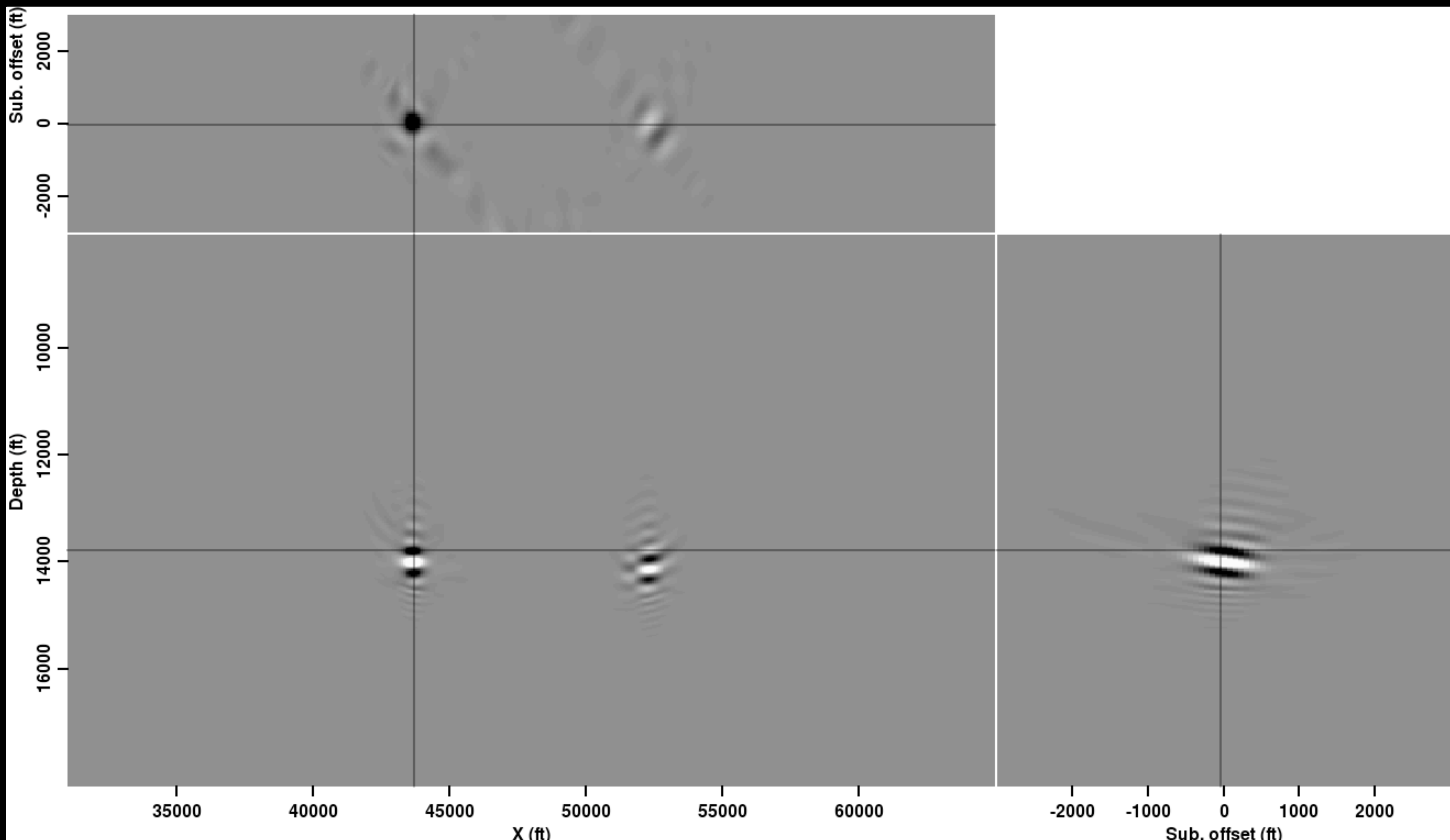
Migration

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

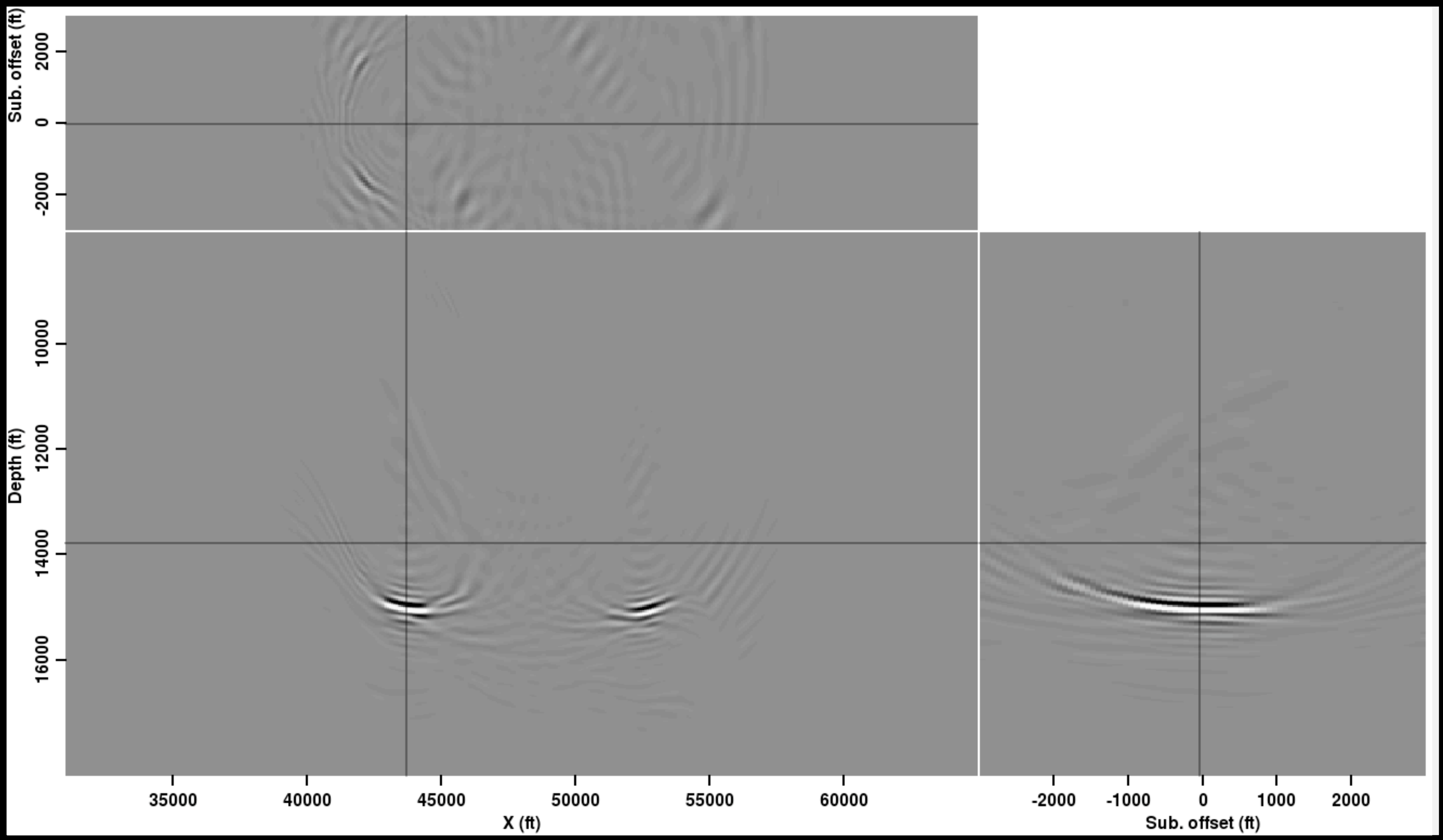
Can be computed using any velocity model!

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

True velocity result

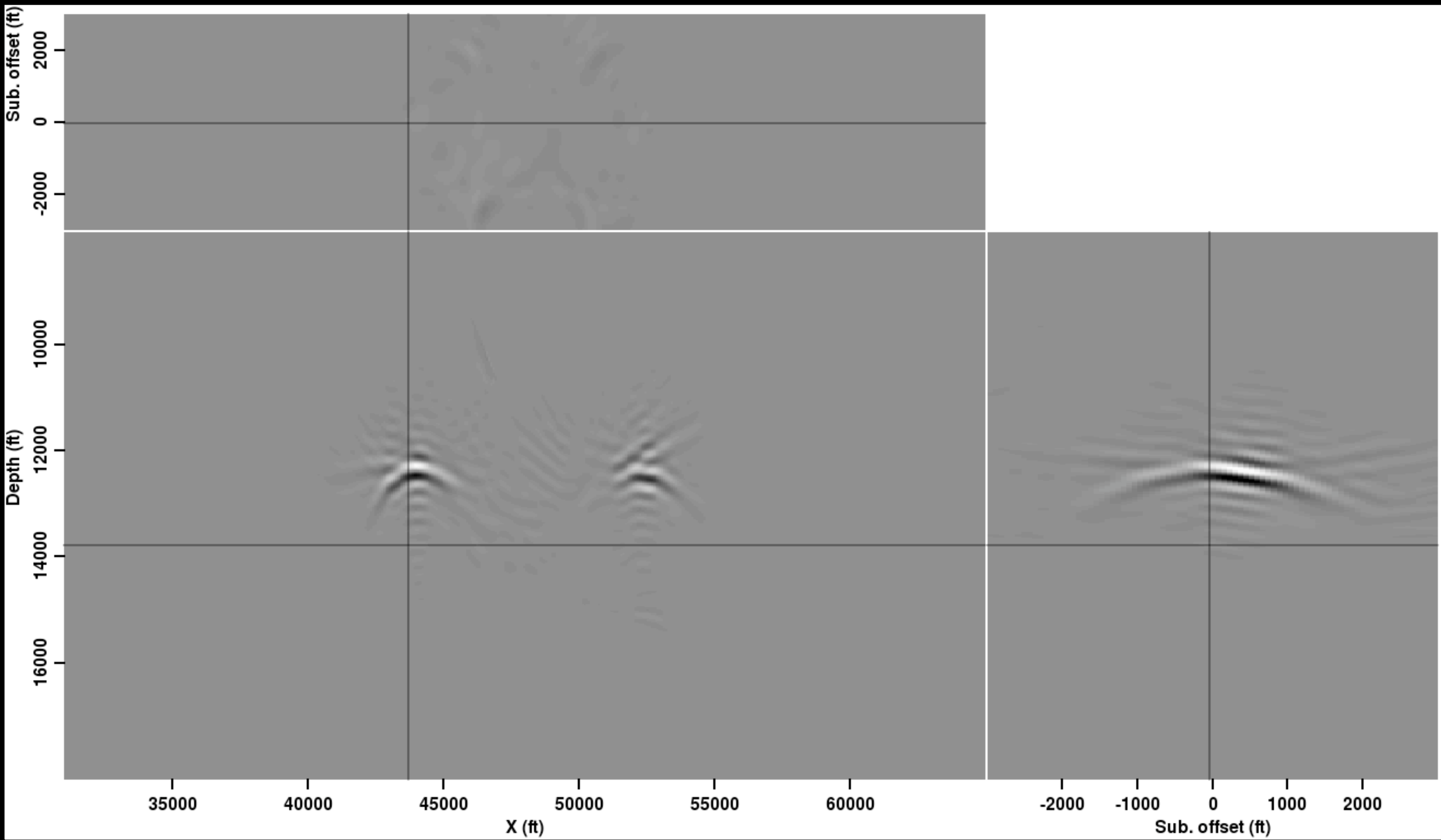


5% fast



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)

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
a **= optional weight**

0 < *F* ≤ 1 (perfectly focused)

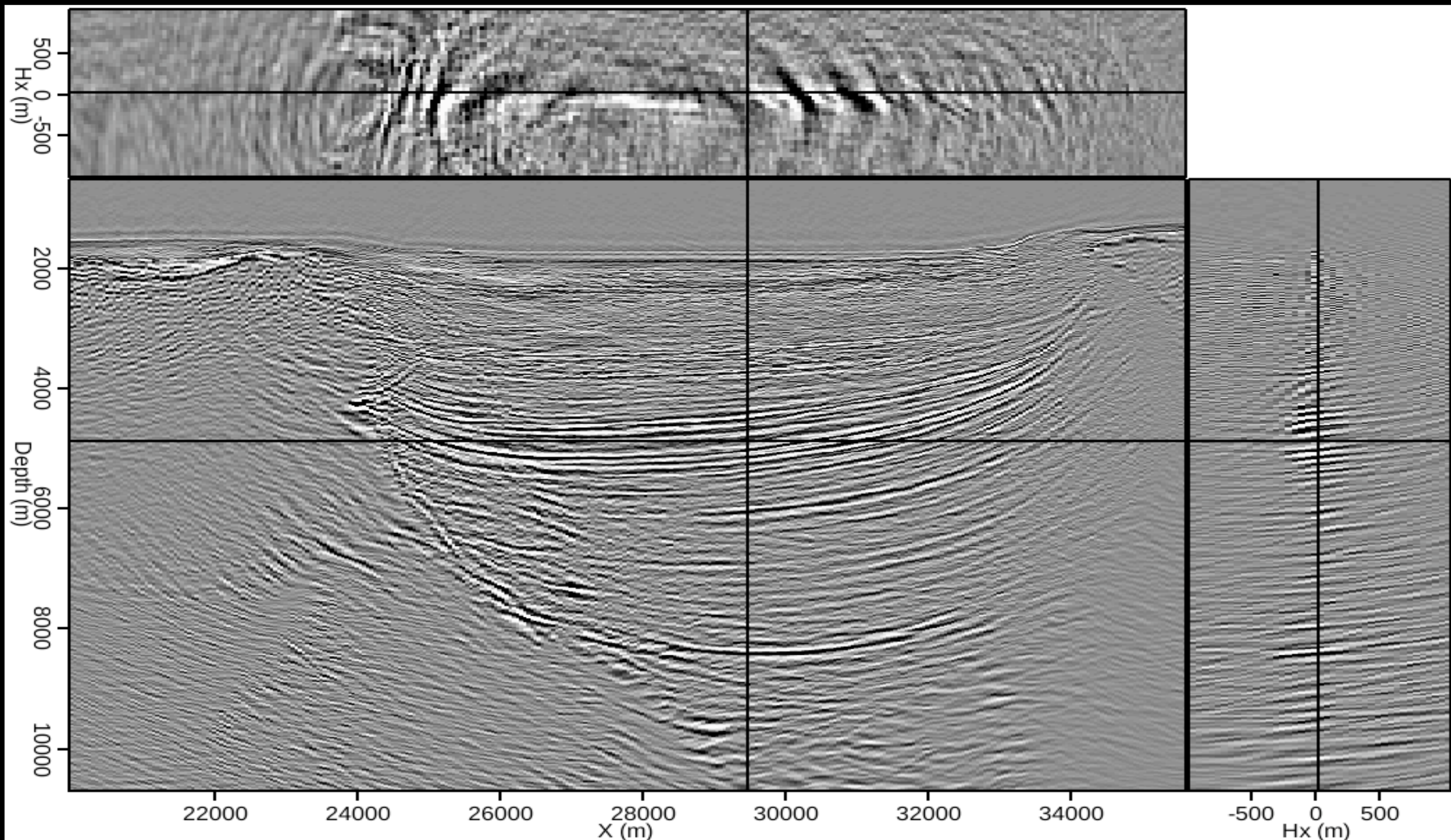
Field dataset

- Wide-azimuth, Gulf of Mexico
  - Courtesy of WesternGeco
  - Provided velocity == “true” model
- 2D: 200 shots, 1876 x 675 model
- 3D: 200 shots (25 x 8), 1200 x 90 x 30 model
- Ultimately: WAZ characteristics should improve imaging of subsalt reflectors, allow for testing of multiple salt scenarios

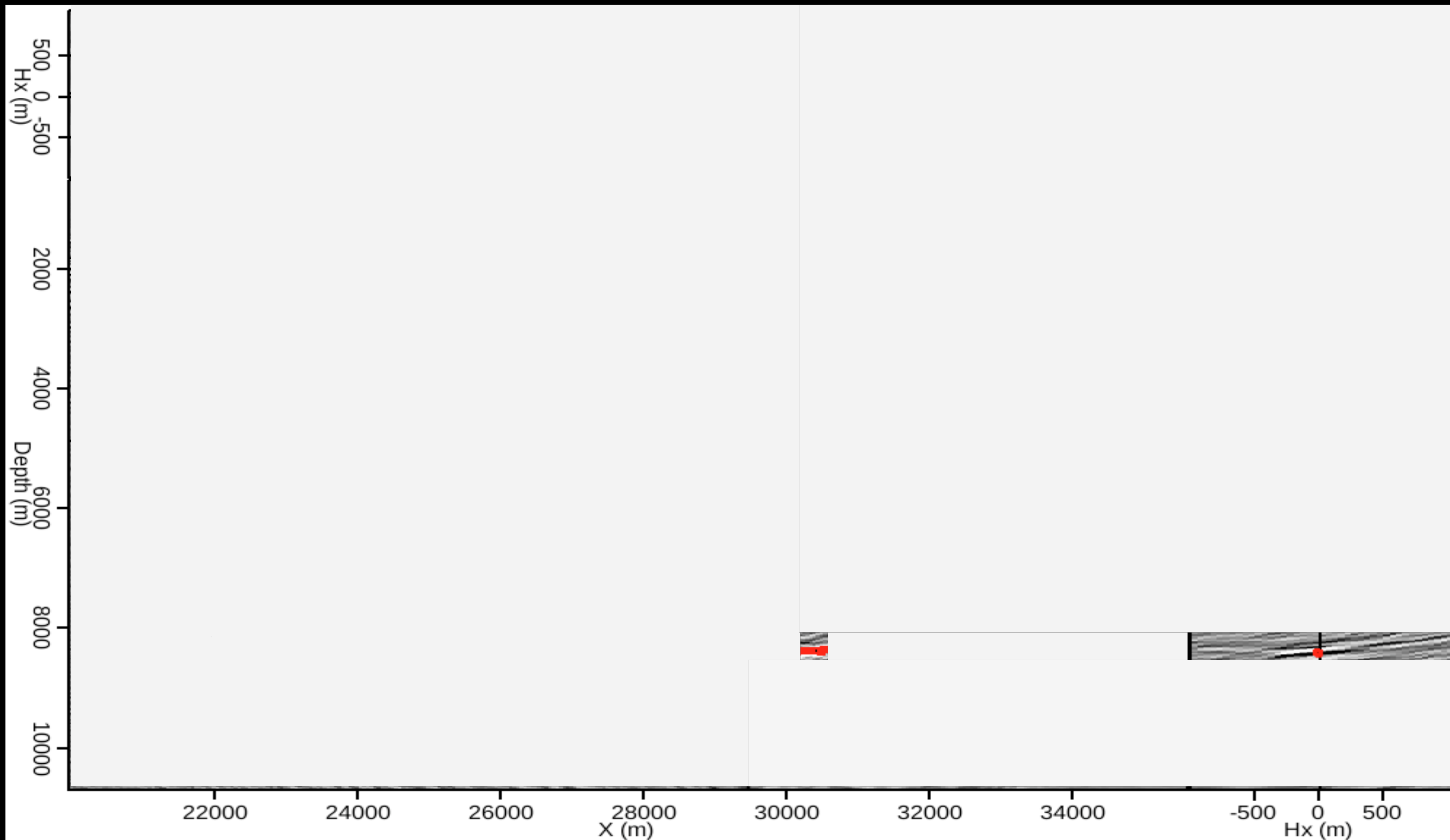
2D test #1

- Initial image: “true” velocity
  - Source and receiver wavefields modeled with true velocity
- Migrate the synthesized wavefields with true, 5% fast, and 5% slow models

2D initial image: true model

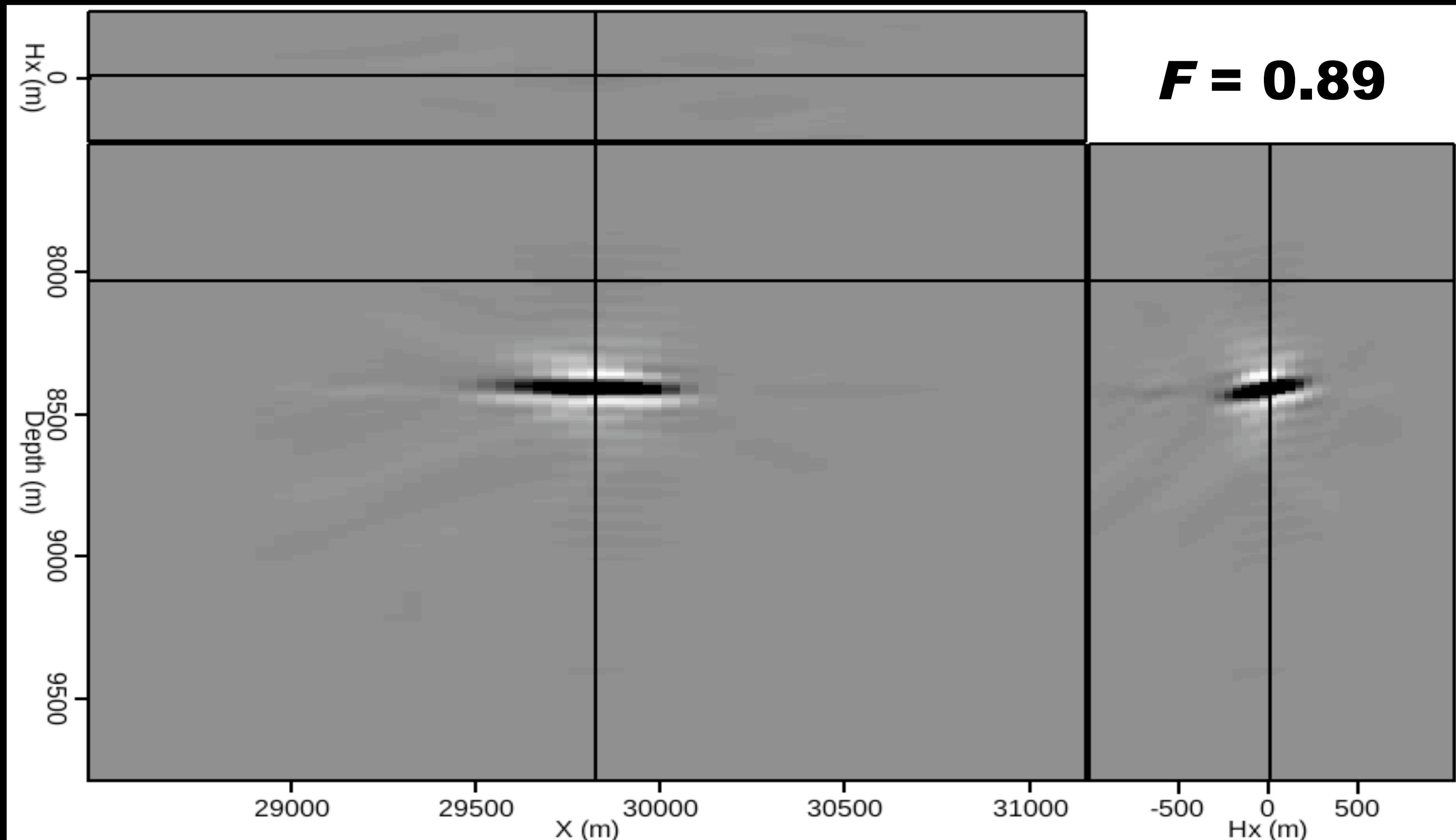


Target reflector



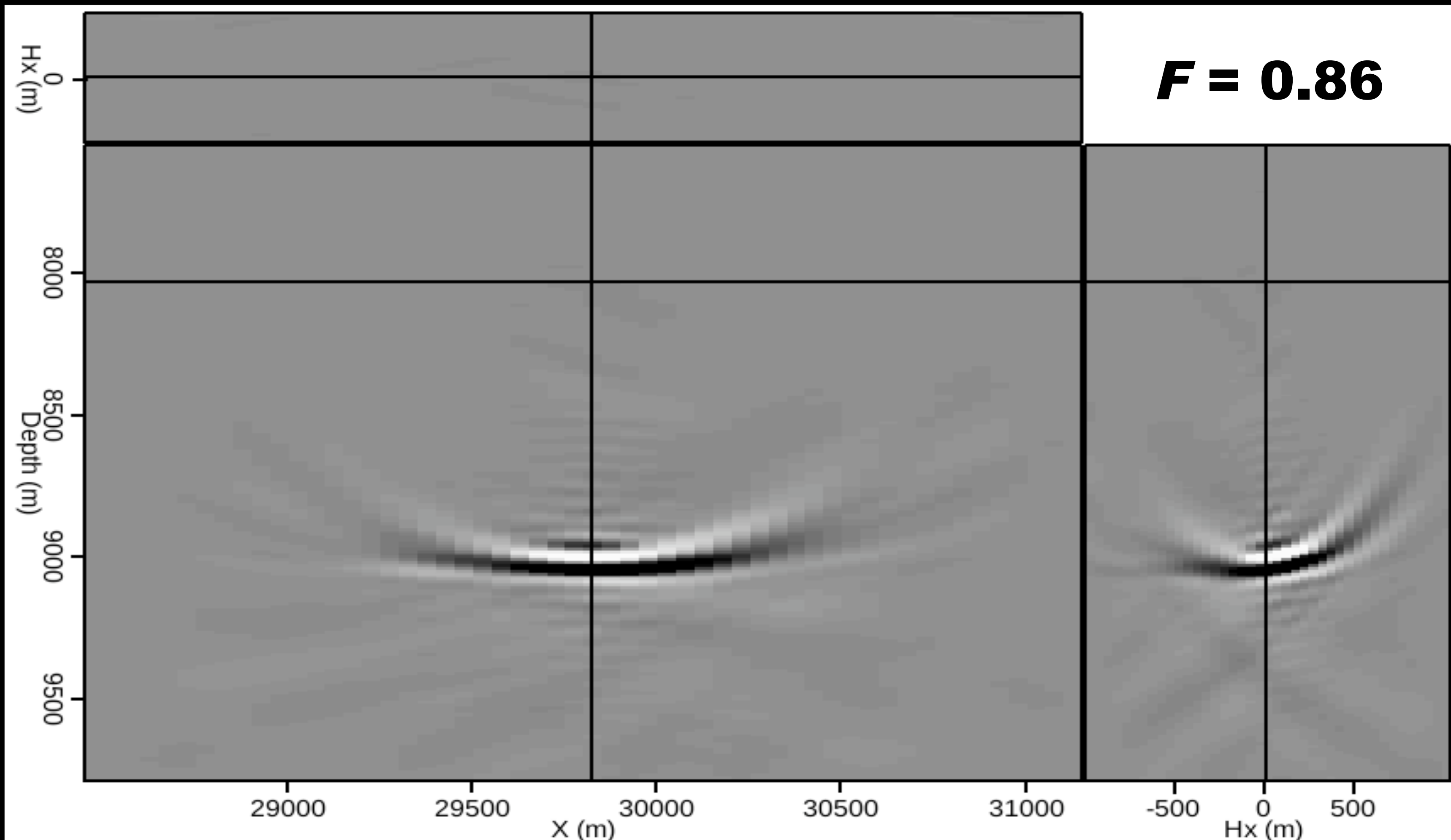
Method ◆ 2D Example ◆ 3D Example ◆ Future work

Born image: true model

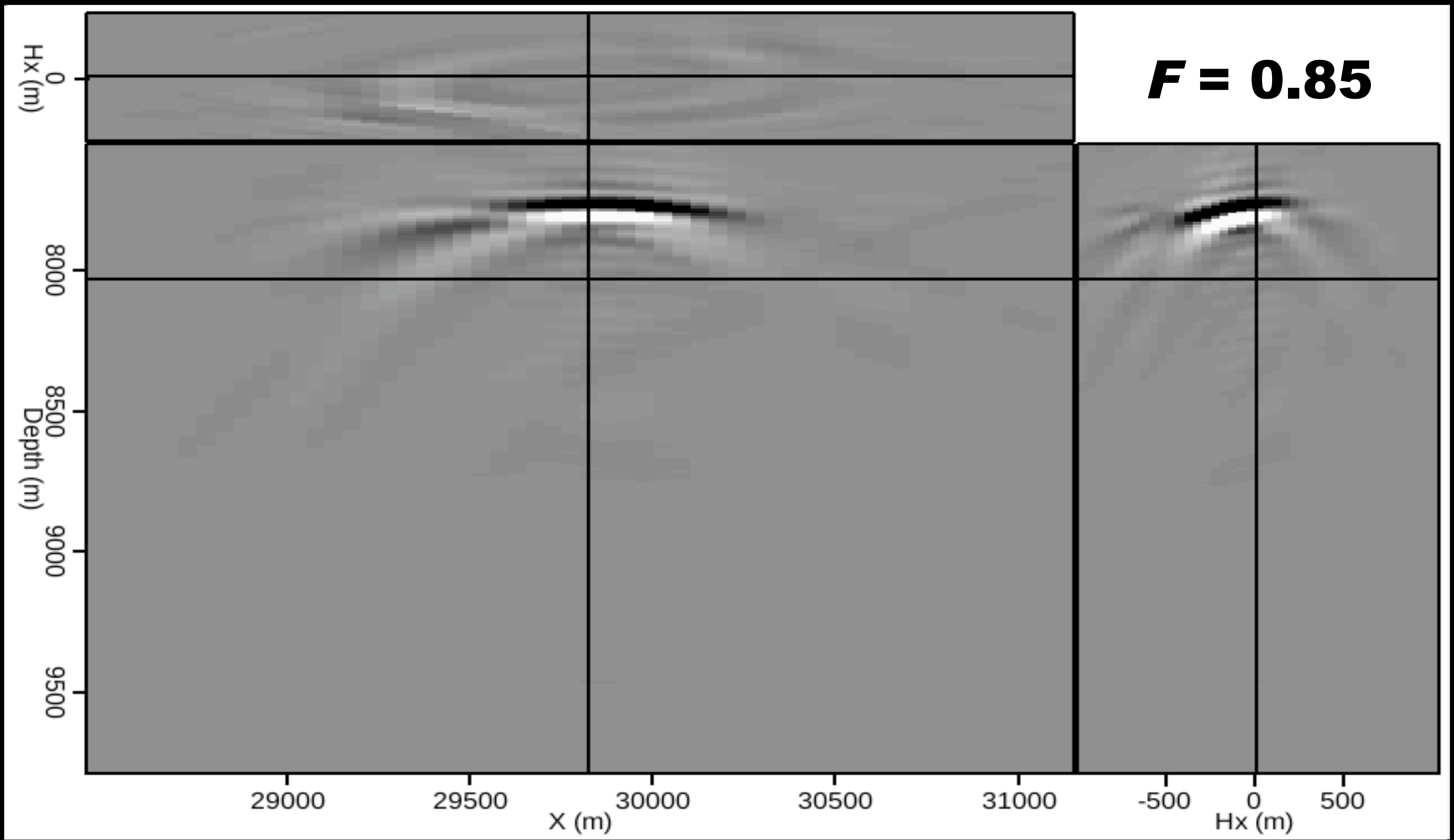


Method ◆ 2D Example ◆ 3D Example ◆ Future work

Born image: fast model



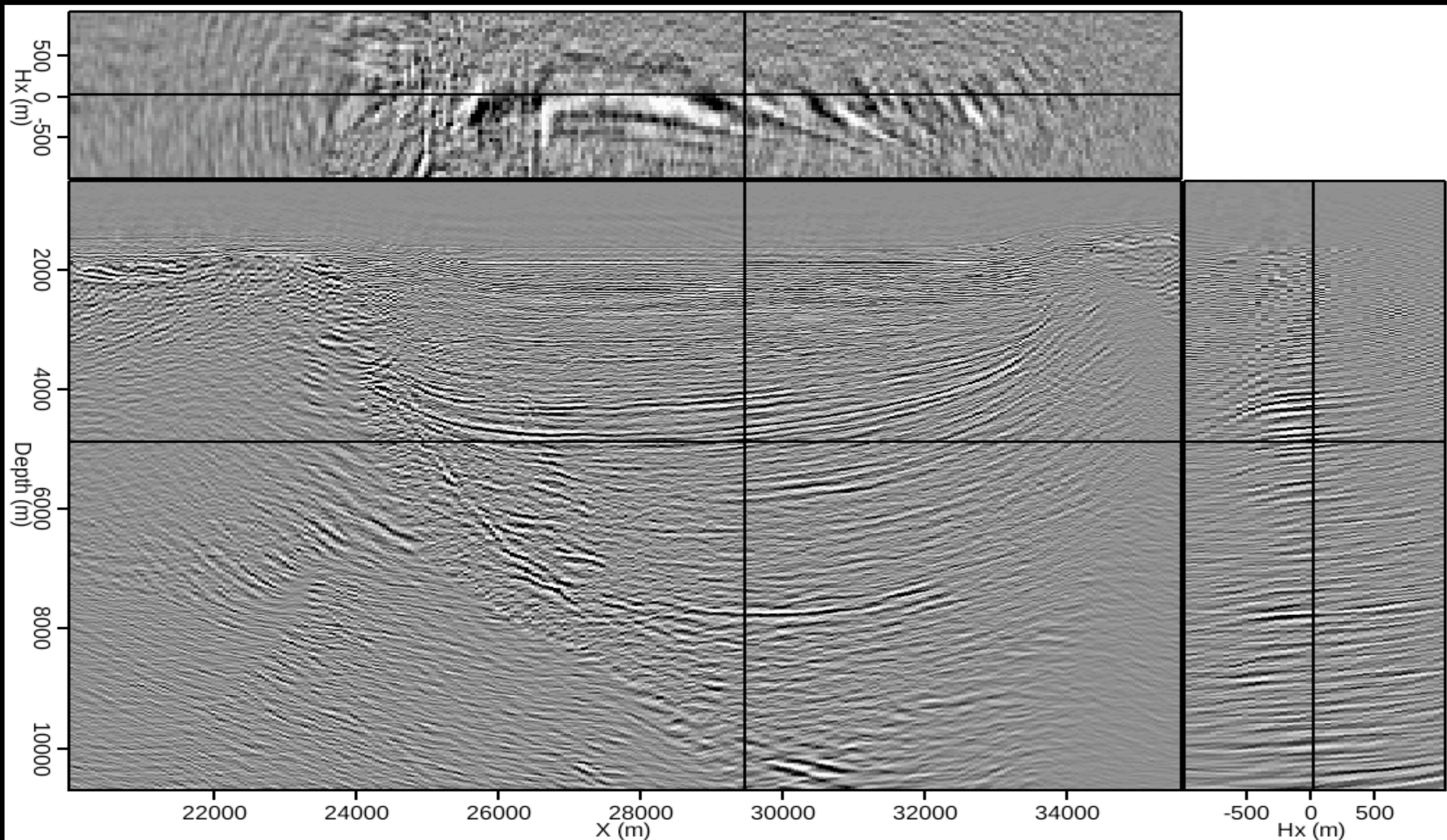
Born image: slow model



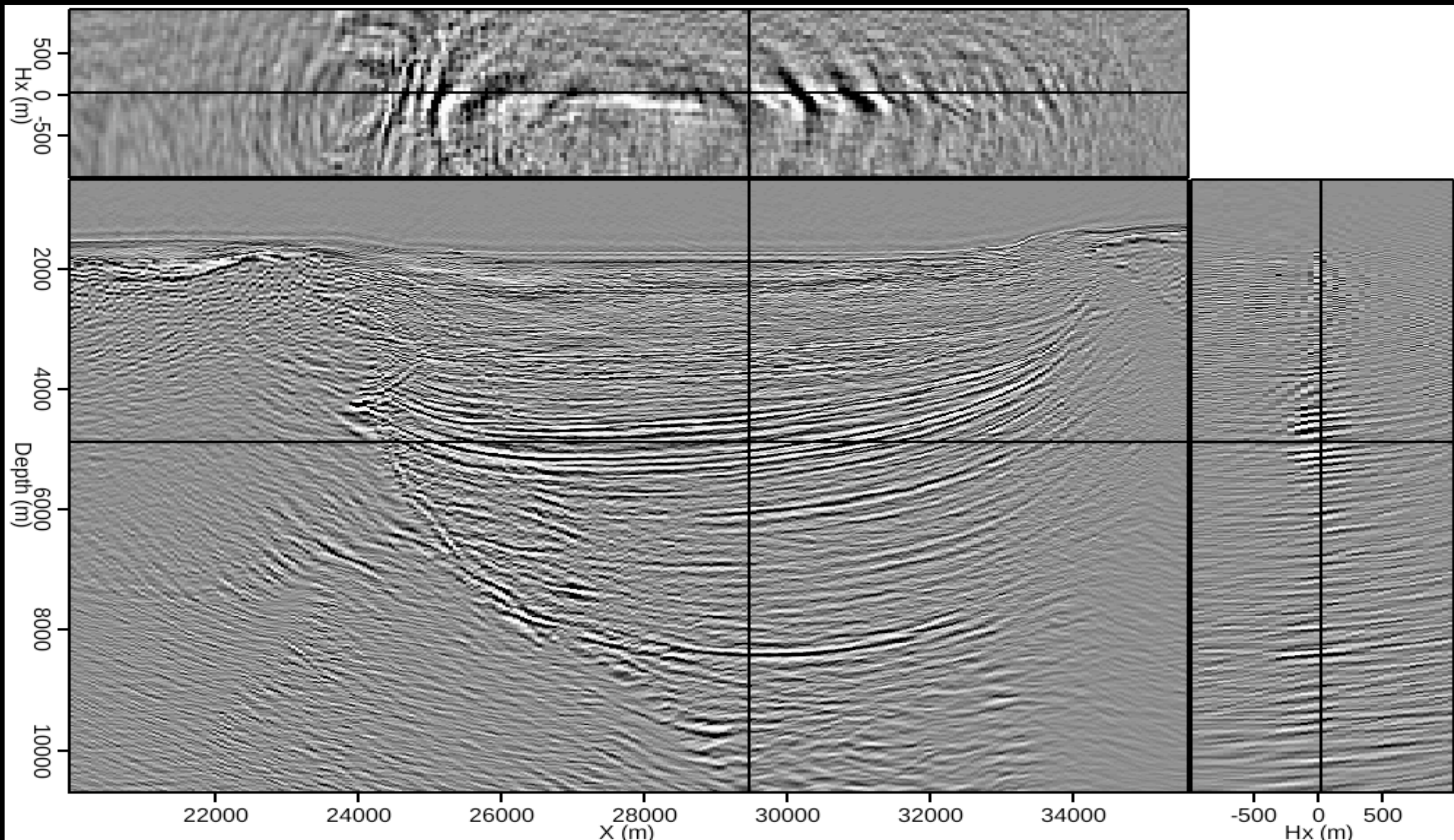
2D test #2

- **Initial image: “slow” velocity**
  - **Source and receiver wavefields modeled with slow velocity**
- **Migrate the synthesized wavefields with slow, true, and fast models**

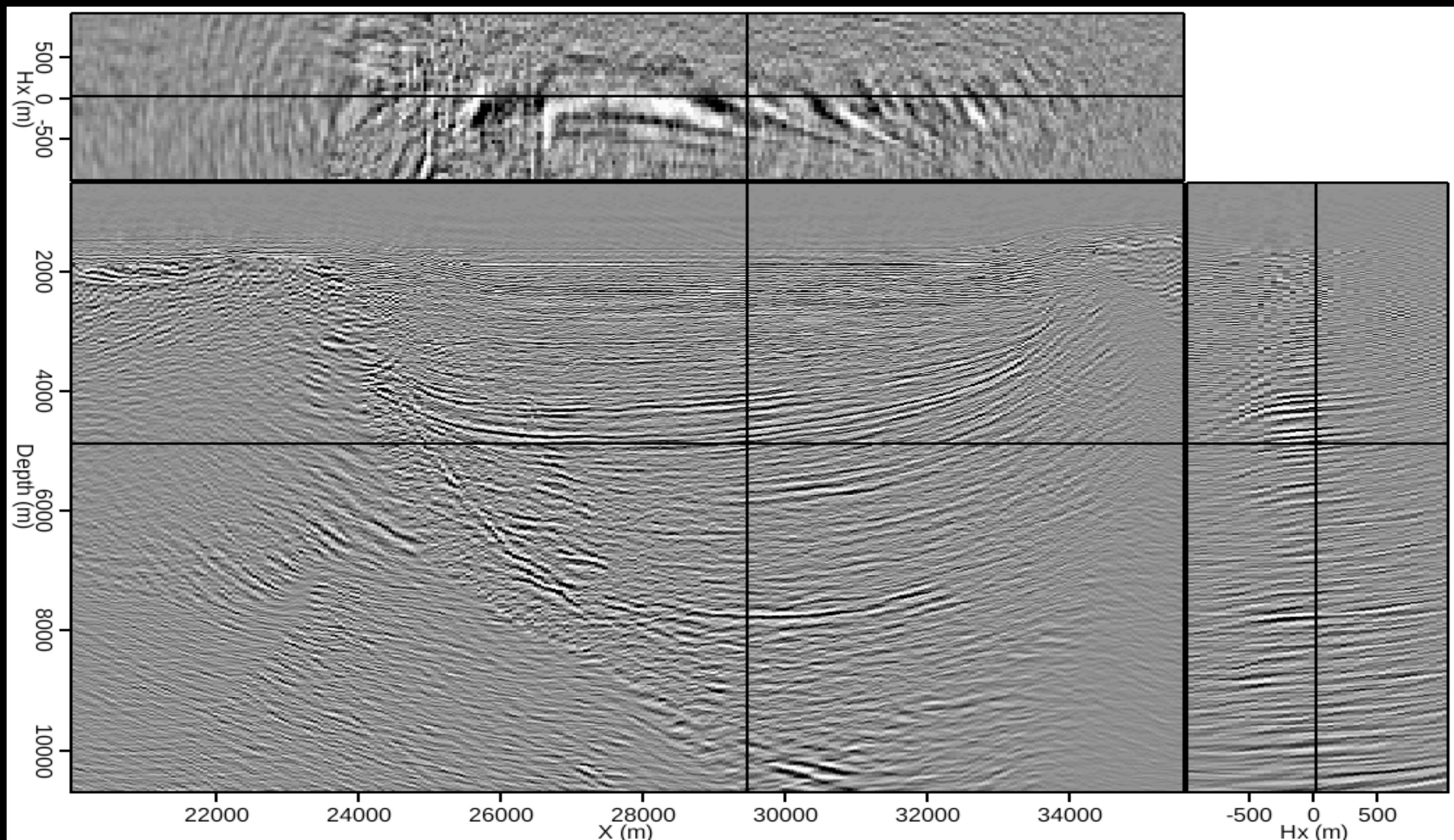
2D initial image: slow model



2D initial image: true model

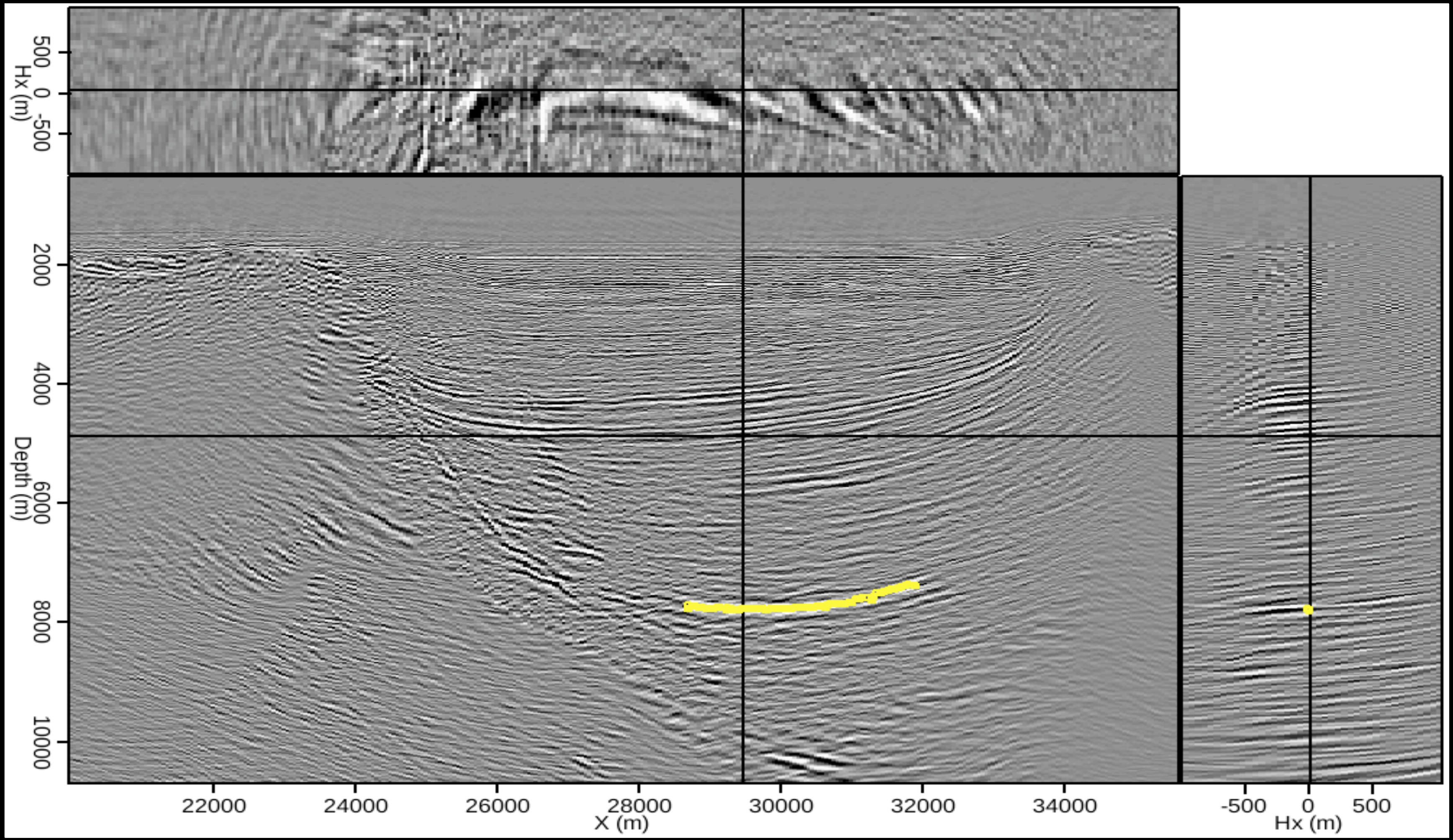


2D initial image: slow model



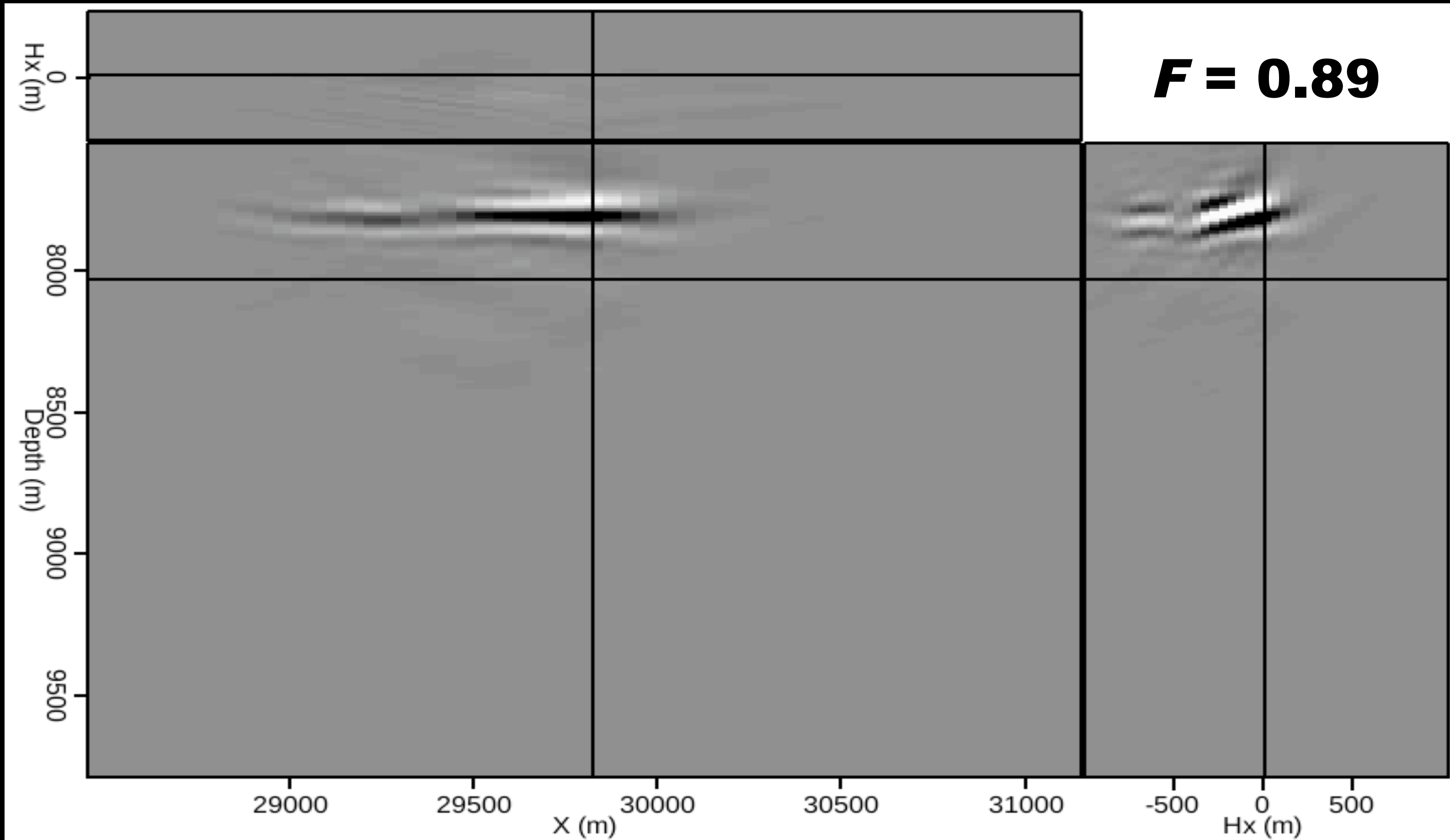
Method ◆ 2D Example ◆ 3D Example ◆ Future work

Target reflector

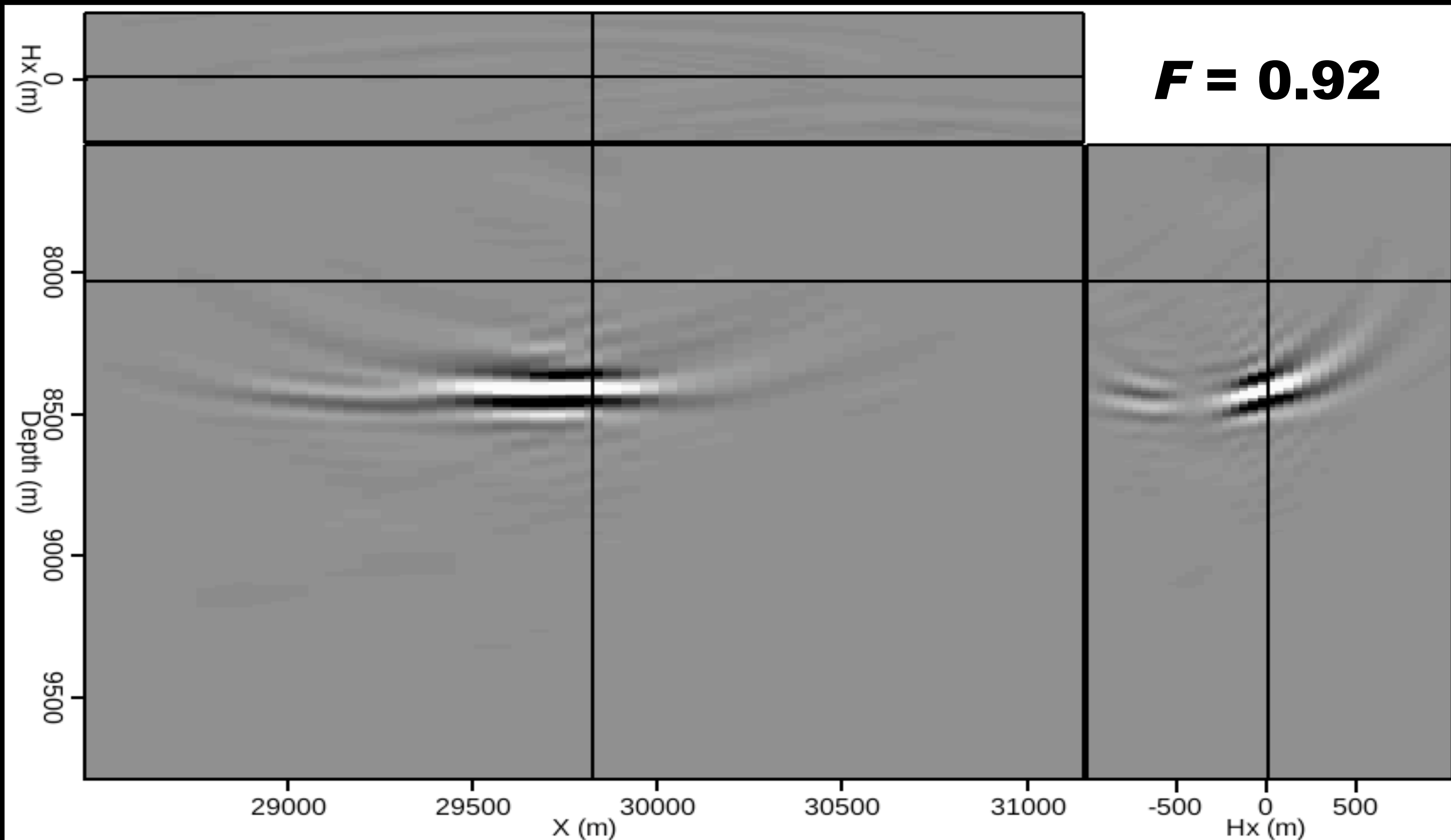


Method ◆ 2D Example ◆ 3D Example ◆ Future work

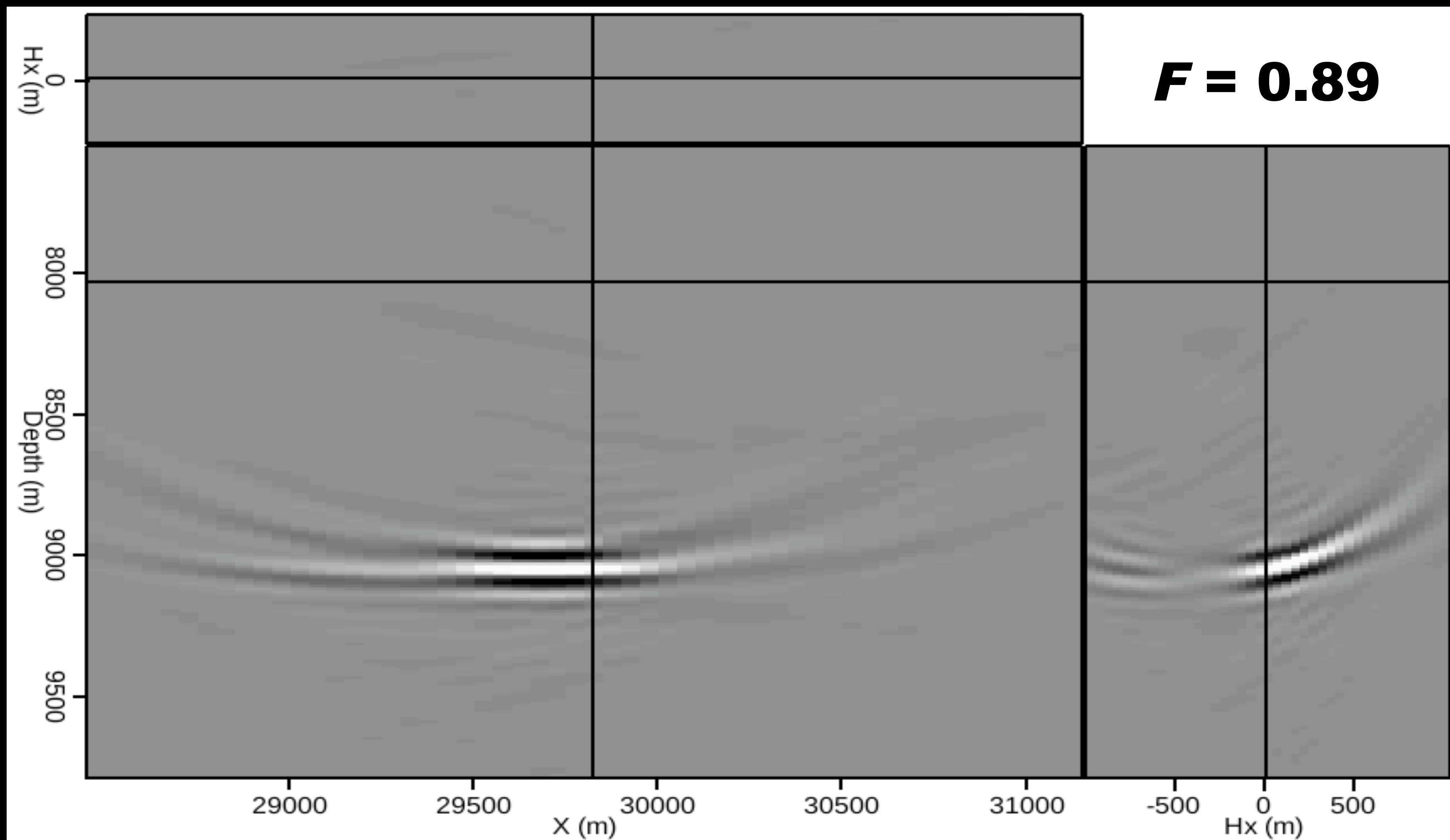
Born image: slow model



Born image: true model



Born image: fast model



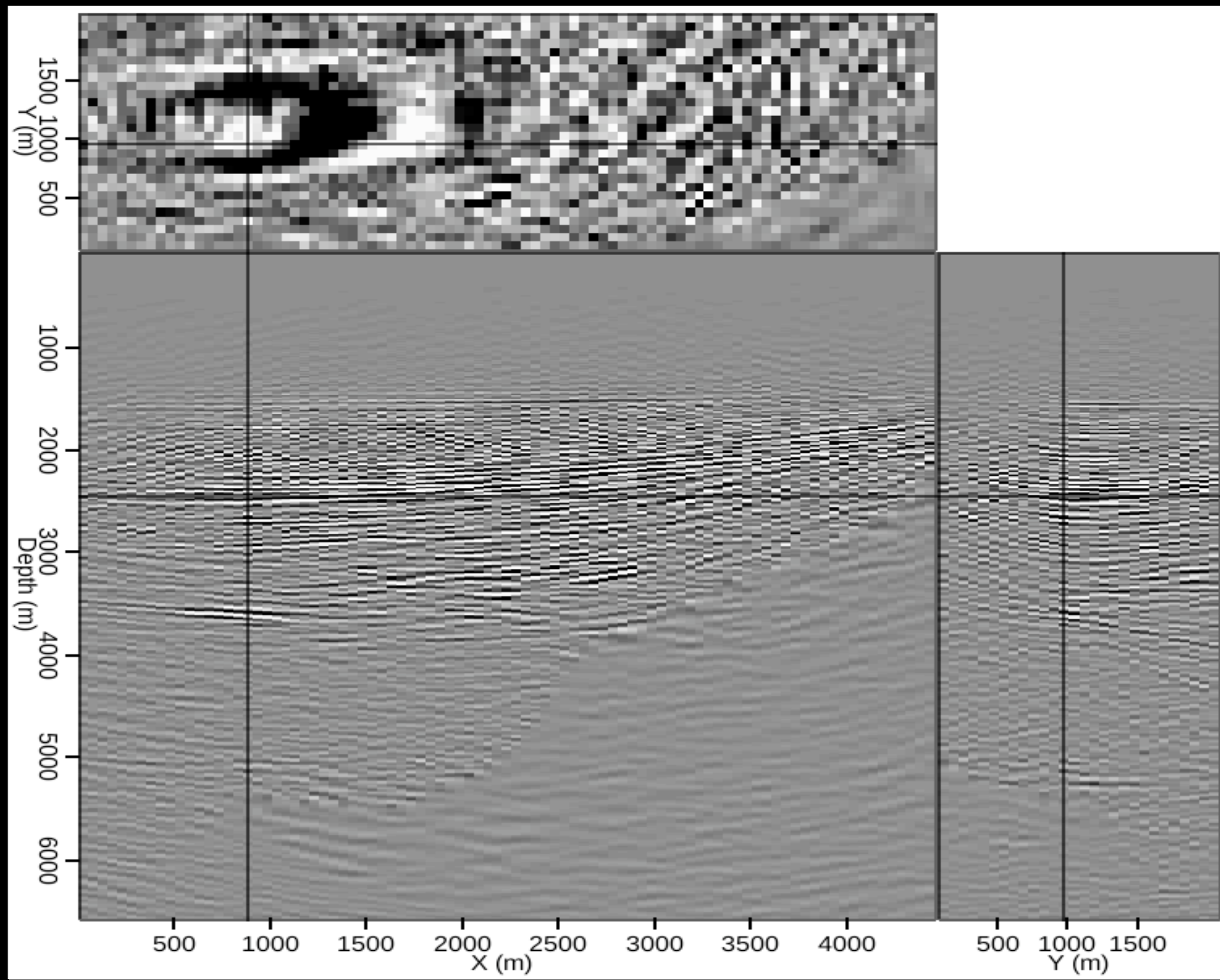
2D recap: *F* values

	Initial Model	
Migration model:	**"True" velocity**	**Slow Velocity**
Slow	**0.85**	**0.89**
True	**0.89**	**0.92**
Fast	**0.86**	**0.89**

3D test #1

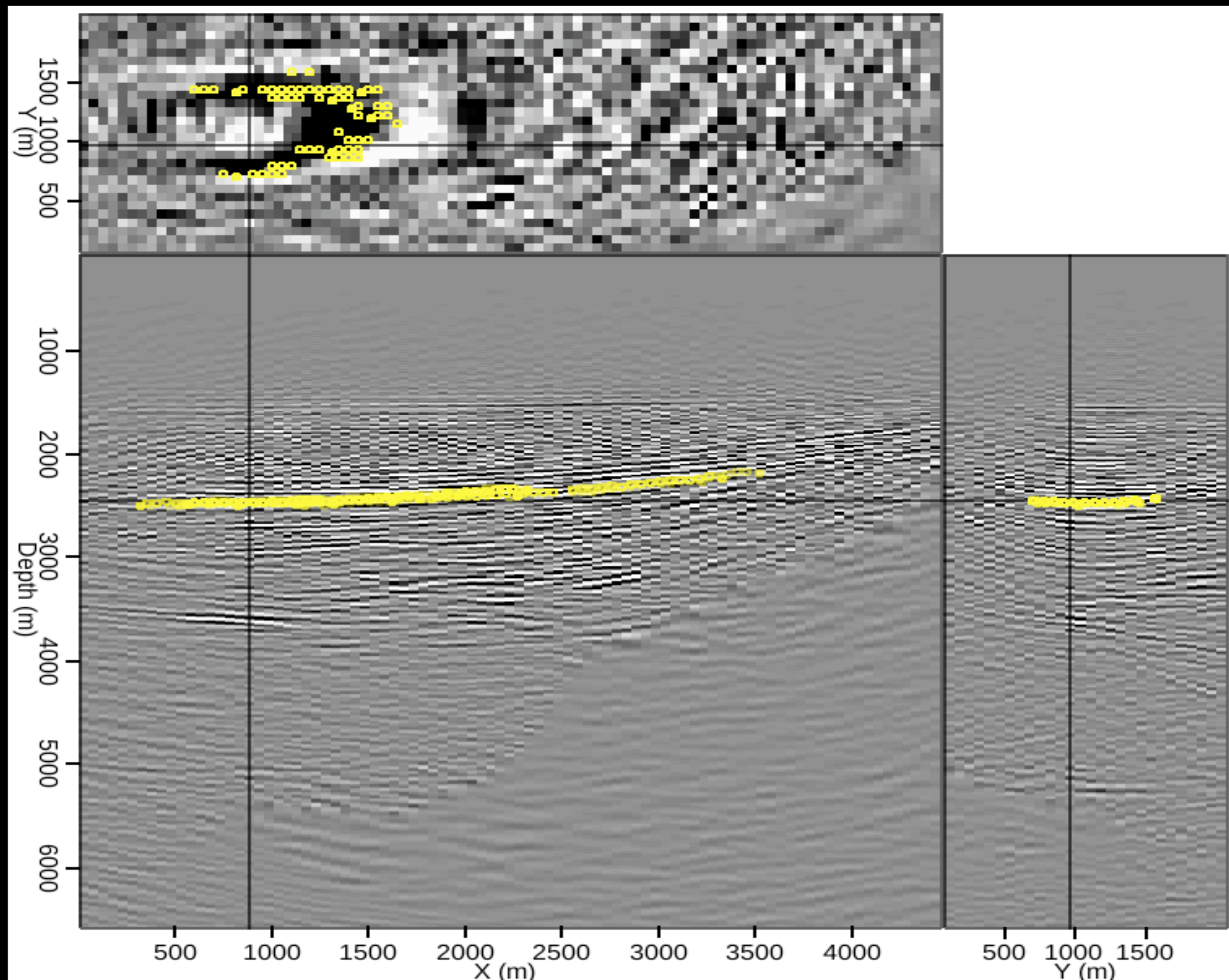
- Initial image: "true" velocity
  - Source and receiver wavefields modeled with true velocity
- Migrate the synthesized wavefields with true, slow, and fast models

3D image: true model

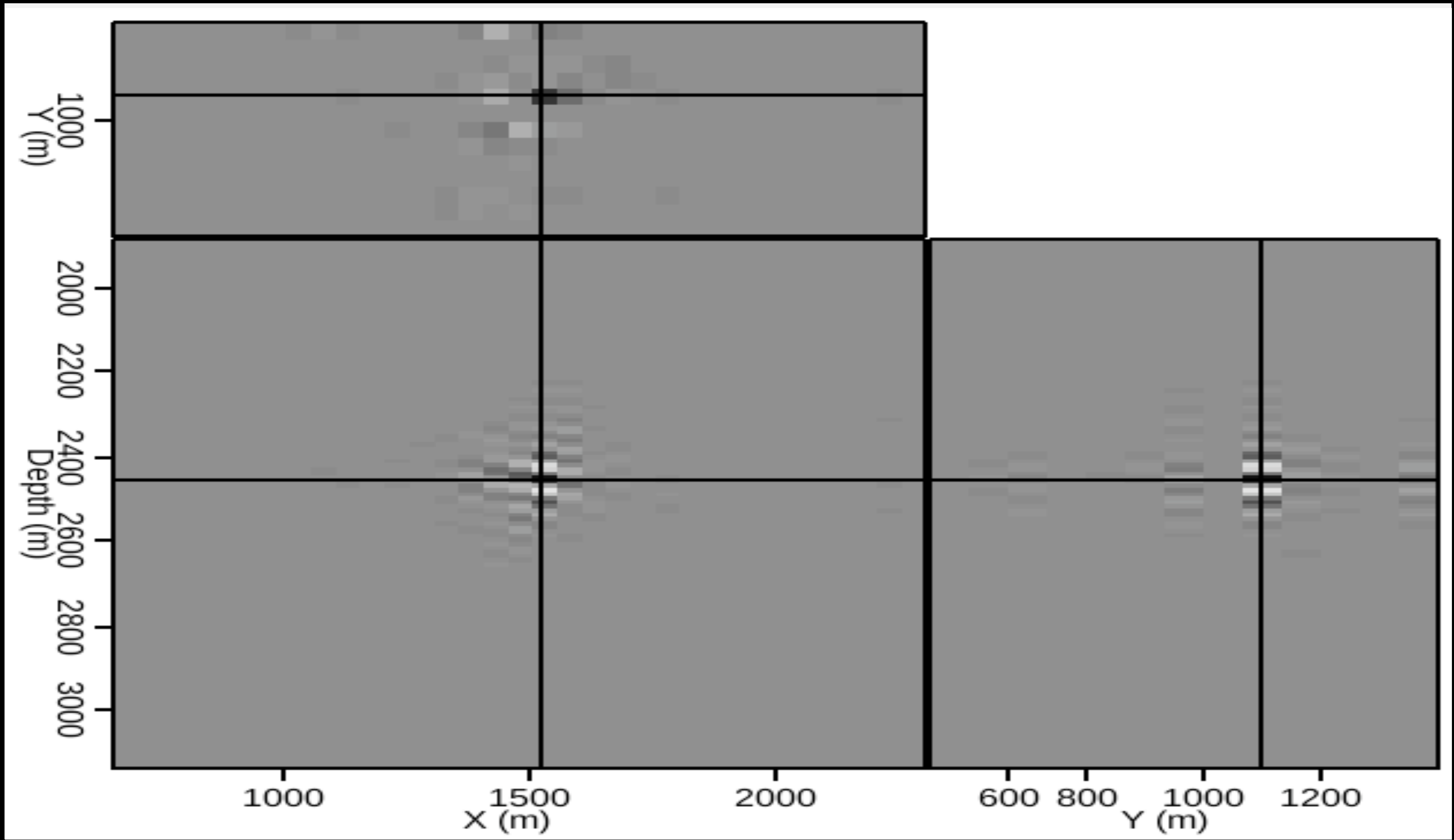


Method ◆ **2D Example** ◆ **3D Example** ◆ **Future work**

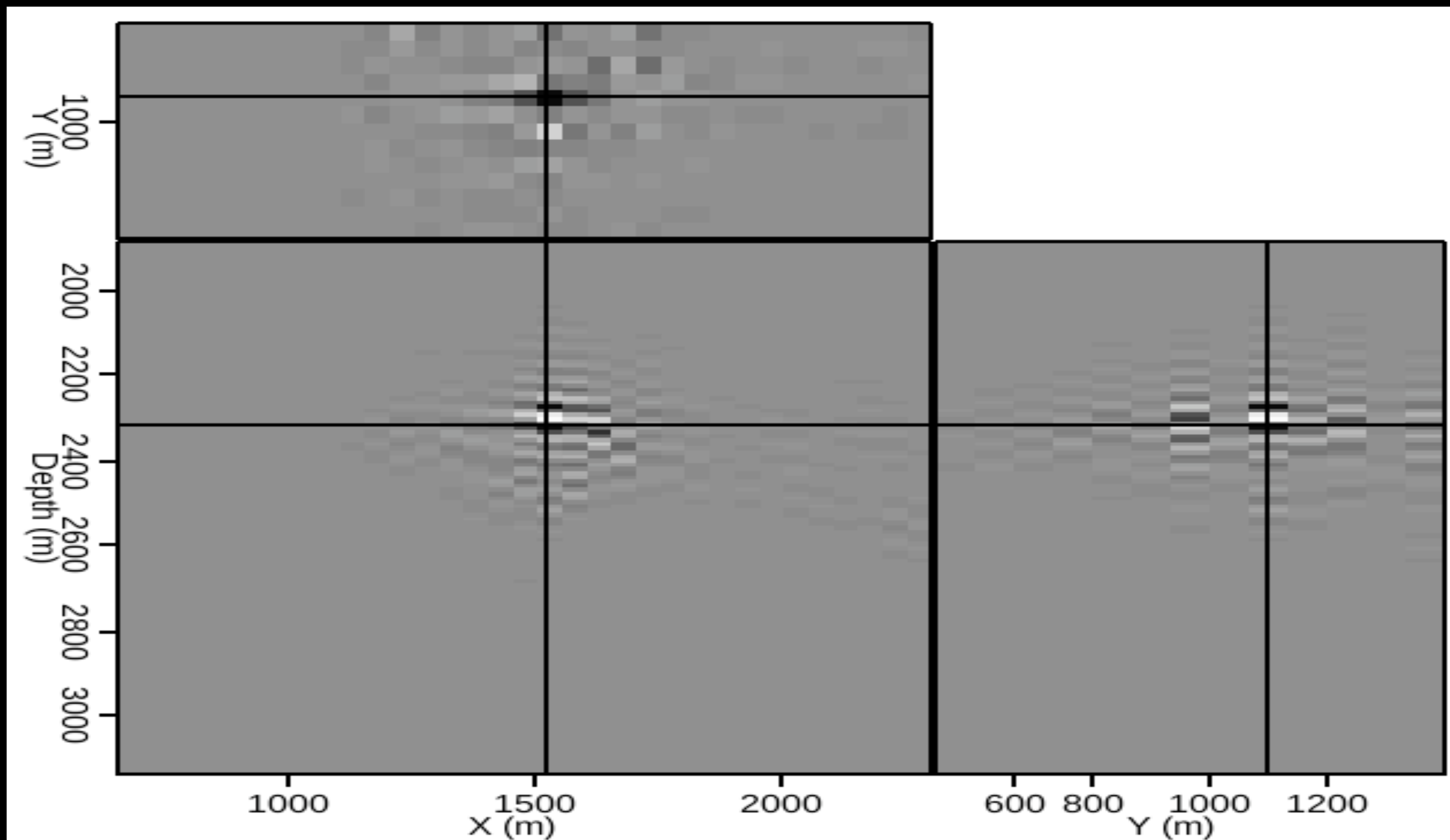
Target reflector



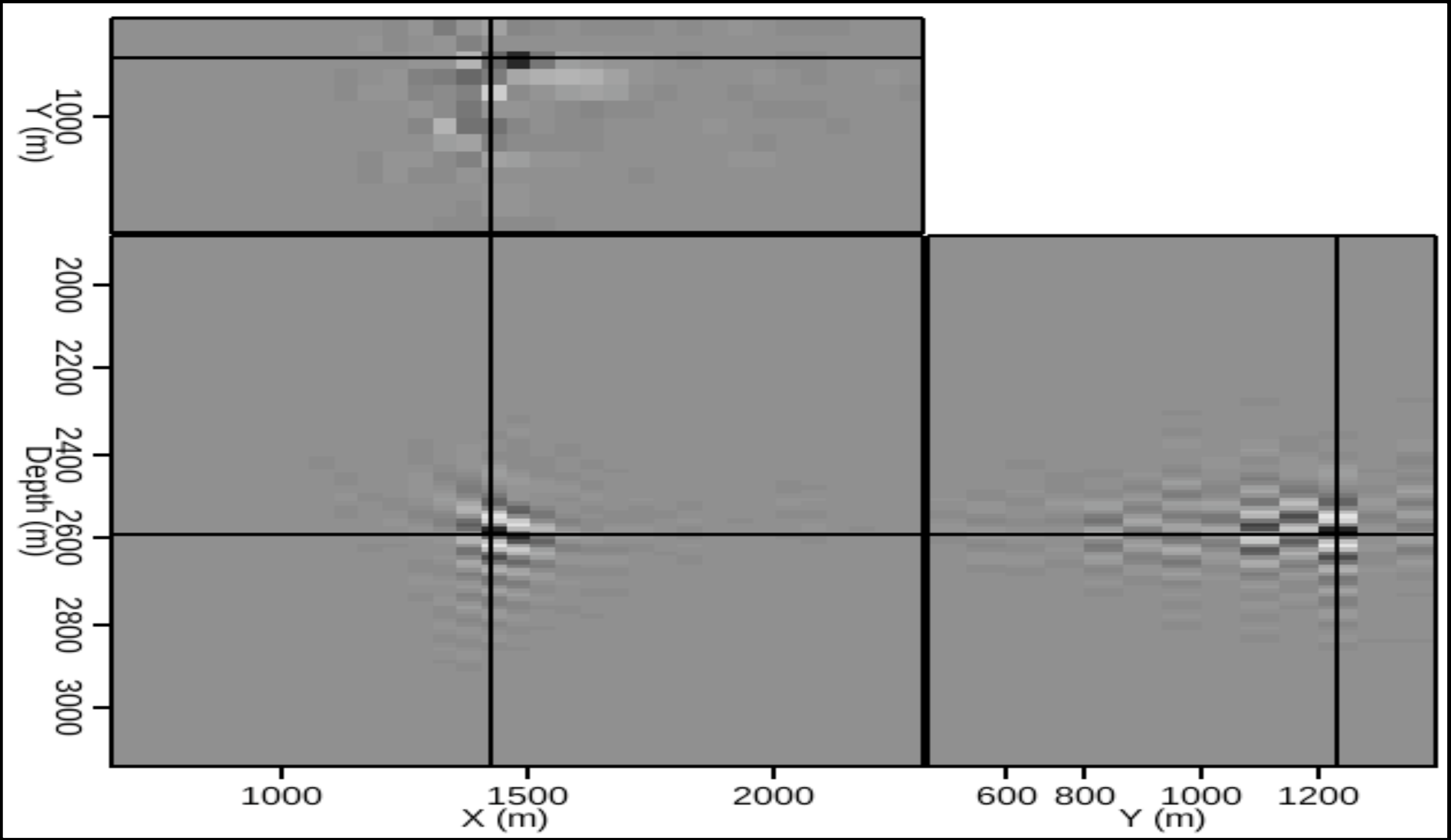
Born image: true model



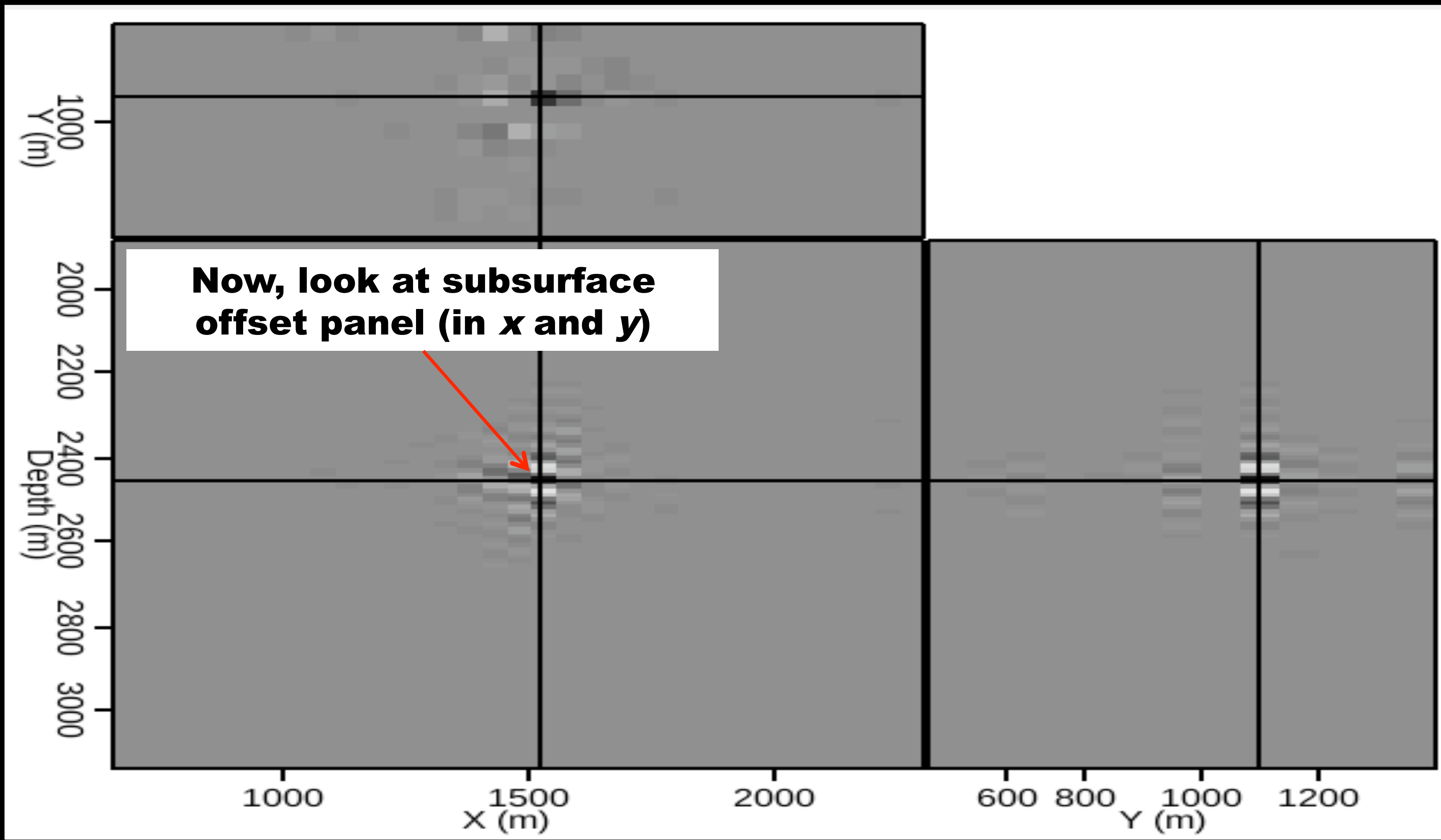
Born image: slow model



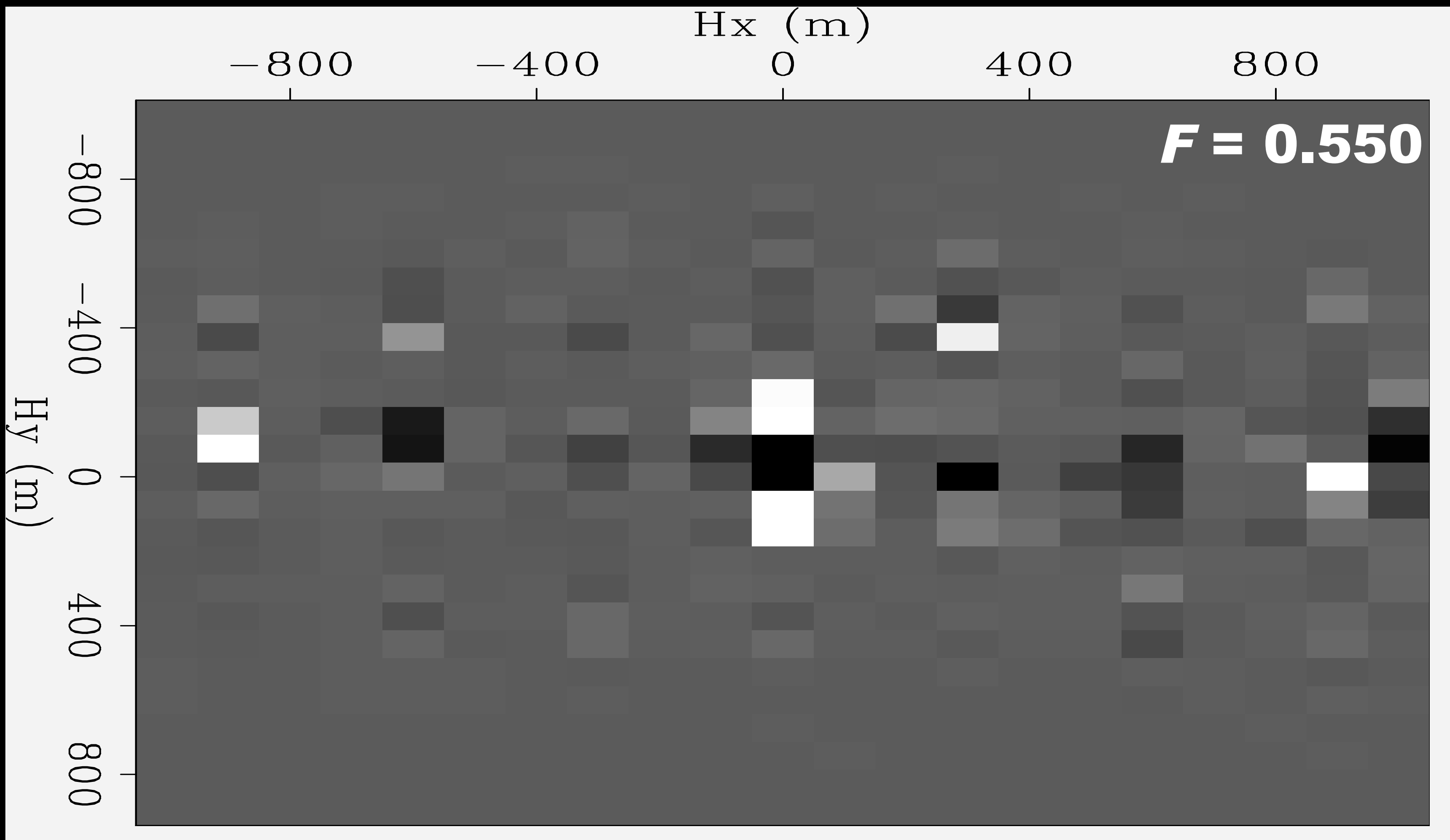
Born image: fast model



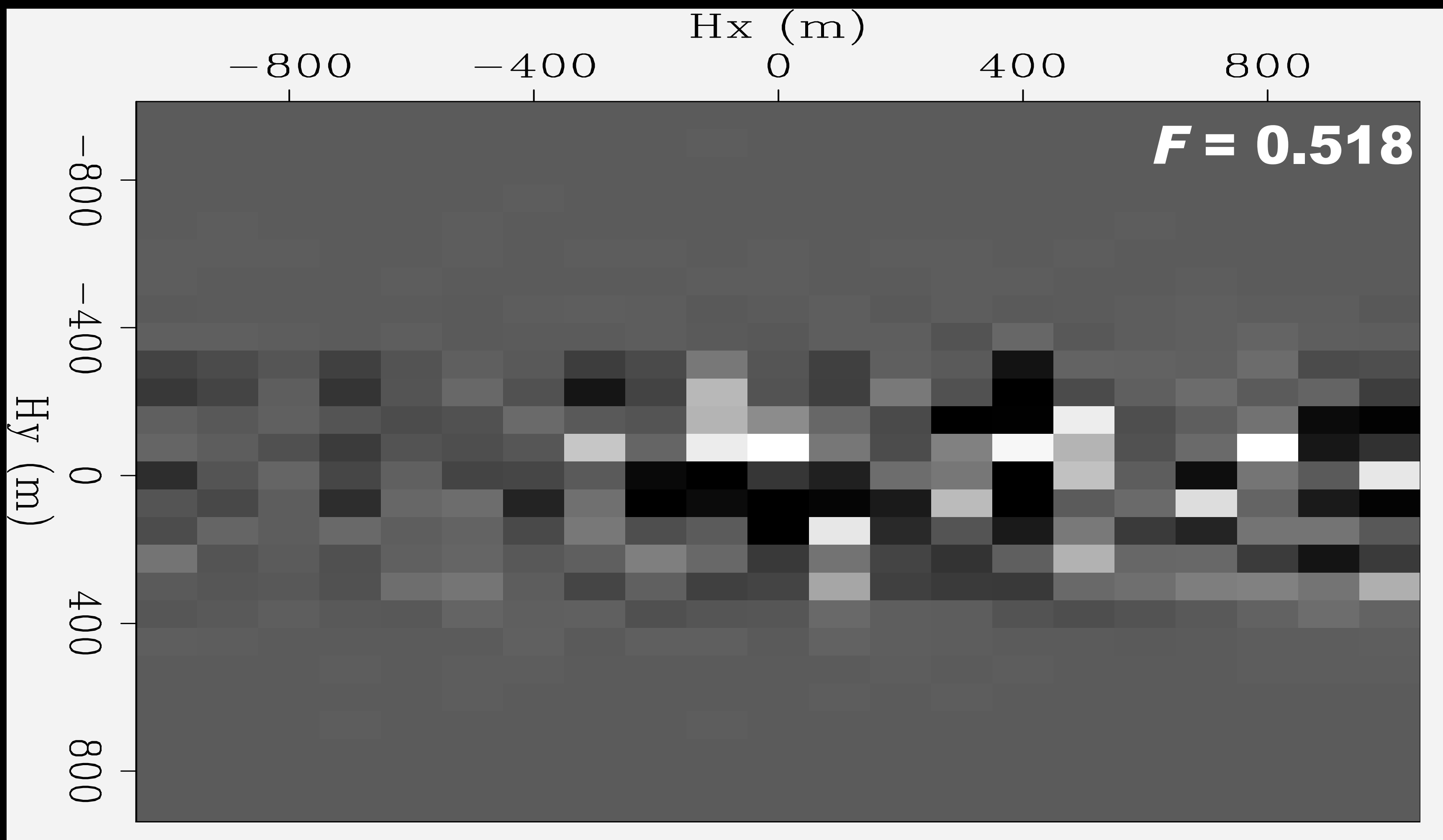
Born image: true model



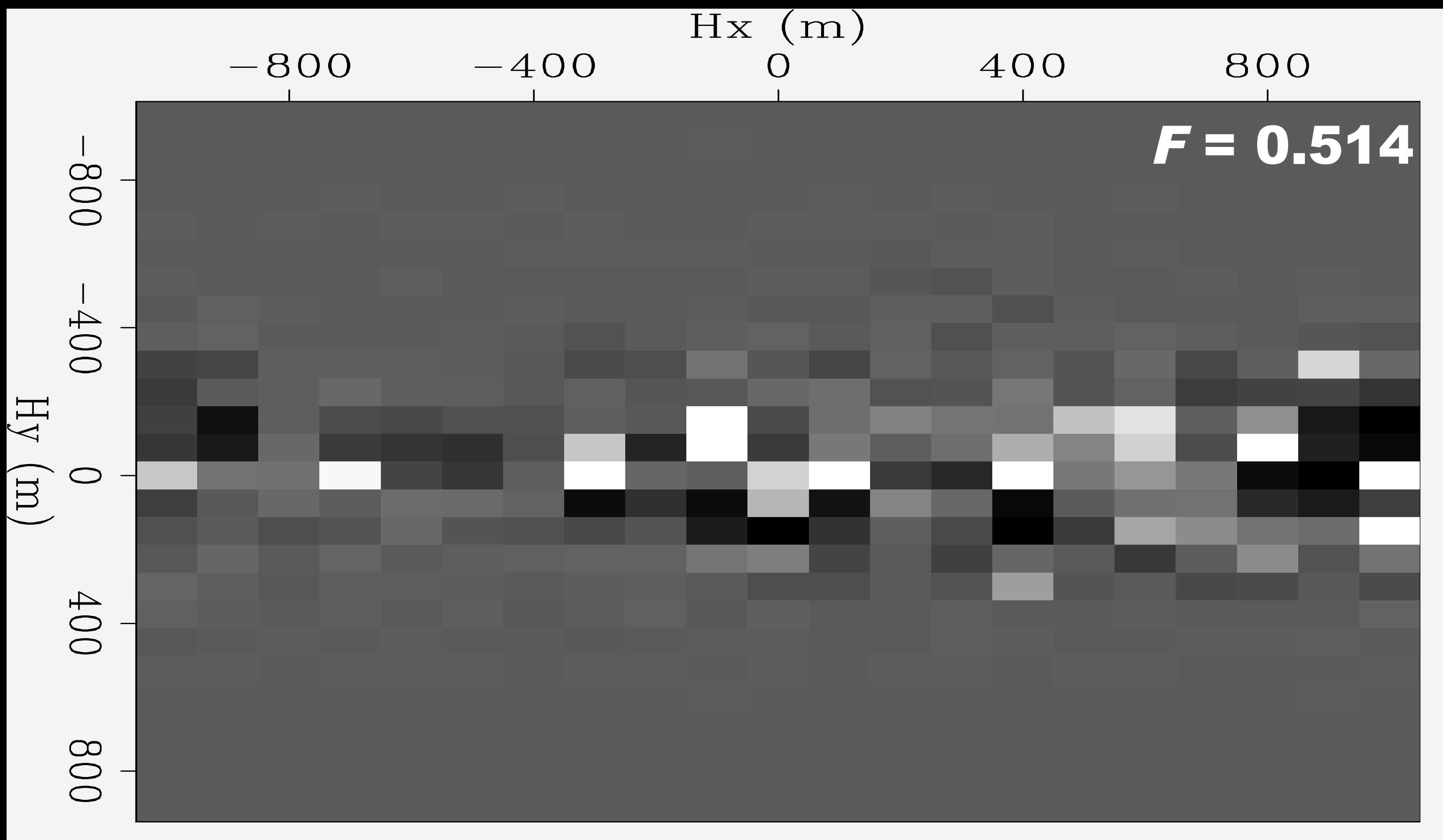
Sub. offset: true model



Sub. offset: slow model



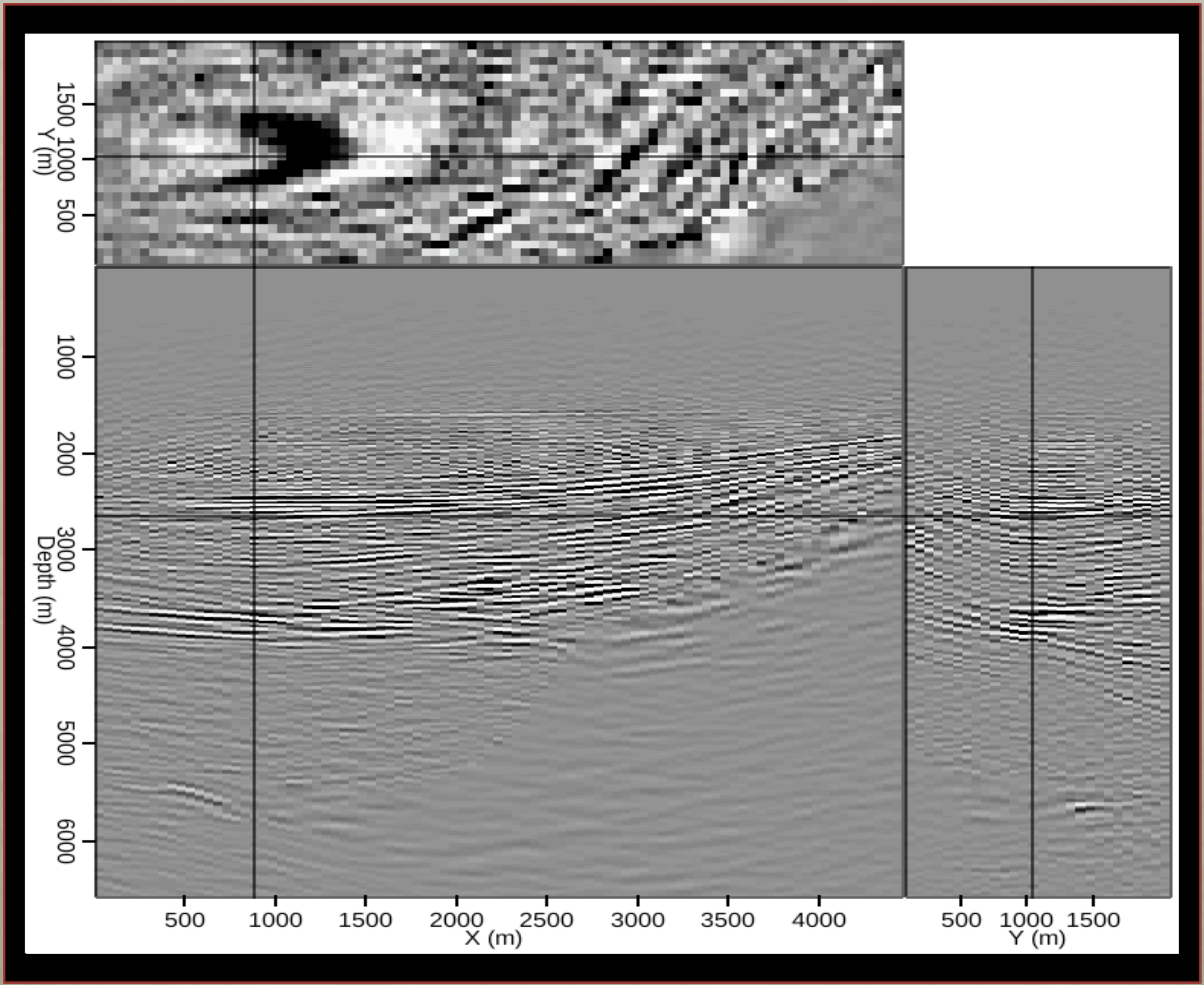
Sub. offset: fast model



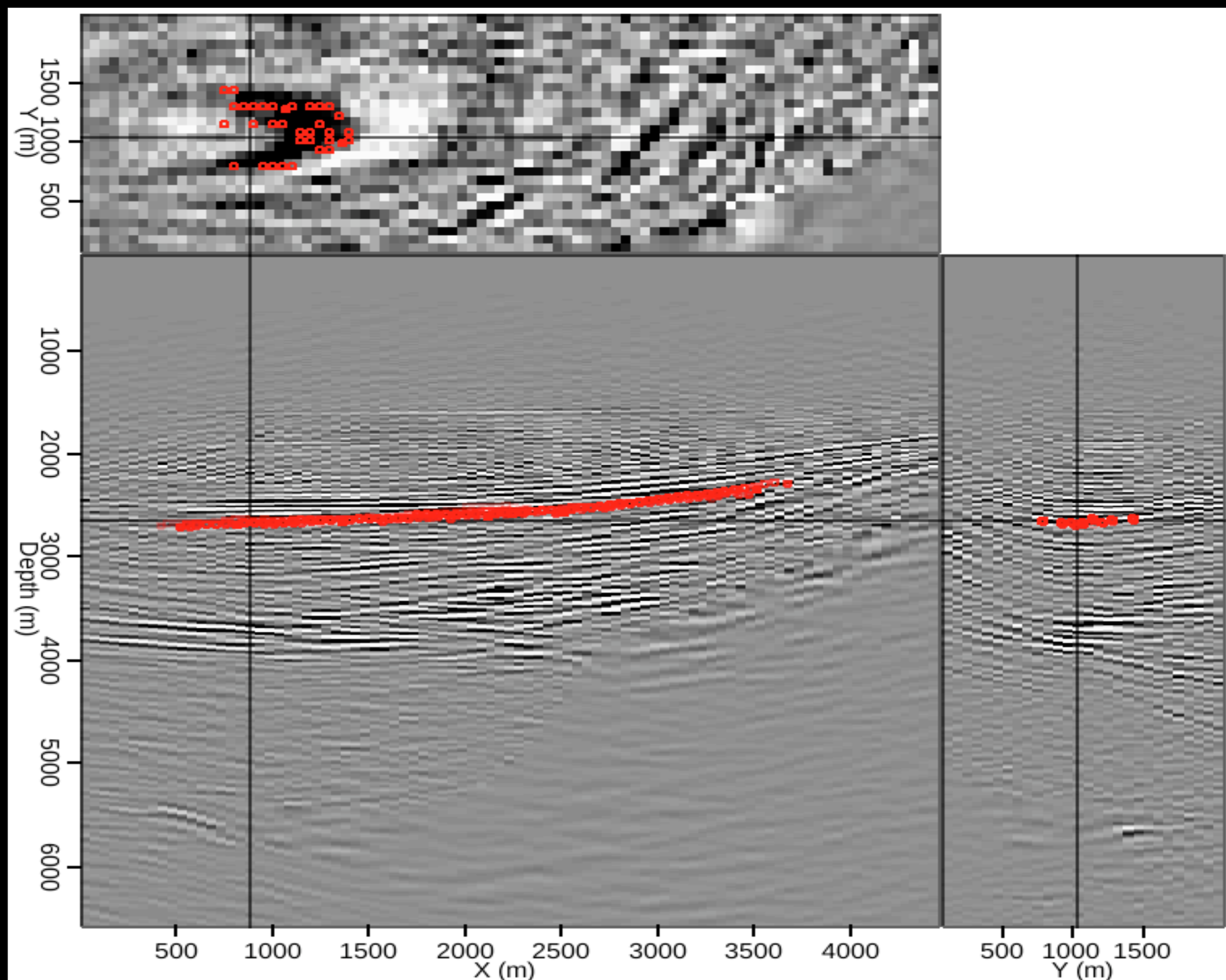
3D test #2

- **Initial image: “fast” velocity**
  - **Source and receiver wavefields modeled with fast velocity**
- **Migrate the synthesized wavefields with fast, true, and slow models**

3D image: fast model

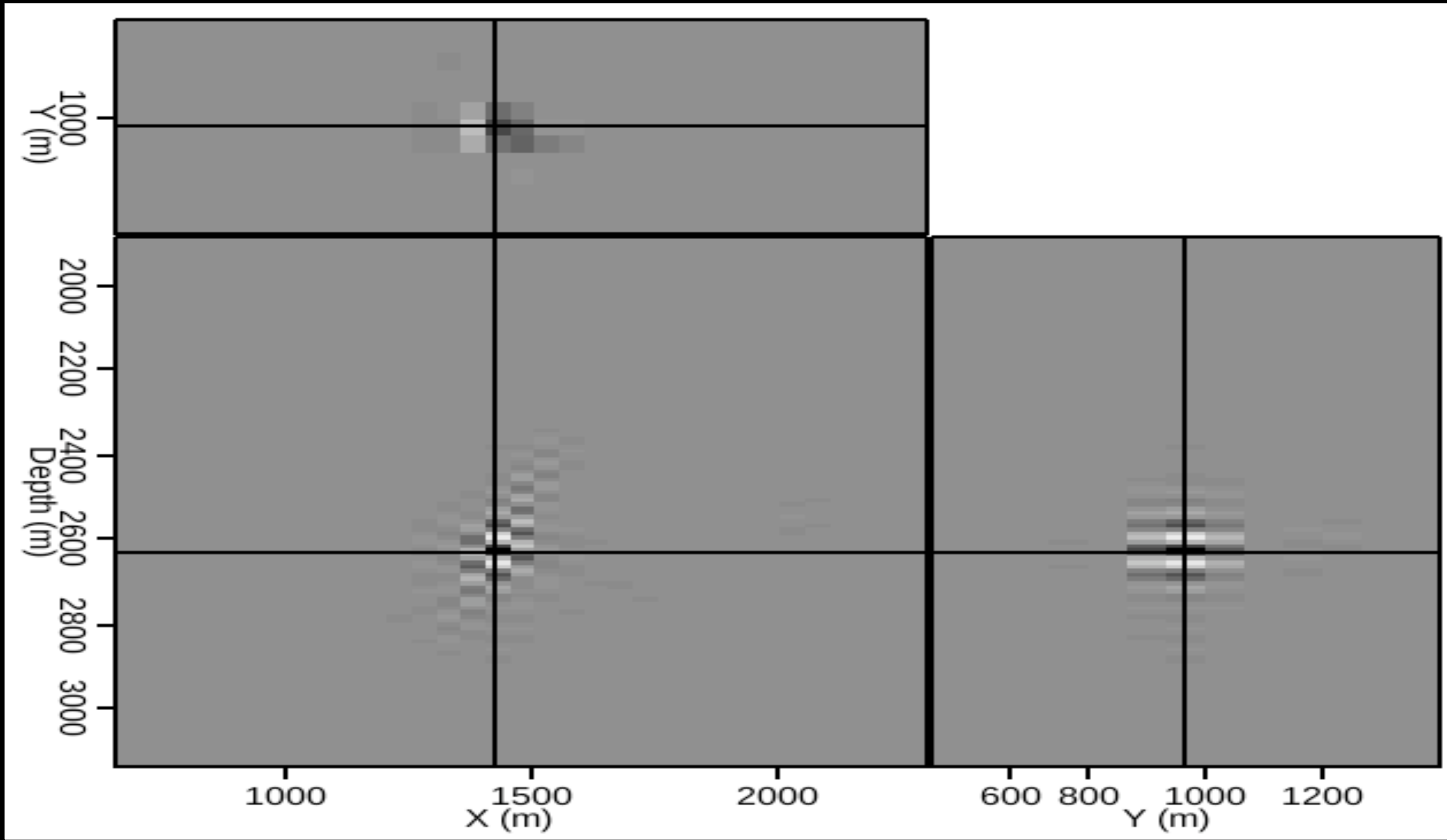


Target reflector



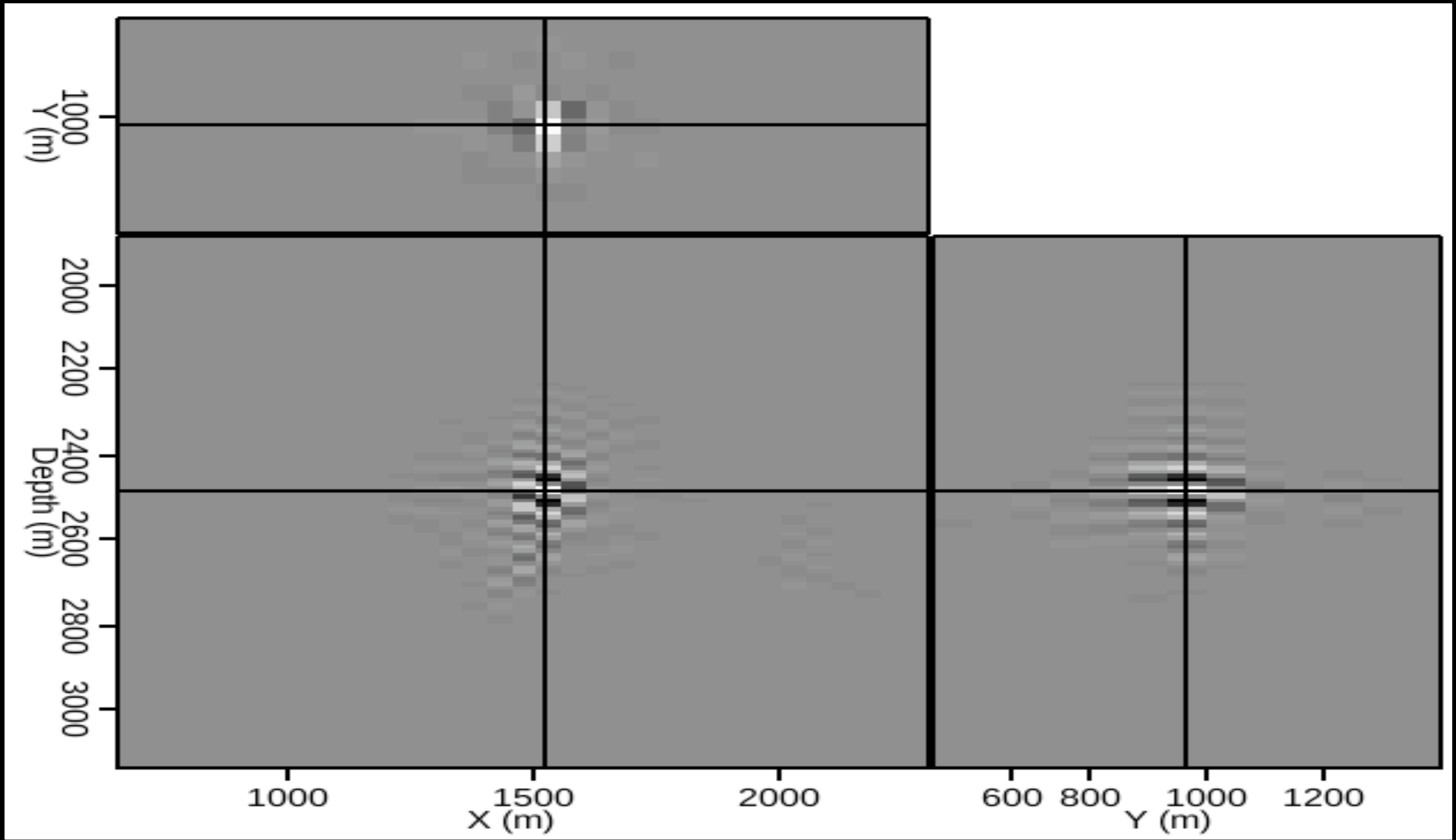
Method ◆ 2D Example ◆ 3D Example ◆ Future work

Born image: fast model



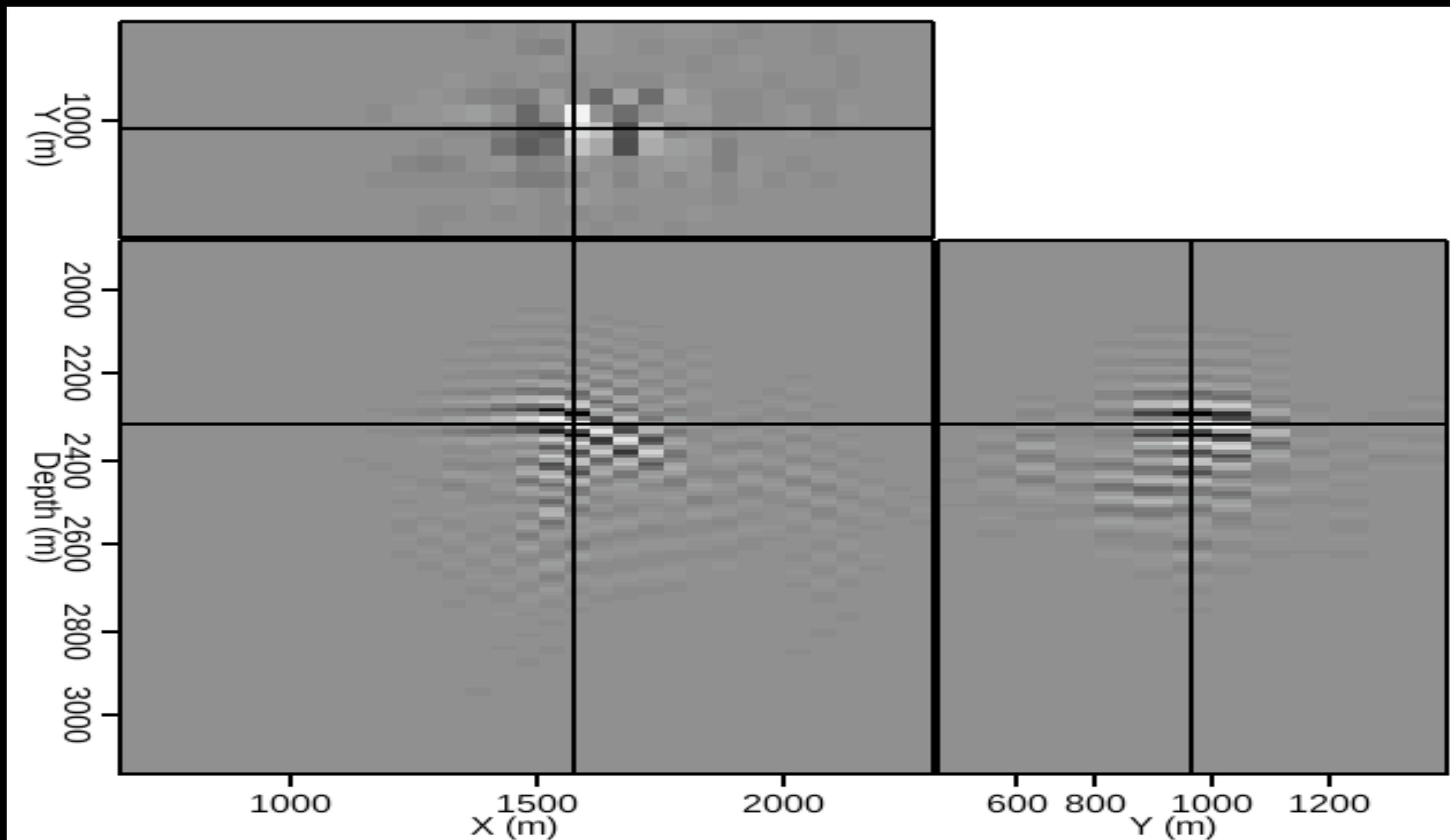
Method ◆ 2D Example ◆ 3D Example ◆ Future work

Born image: true model

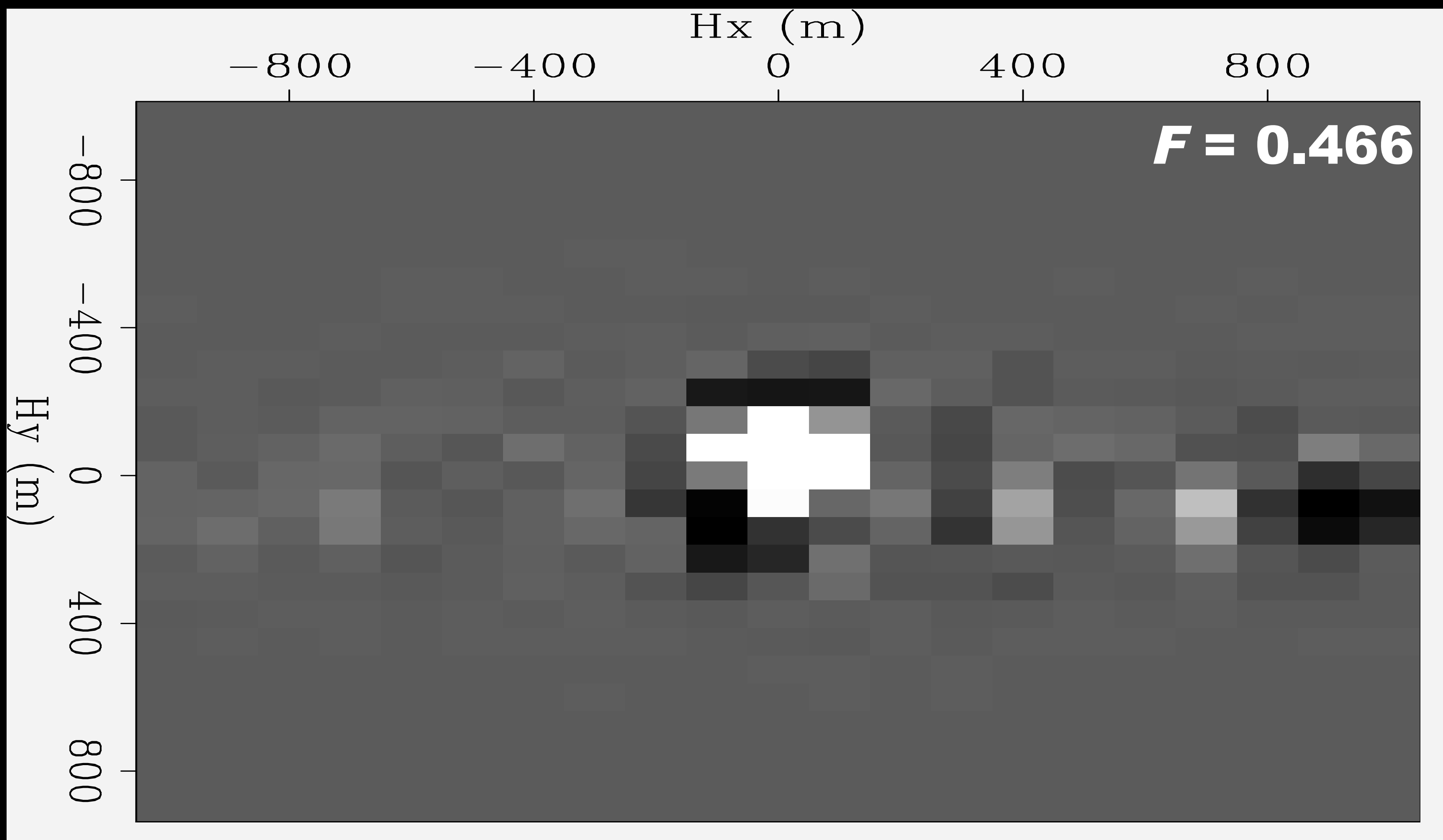


Method ◆ 2D Example ◆ 3D Example ◆ Future work

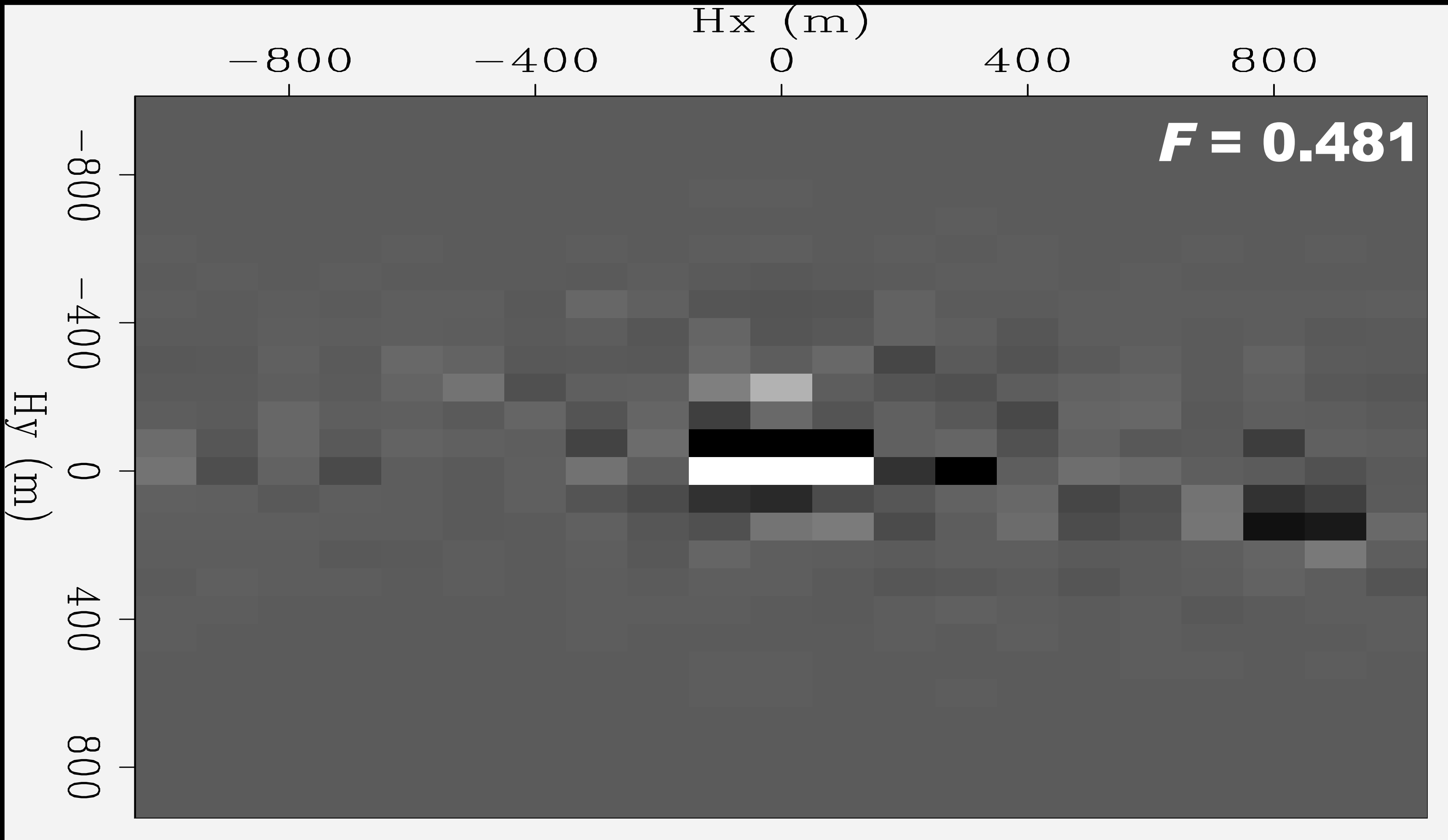
Born image: slow model



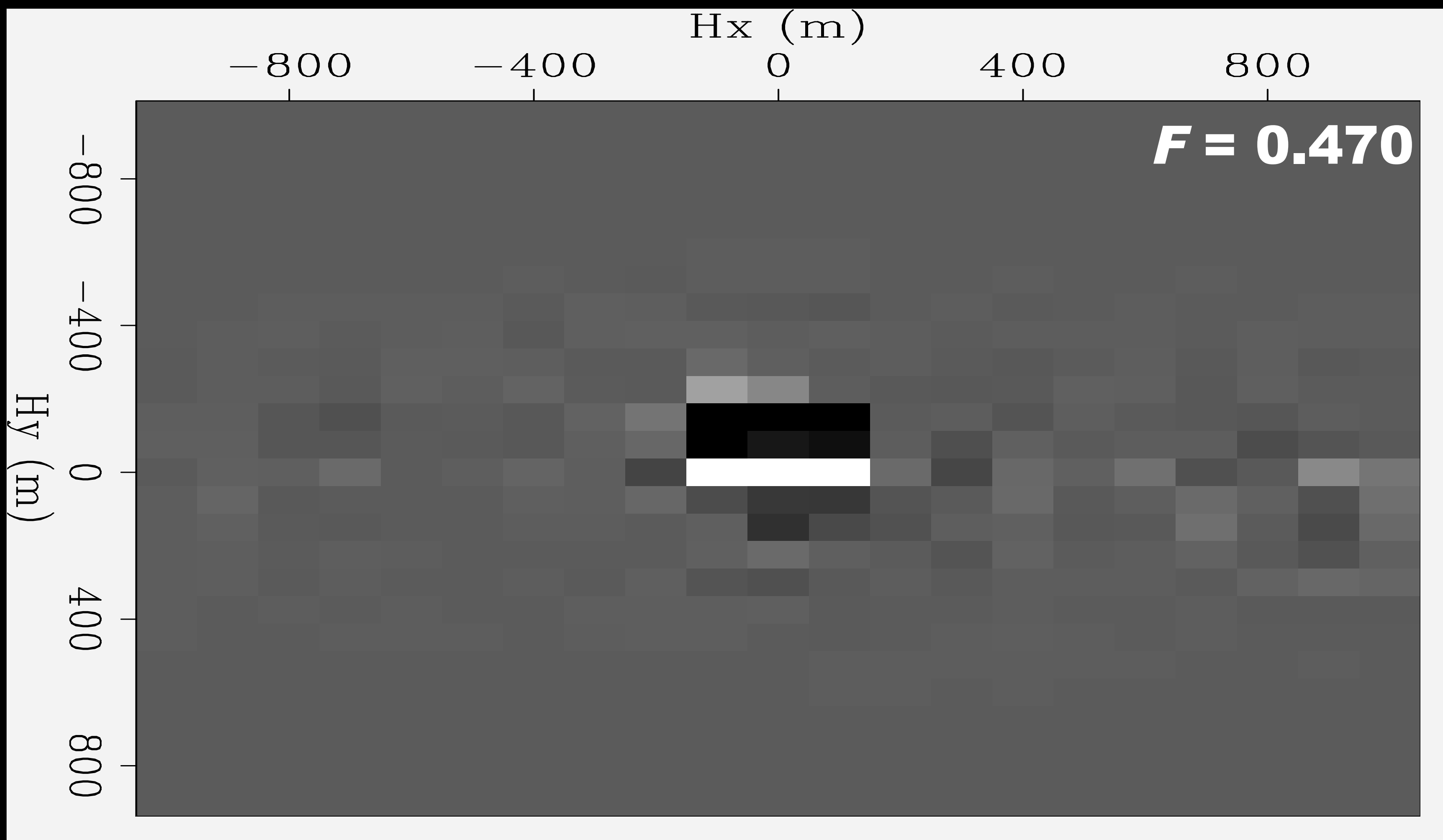
Sub. offset: fast model



Sub. offset: true model



Sub. offset: slow model



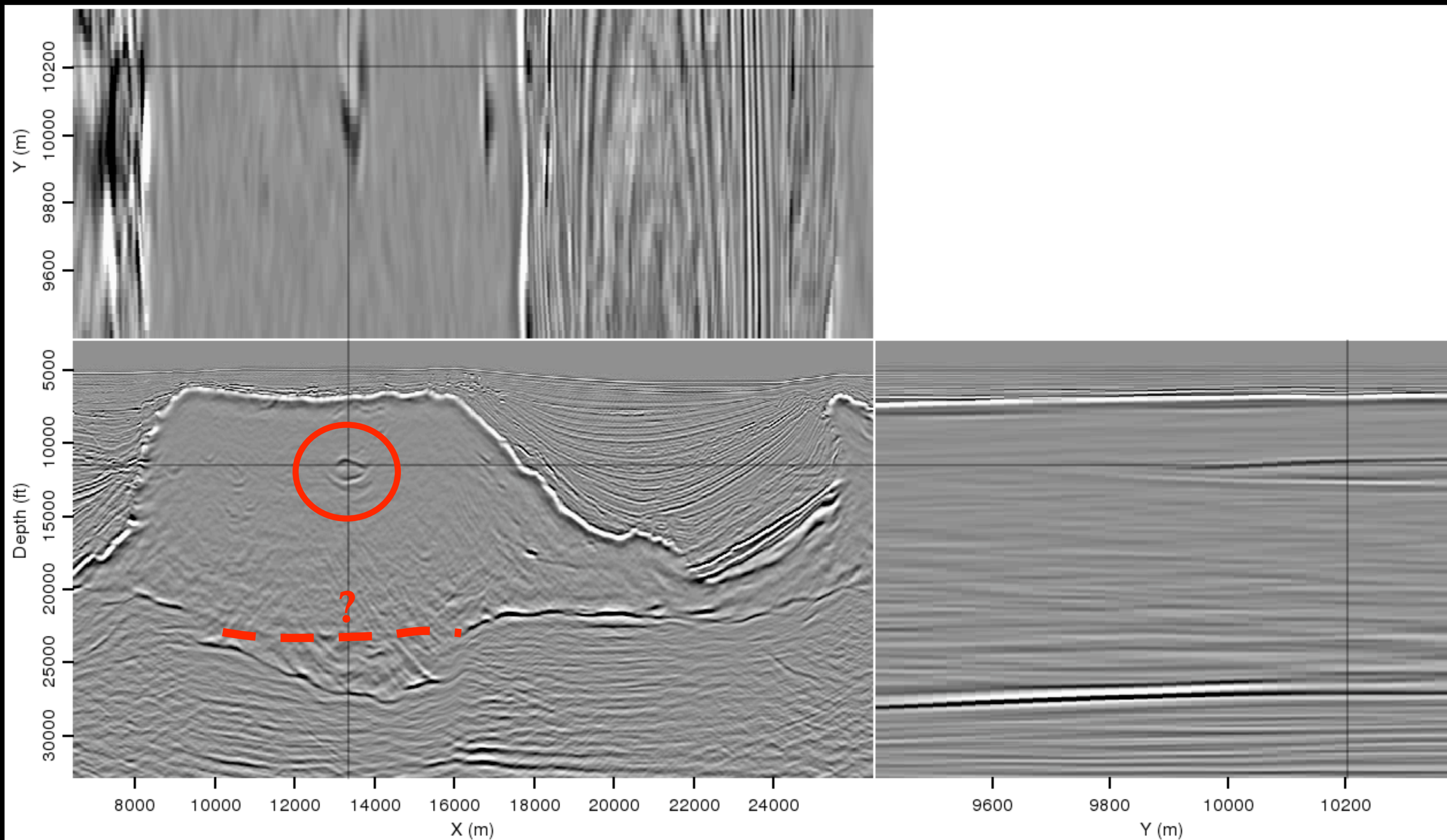
3D recap: *F* values

	Initial Model	
Migration model:	**"True" velocity**	**Fast Velocity**
Slow	**0.518**	**0.470**
True	**0.550**	**0.481**
Fast	**0.514**	**0.466**

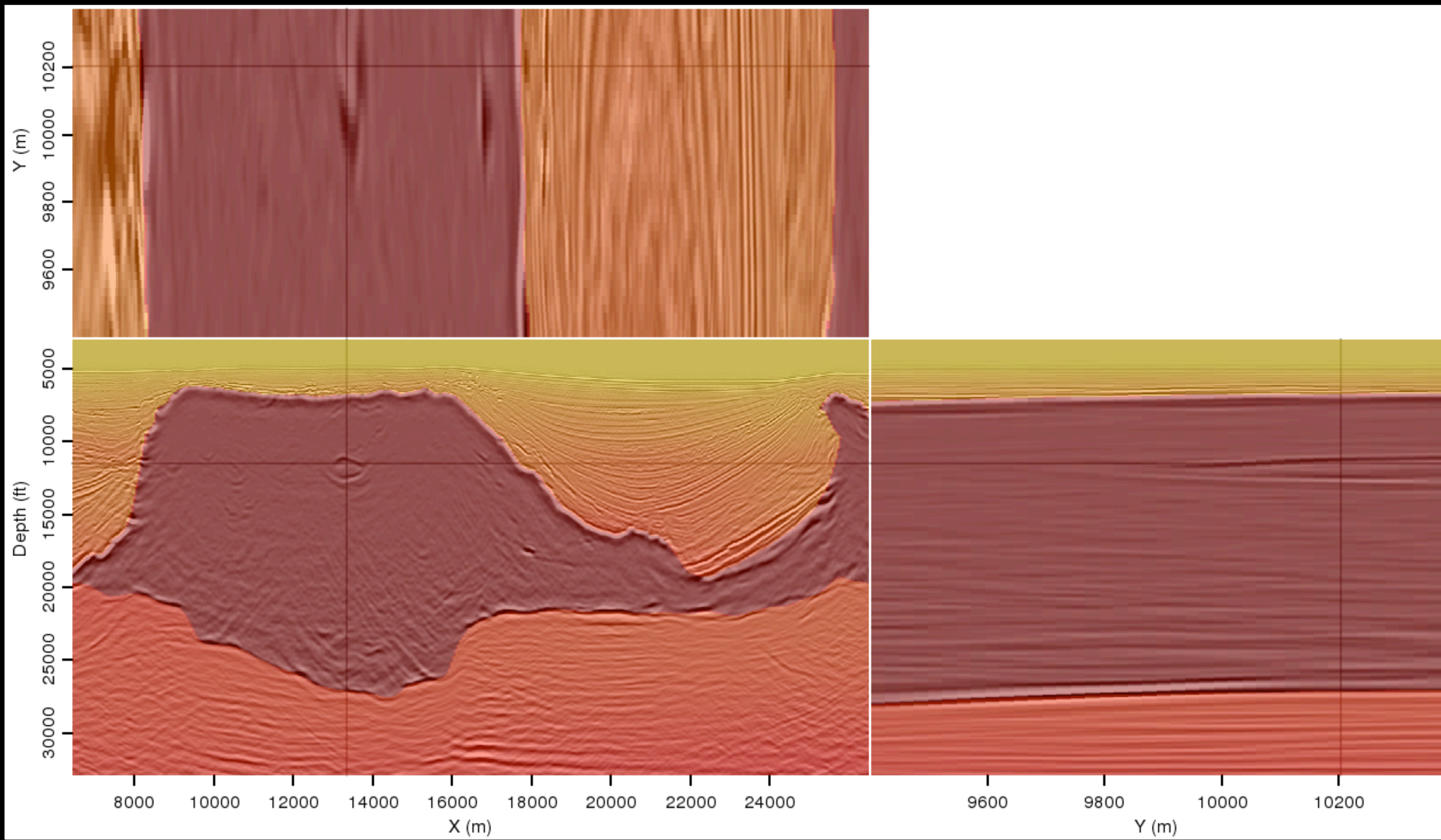
Future work

- **Thesis preview**
  - ***Interpreter guided seismic image segmentation*** **(SEP149, p. 107)**
  - ***Efficient velocity model evaluation using synthesized wavefields***
  - ***Semi-automatic model building via integrated image segmentation and model evaluation tools***

Integration opportunities

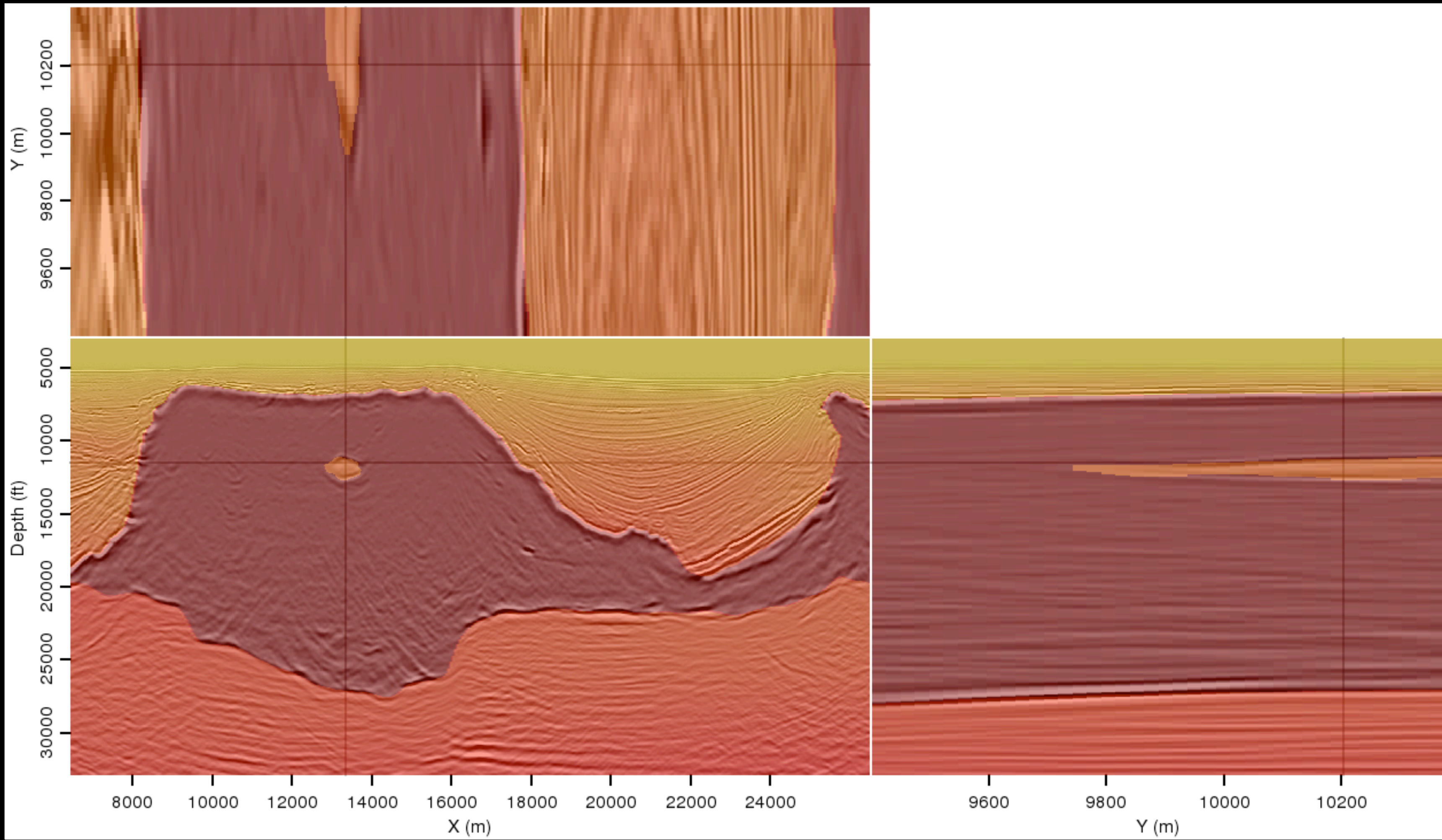


Original velocity

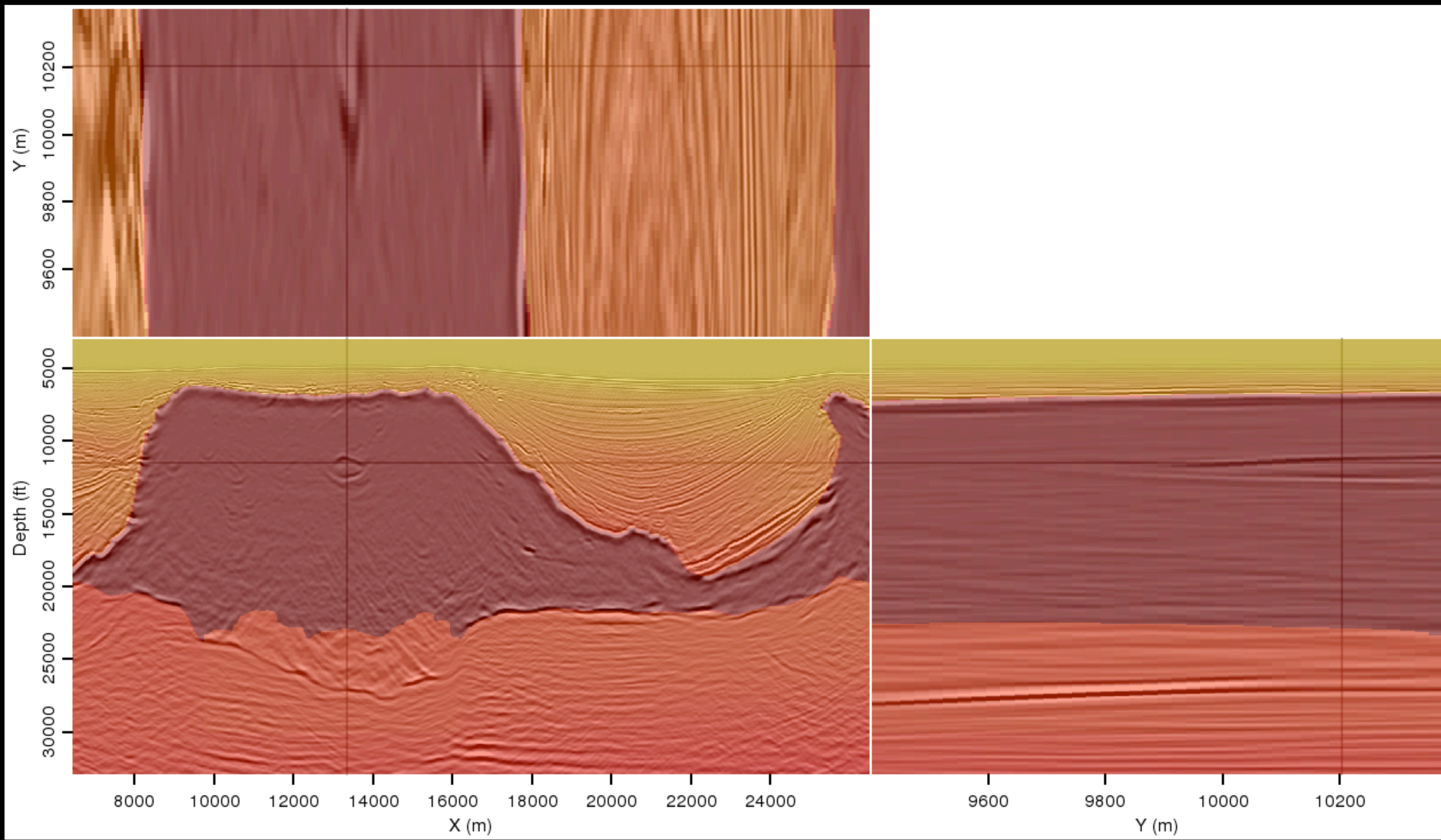


Method ◆ 2D Example ◆ 3D Example ◆ Future work

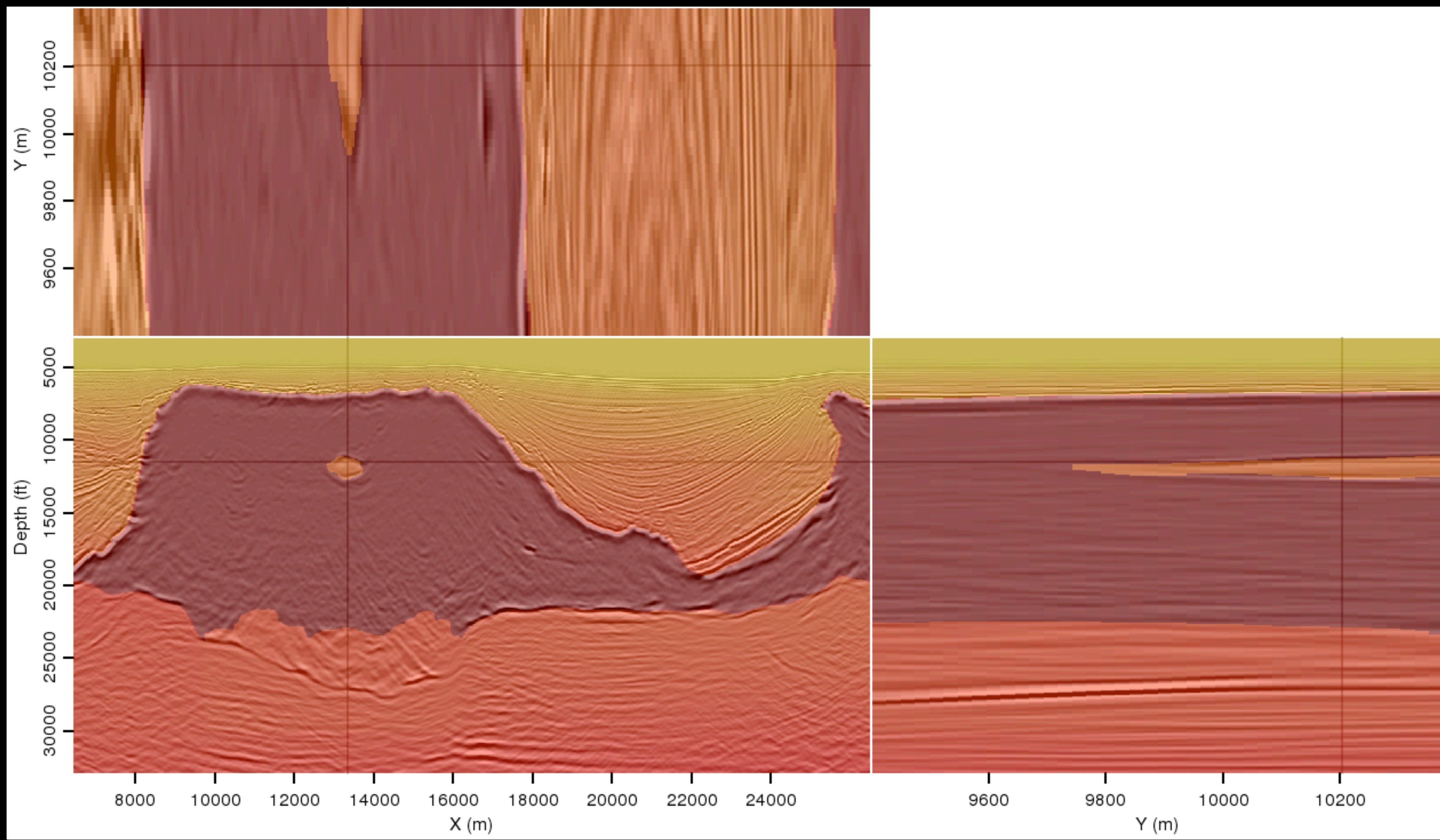
Alternative model #1



Alternative model #2



Alternative model #3



Method ◆ 2D Example ◆ 3D Example ◆ Future work

Conclusions

- A fast Born modeling and migration scheme can efficiently evaluate velocity models for 2D and 3D field datasets
- Quantitative evaluation of these experiments is possible, and desirable (especially for 5D image cubes)
- When integrated with other 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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- SmaartJV and WesternGeco for providing the data and models used for examples
- Yaxun Tang for his work on the Born modeling and migration framework used here
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