When FWI Goes Wrong

Mike Warner

Imperial College London

Overview

- FWI most often goes wrong because of:
  - cycle skipping
  - operator error

…we mostly know how to identify and deal with these

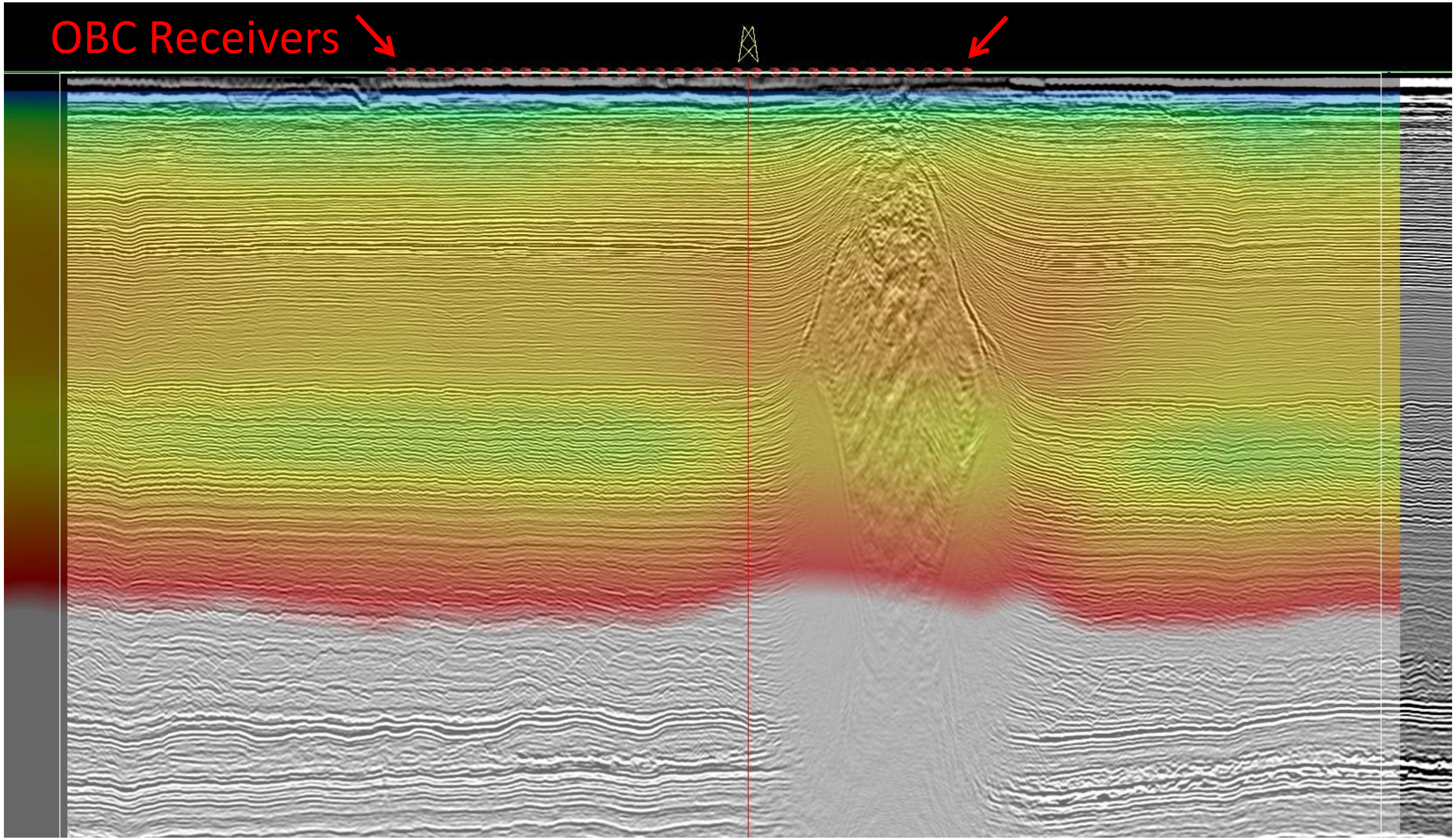
- But can go wrong for less-obvious reasons:
  - FWI side-bands can be problematic
  - elastic effects are significant

OBC dataset, North Sea

Example 1

- Conventional shallow-water full-azimuth OBC
- FWI normally works well on such datasets
- Commercial FWI with leading contractor
- Produces spurious low-velocities
- Produces unrealistic velocity oscillations in depth

Starting model



No salt in starting model

OBC dataset, North Sea

Commercial FWI

- ✓ Matched transmitted arrivals within a 4-s window with offsets to 8500 m to update the shallow overburden down to 2000 m
- ✓ Good waveform match is achieved within this window between the observed and synthetic data after 3 multi-scale FWI iterations at 5Hz, 6Hz and 7Hz
- ✓ Migrated gathers show reduced RMO
- ✓ Improved shallow channel definition

OBC dataset, North Sea

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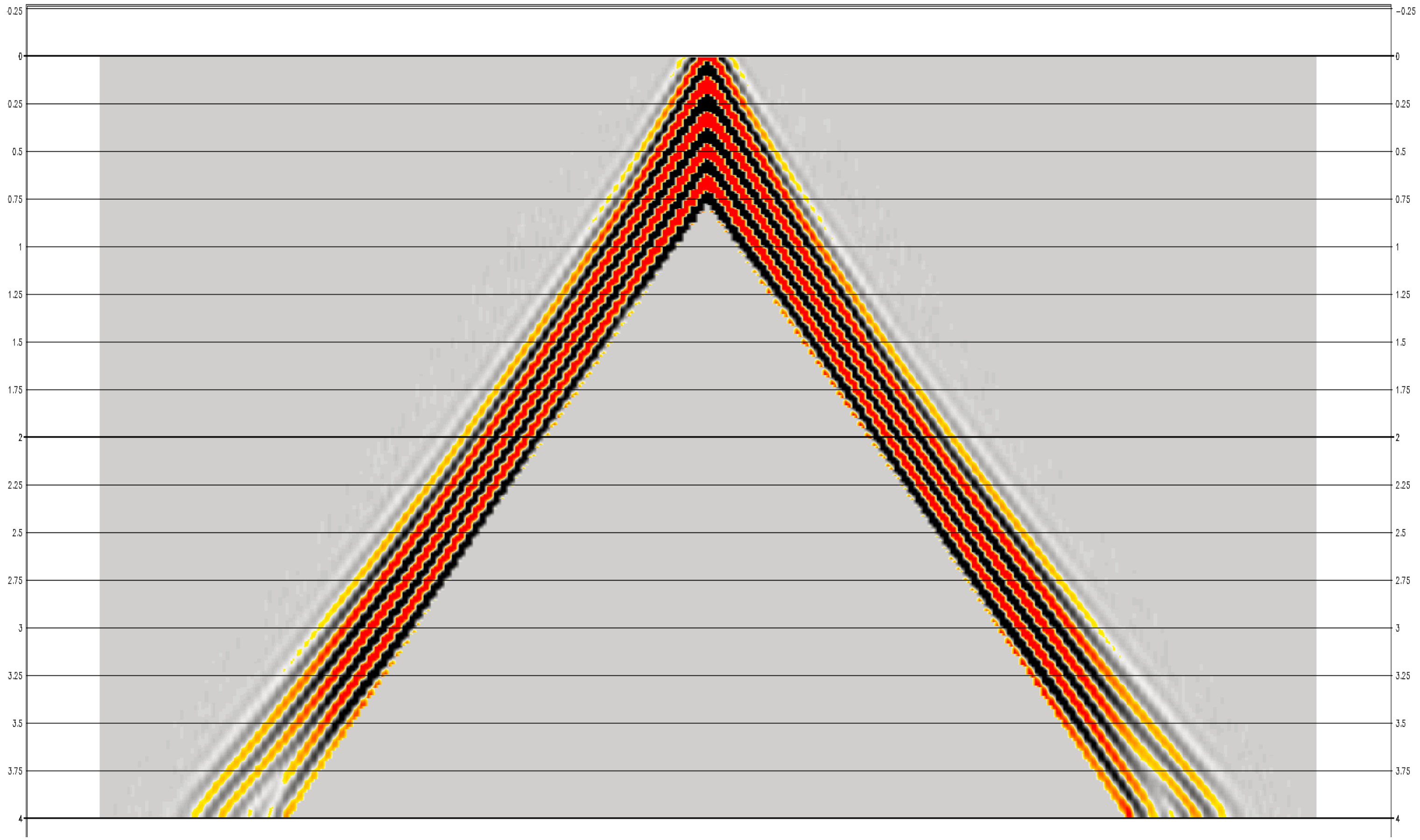

Observed data

OBC dataset, North Sea

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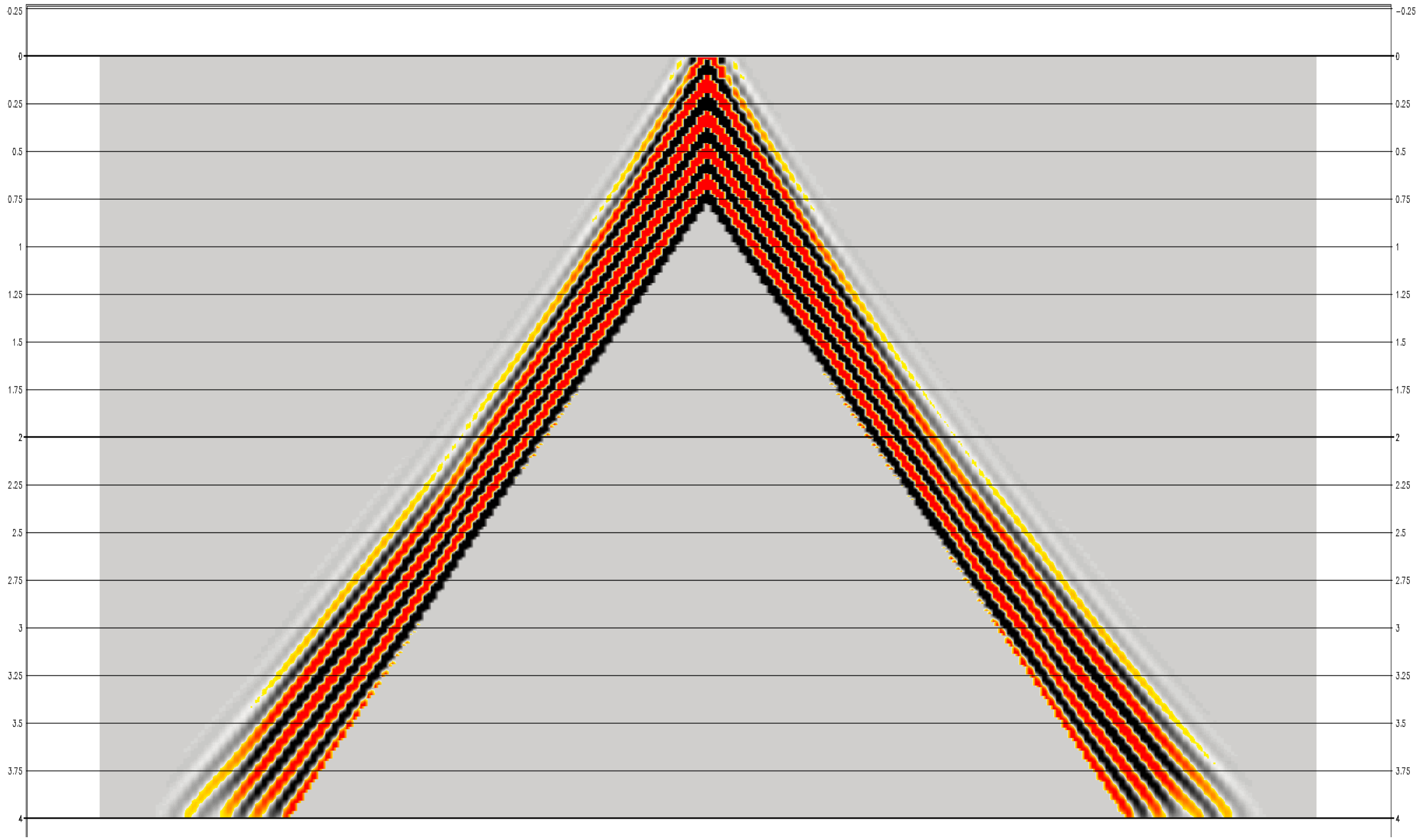
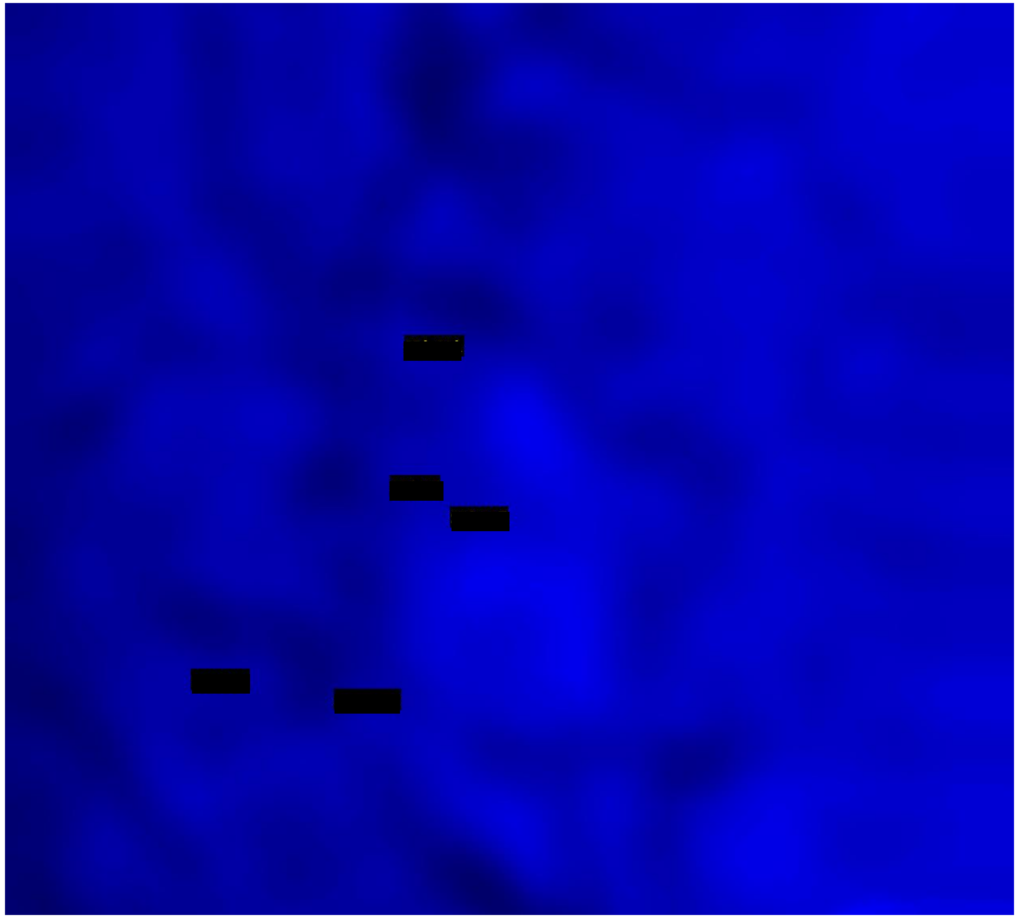


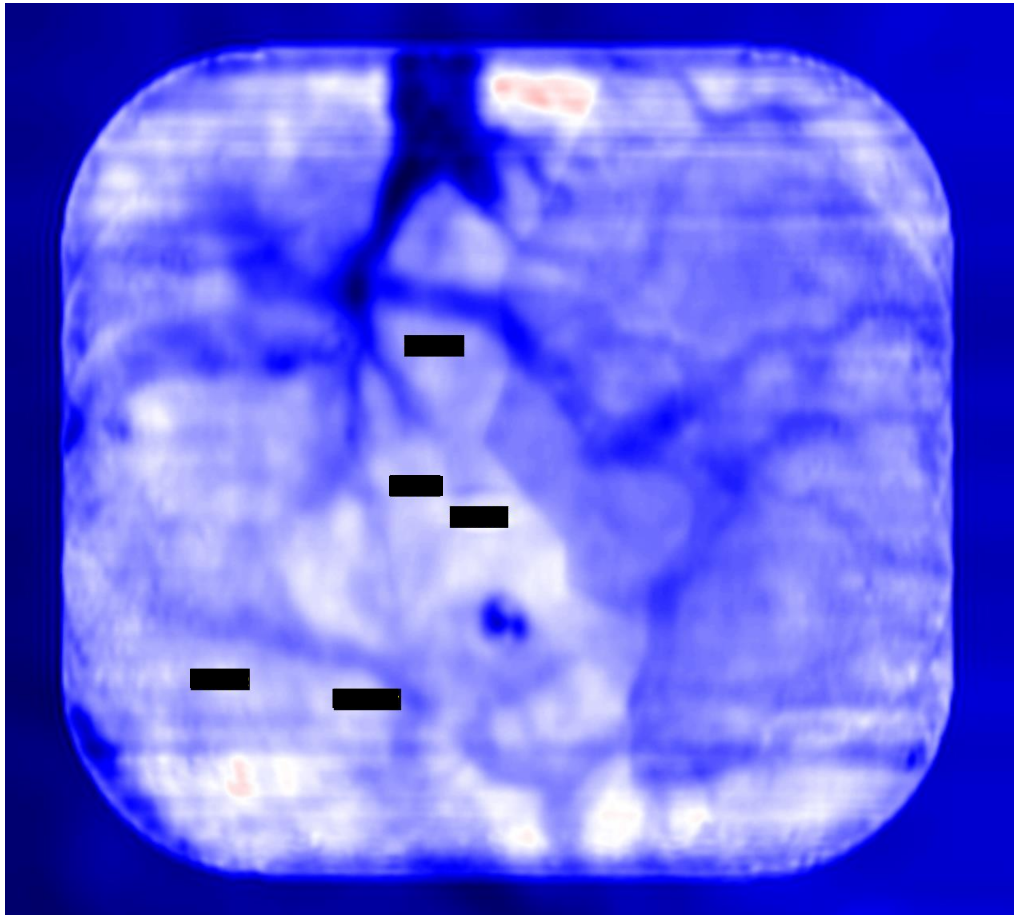
Synthetic data after 7-Hz FWI

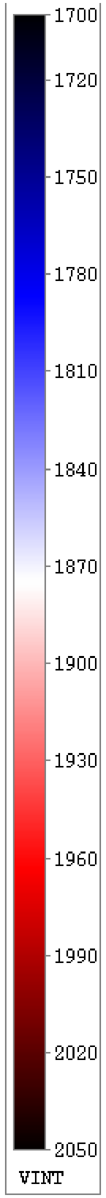
OBC dataset, North Sea

tomo start model



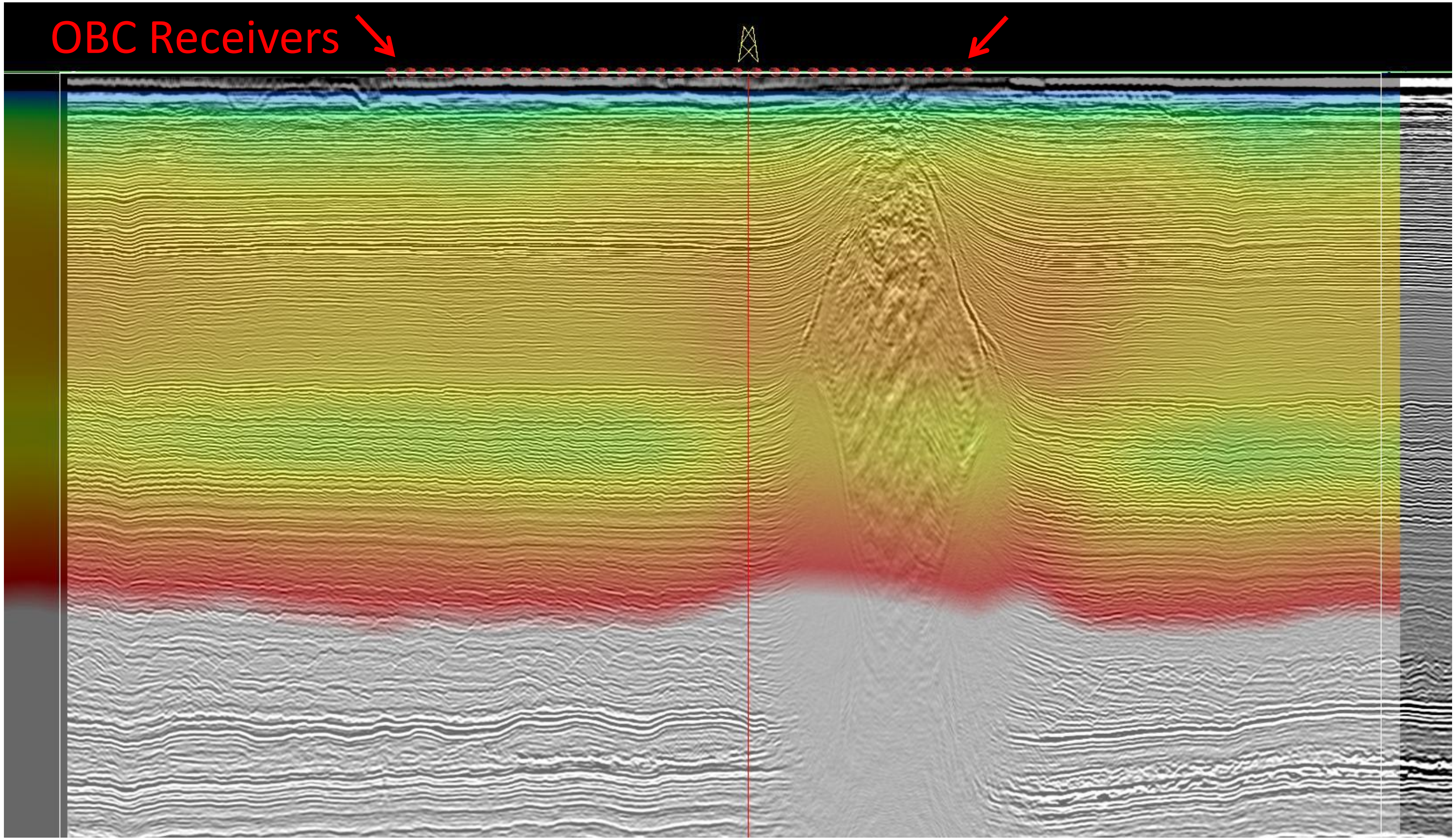
7Hz commercial FWI





150 m depth

Starting model



No salt in starting model

7-Hz FWI model

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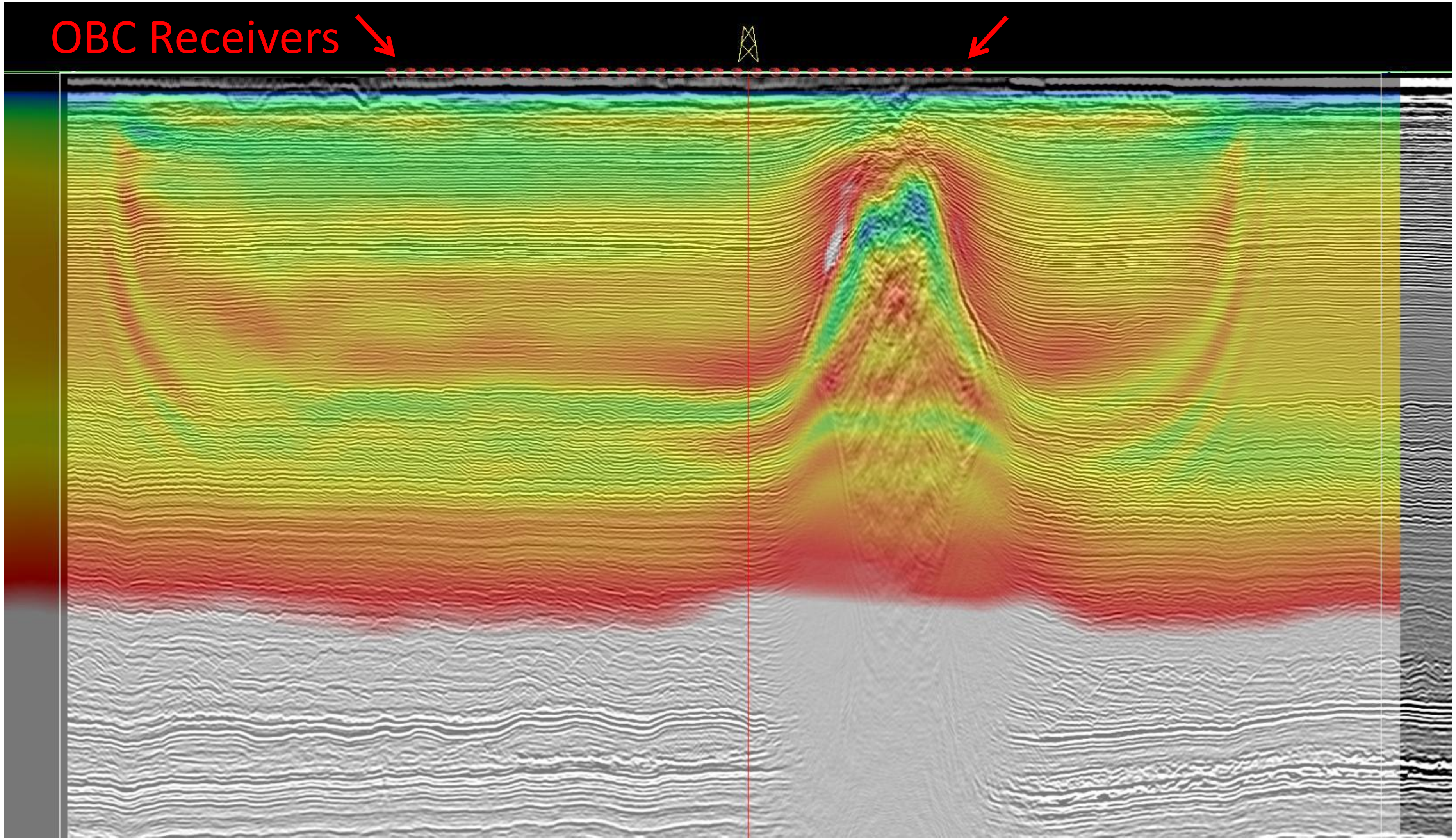
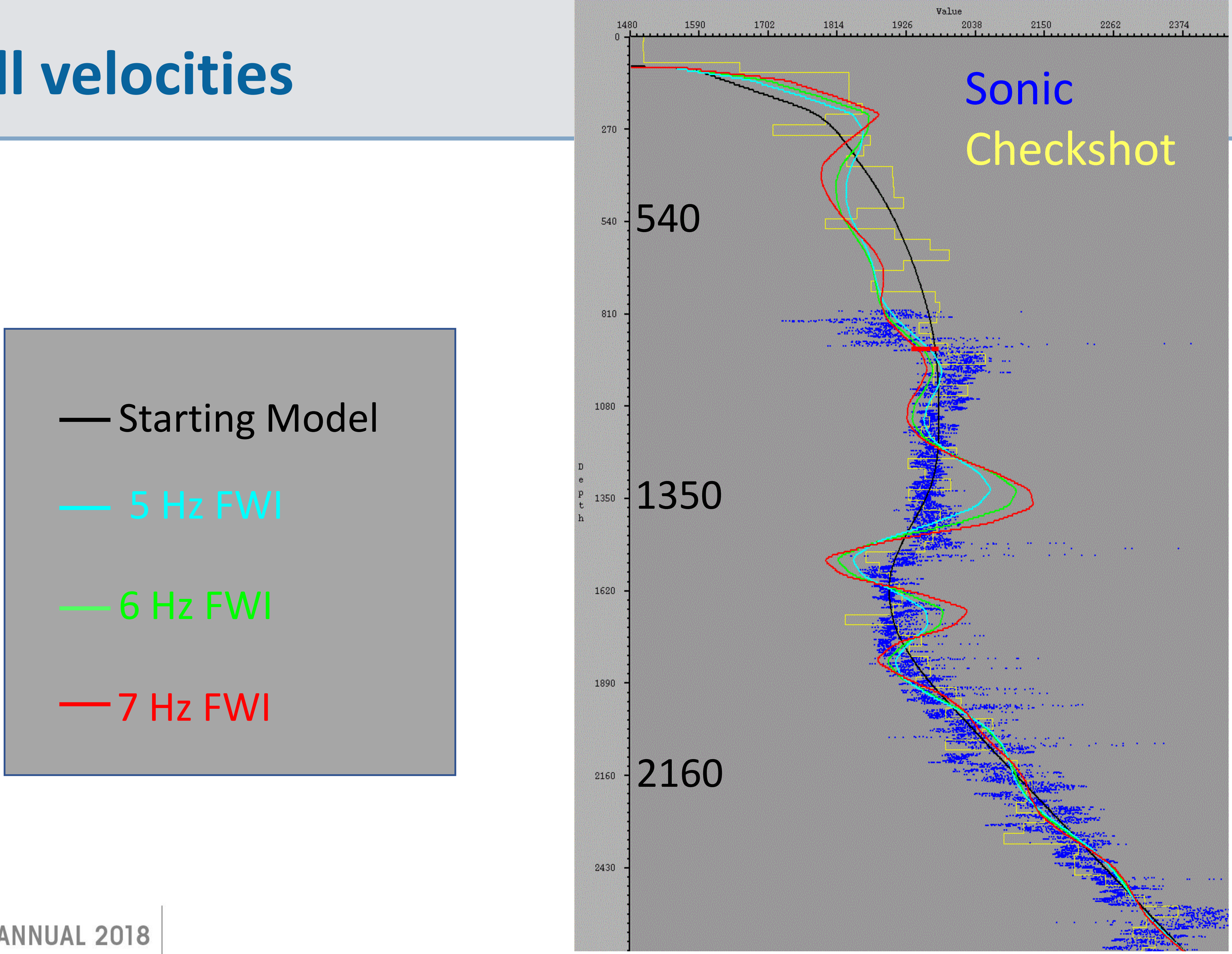


Reduced velocities appearing in diapir

FWI result

1. Strong velocity inversion below strong top-diapir reflection where seismic amplitude indicates a positive reflection.

Well velocities



7-Hz FWI model

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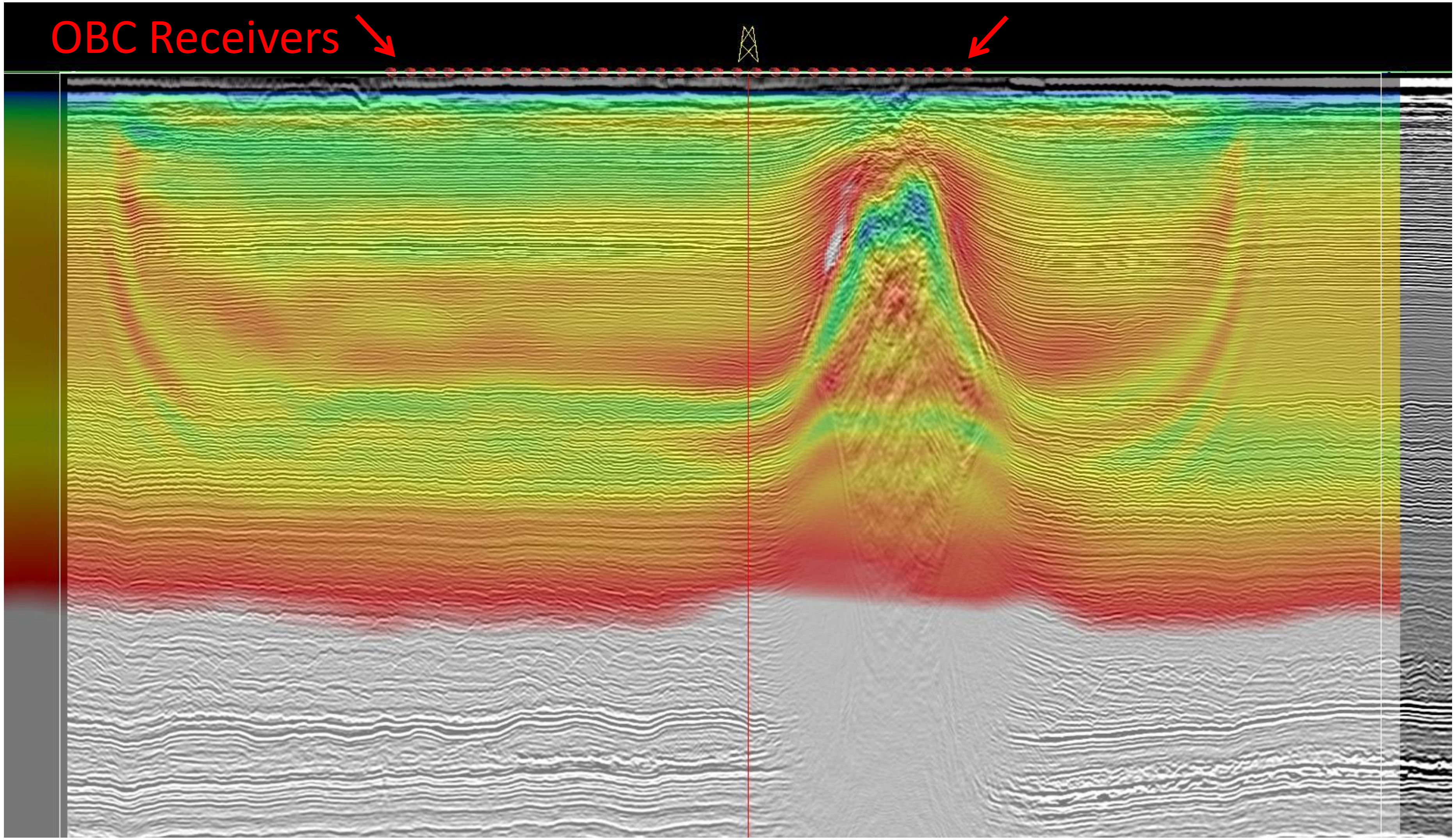


Oscillations in depth within LVZ

FWI result

1. Strong velocity inversion below strong top-diapir reflection where seismic amplitude indicates a positive reflection.
2. High/low velocity oscillations, related to low velocity zone, increasing in magnitude with increasing FWI.

Explanation?

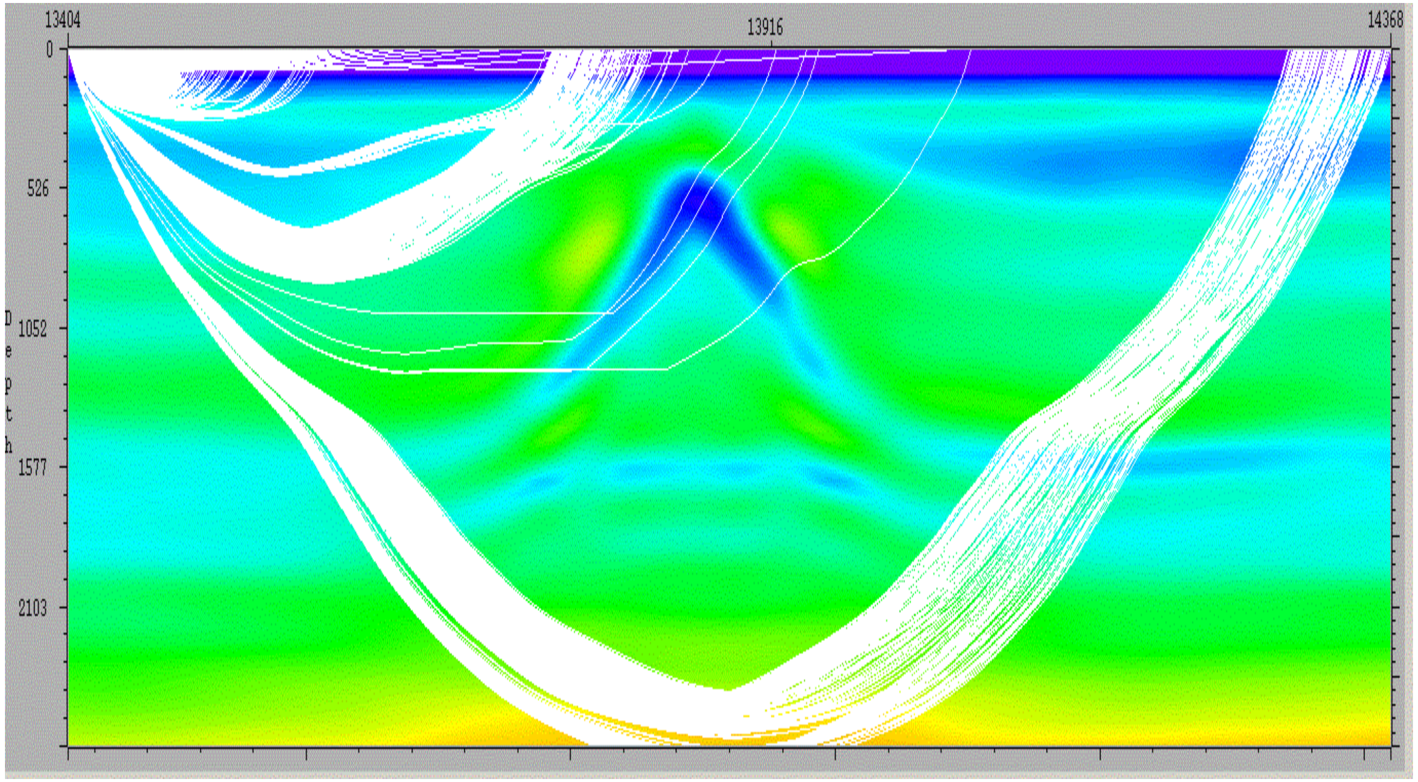
- Finite aperture can enhance side bands in FWI impulse response
- Can occur when data are artificially truncated in offset, time, depth or lateral extent
- Solution is to taper data, removing sharp edges to spatail and temporal aperture – i.e. taper the end of the array, and do not mute too harshly
- And/or use an objective function that is less sensitive to this

Ray trace data coverage

Ray trace data coverage

receivers

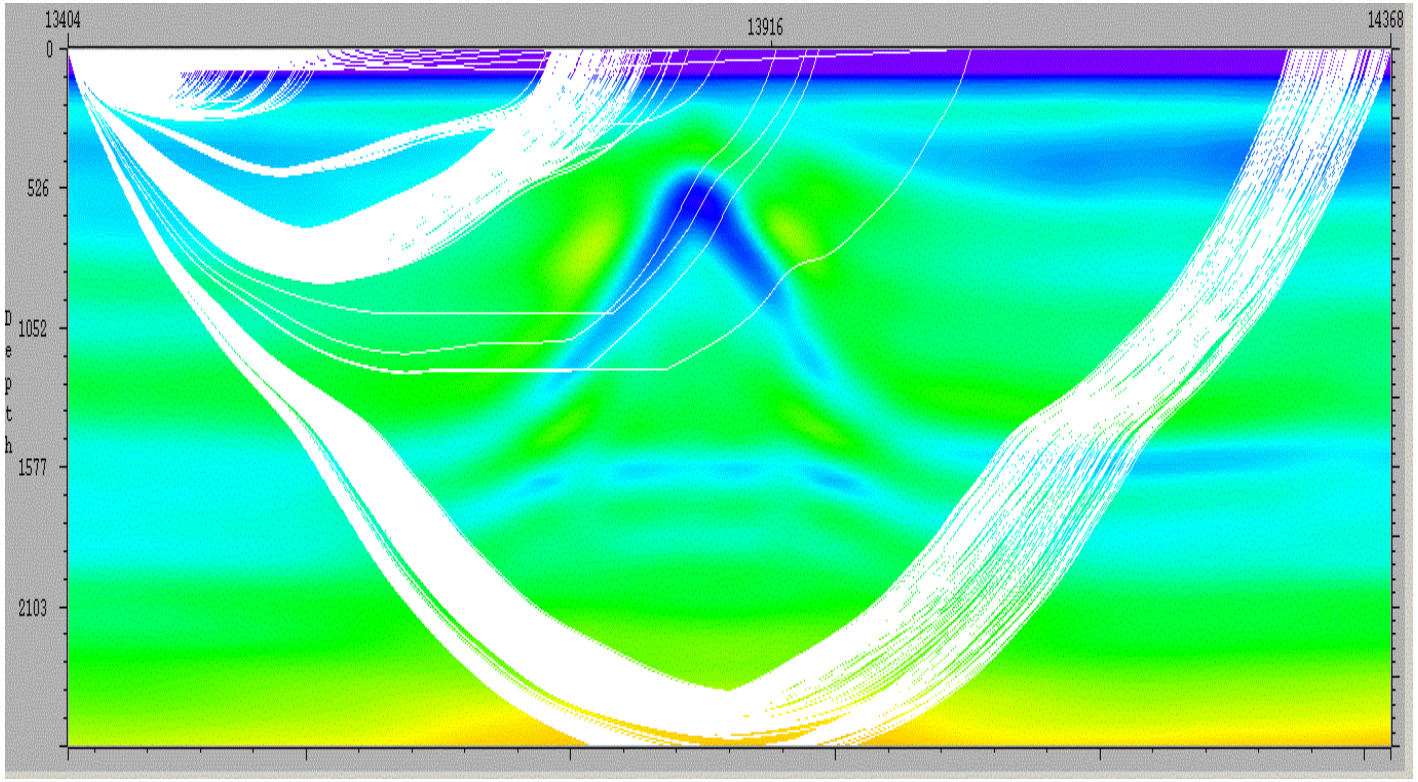
shots



Ray trace data coverage

receivers

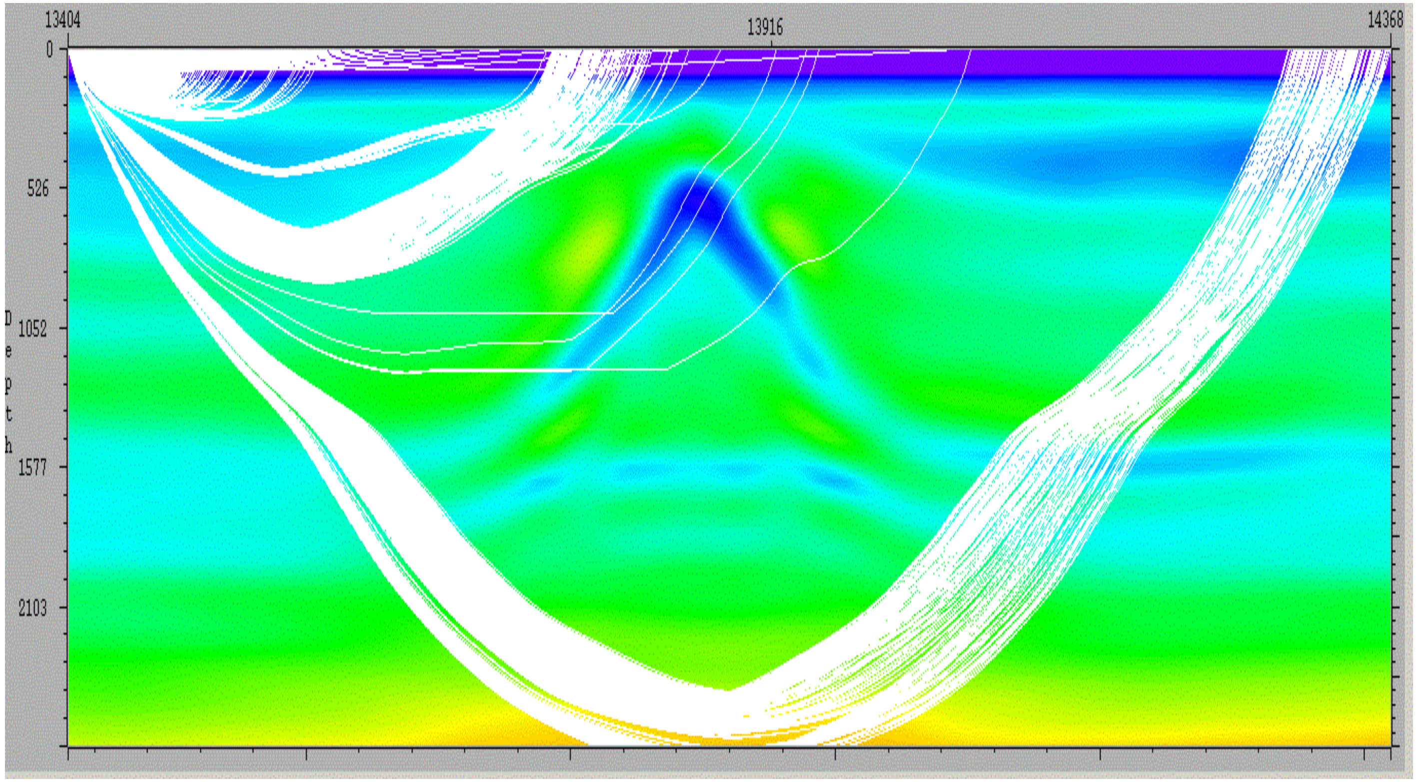
shots



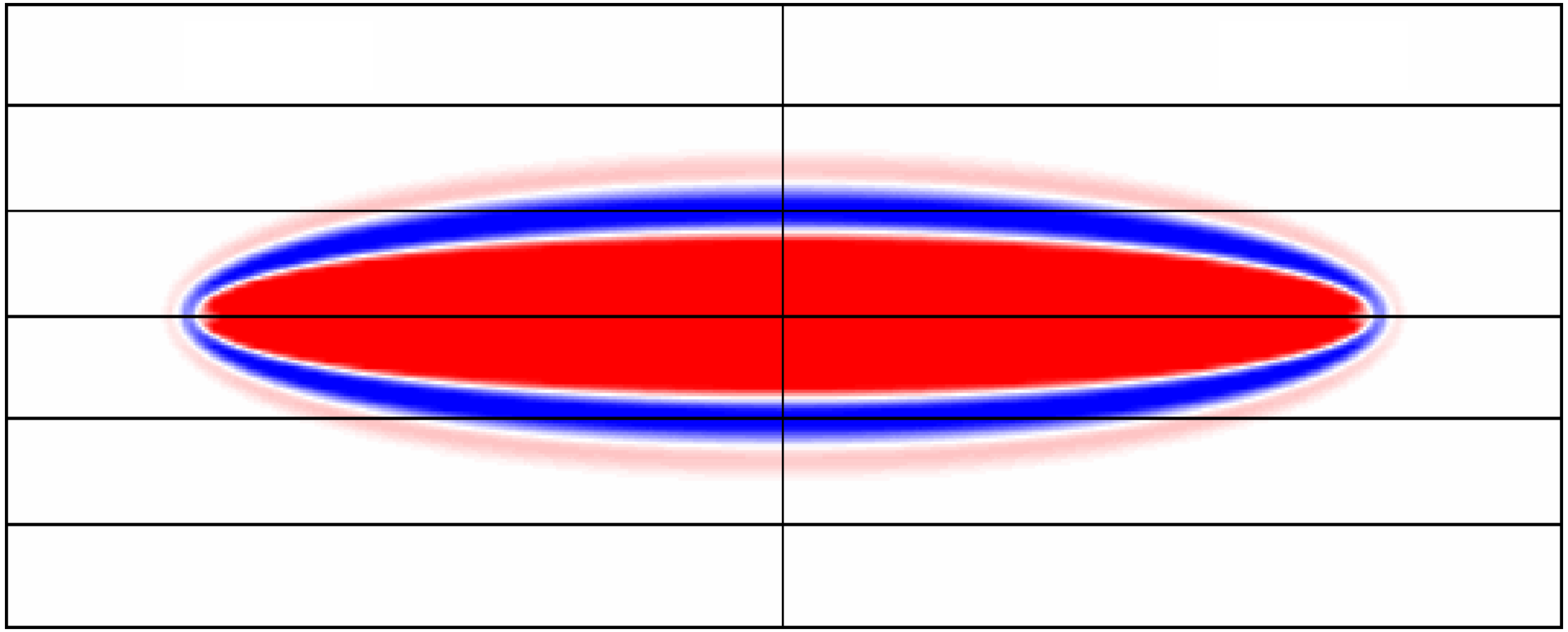
Ray trace data coverage

receivers

shots



FWI update in homogeneous model

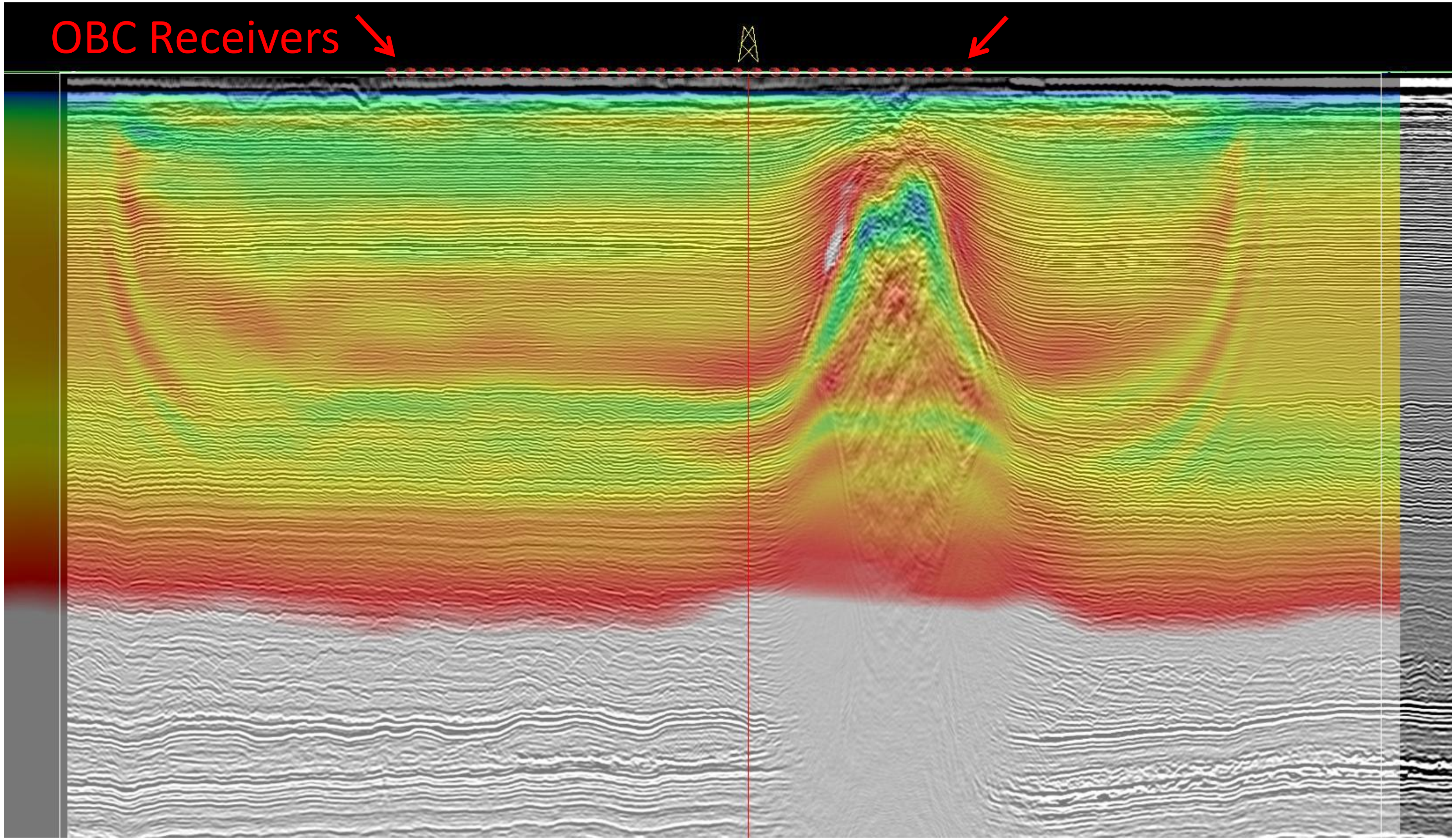


contains strong negative sideband
outside first Fresnel zone

FWI sidebands

- With good data coverage, the sideband interferes away e.g. within the interior of a moving-streamer survey
- At survey edges, the sideband can interfere constructively producing spurious velocity updates with the wrong sign
- They are especially prominent at the edges of ocean-bottom surveys where the array is fixed
- Can also occur in depth where offset is truncated
- Can appear within low-velocity zones if using strong mutes

7-Hz FWI model



A multitude of edge effects

OBC dataset, North Sea

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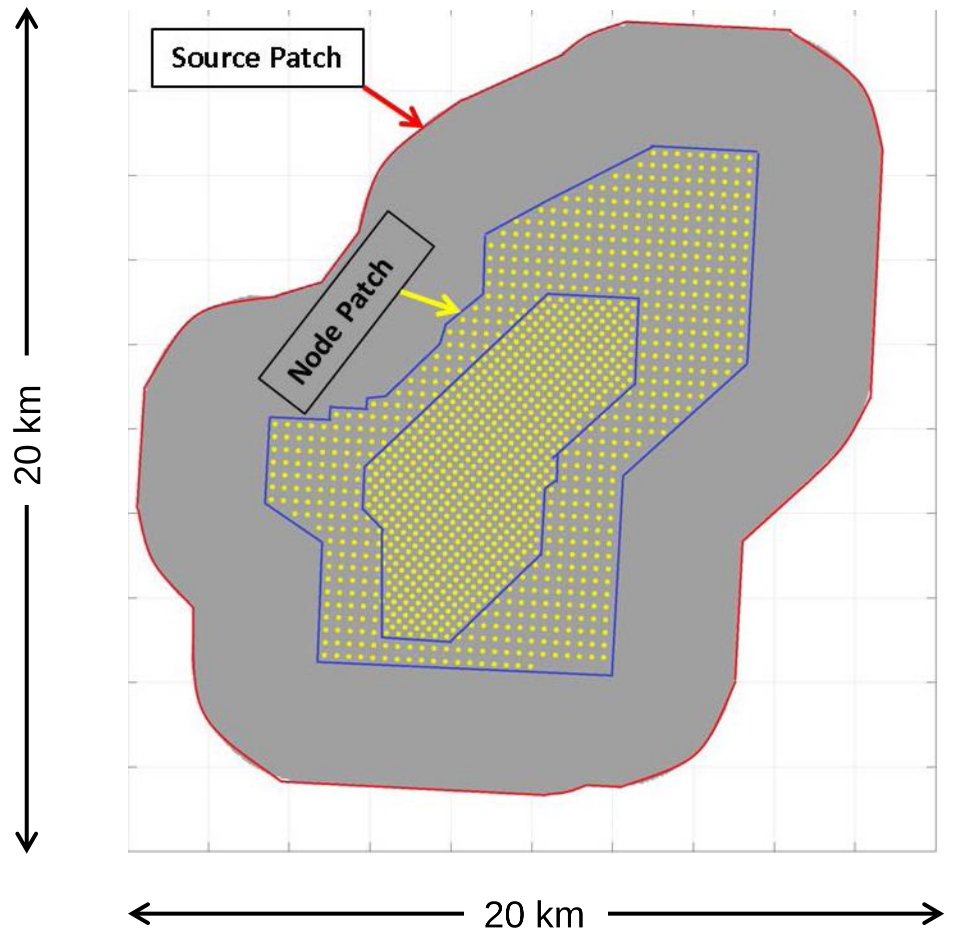
Example 2

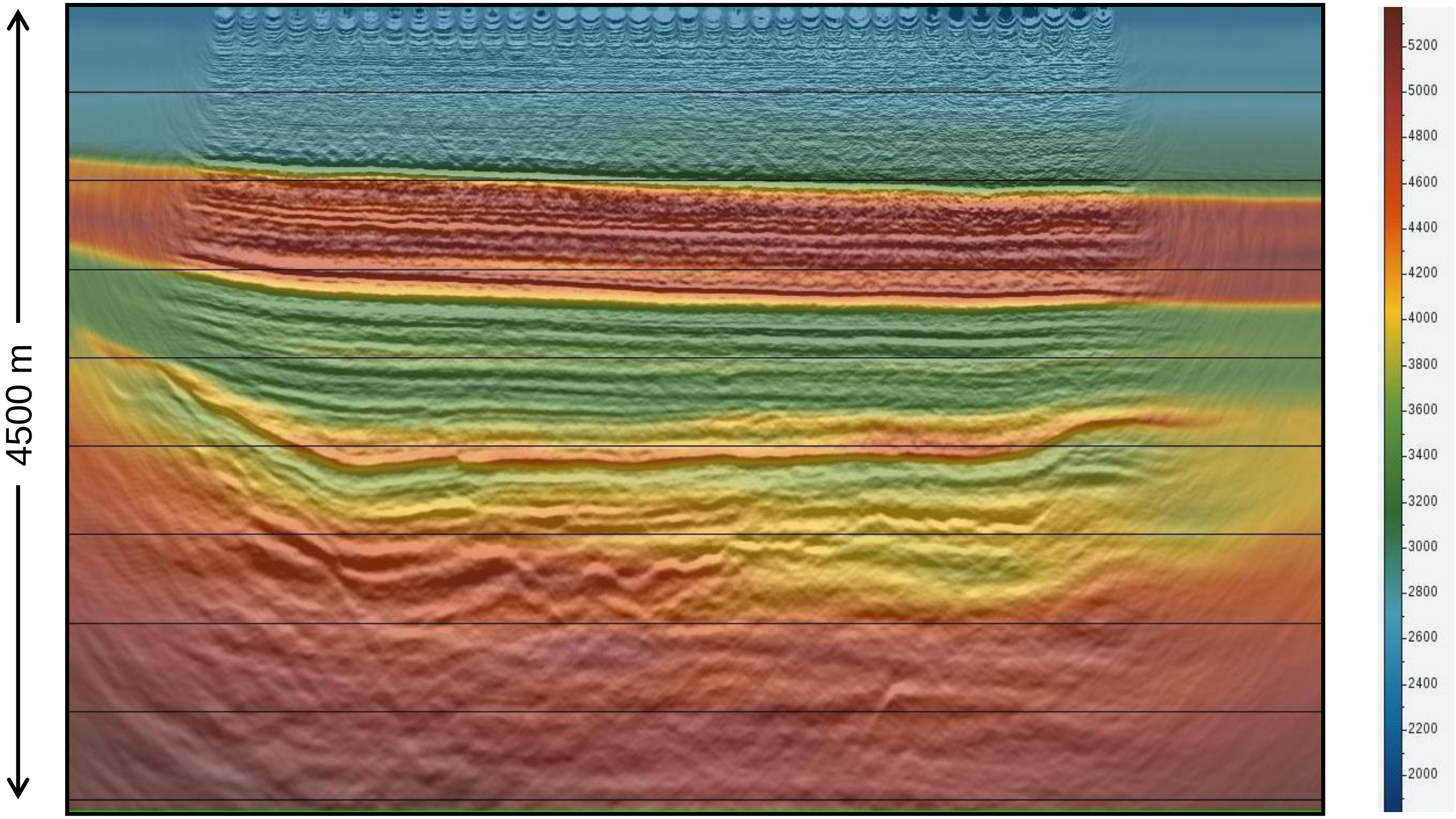
- Conventional shallow-water full-azimuth OBC
- Shallow, over-compacted chalk with sharp top
- Acoustic FWI tries to destroy the chalk
- Limited angles available below chalk

Survey geometry

- shallow water
- 300 m nodes
- dense shots



PSDM with Vp overlay



Field data

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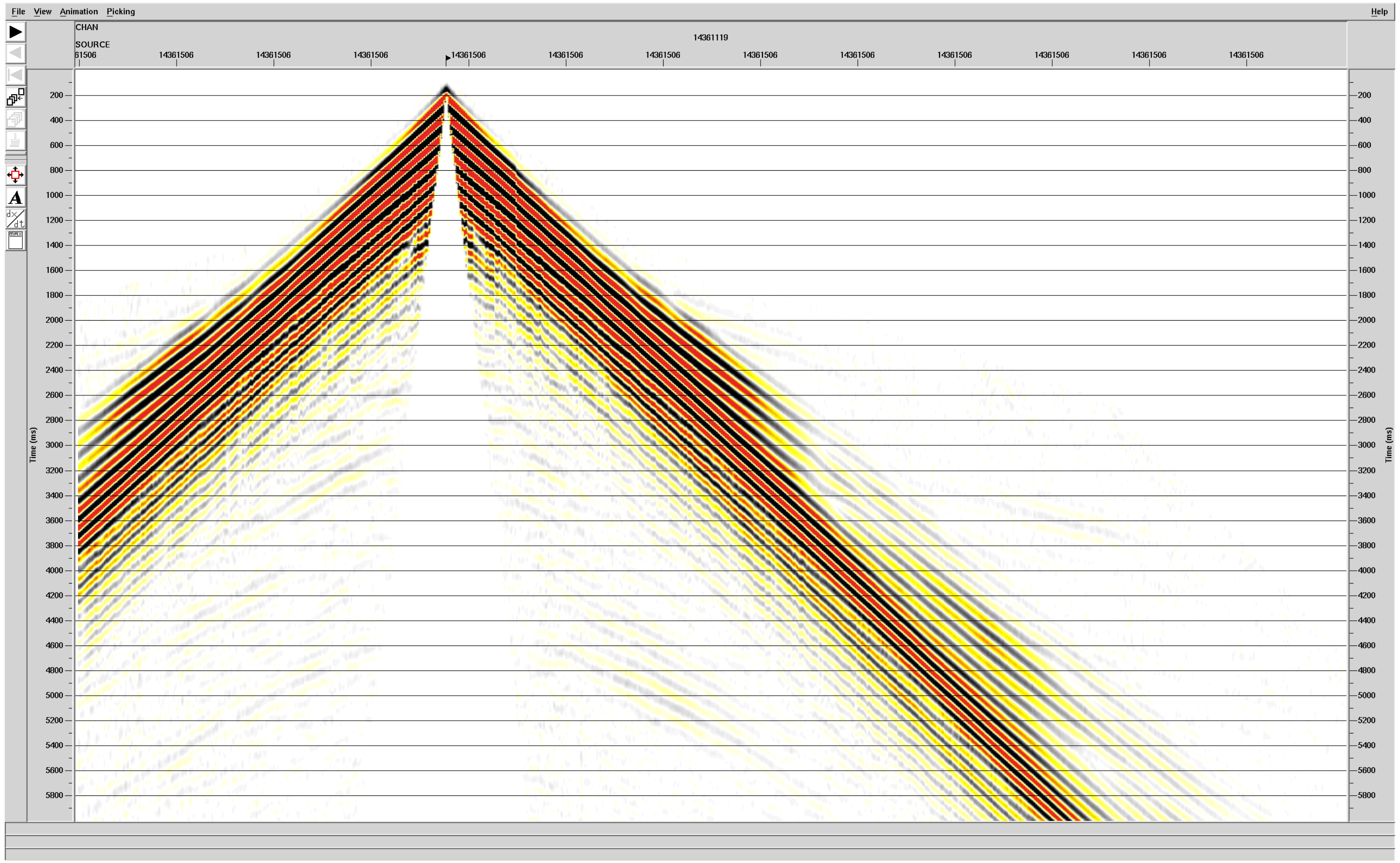

Synthetic from VTI starting model

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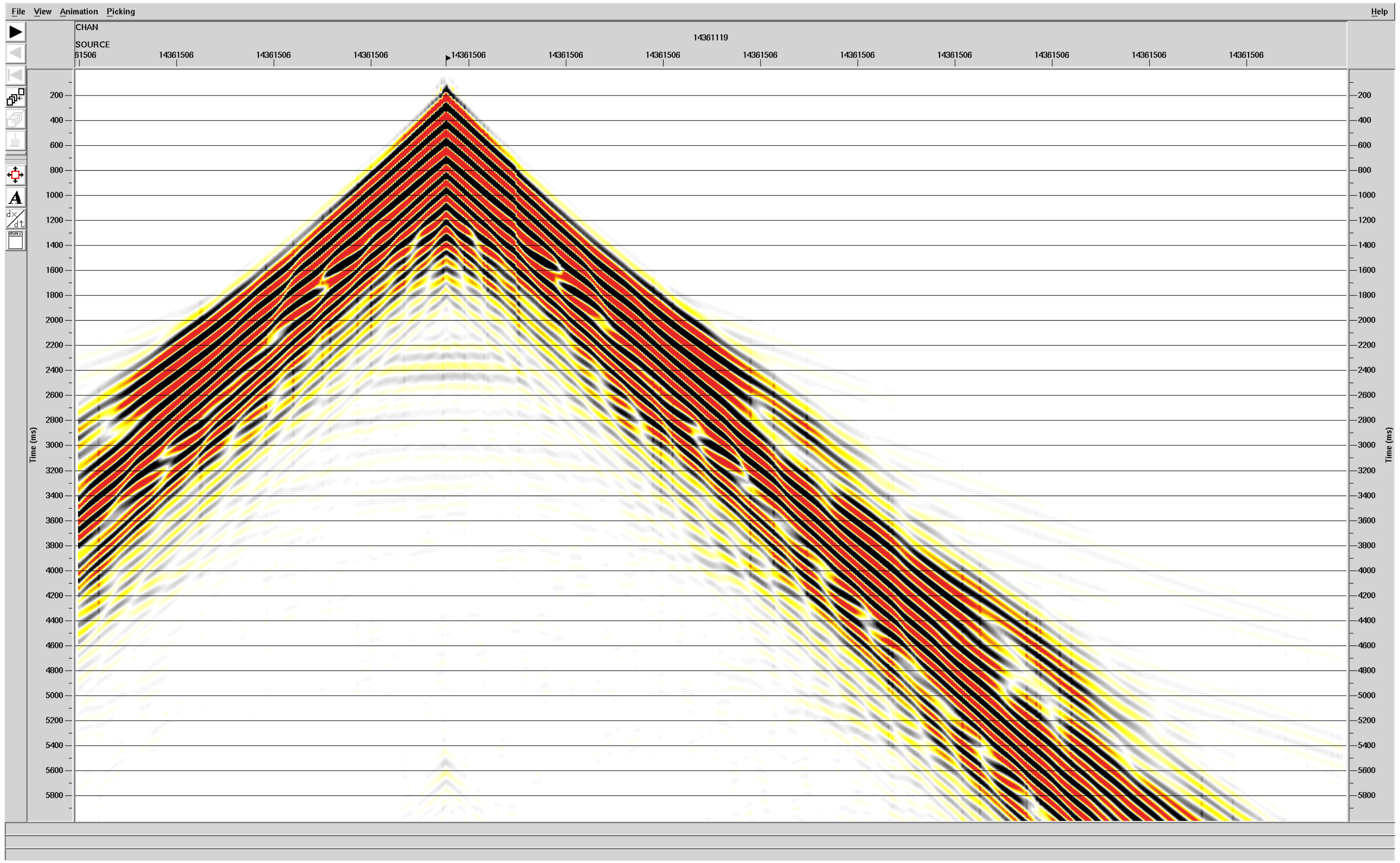
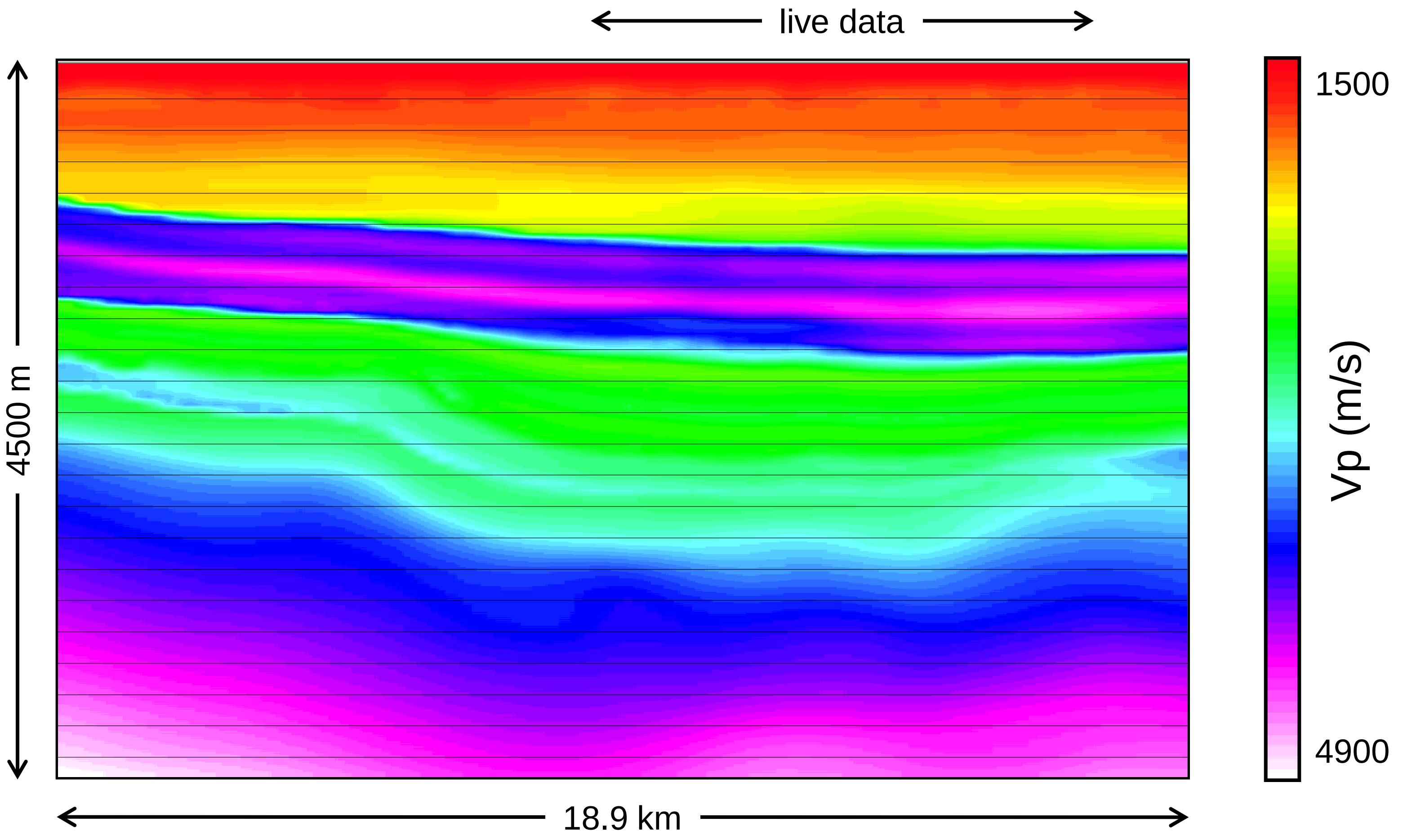


Starting Vp



Vp after acoustic FWI

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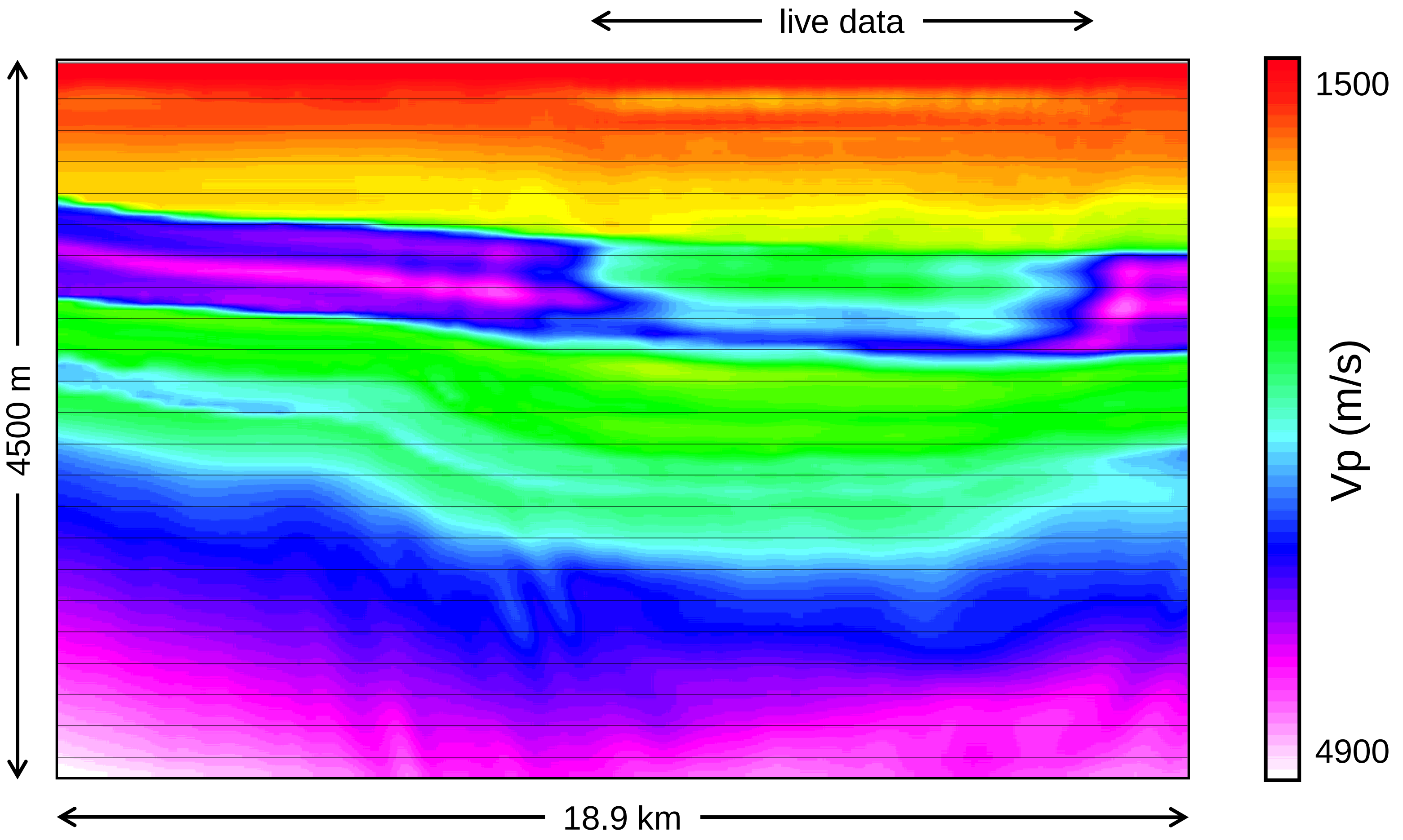
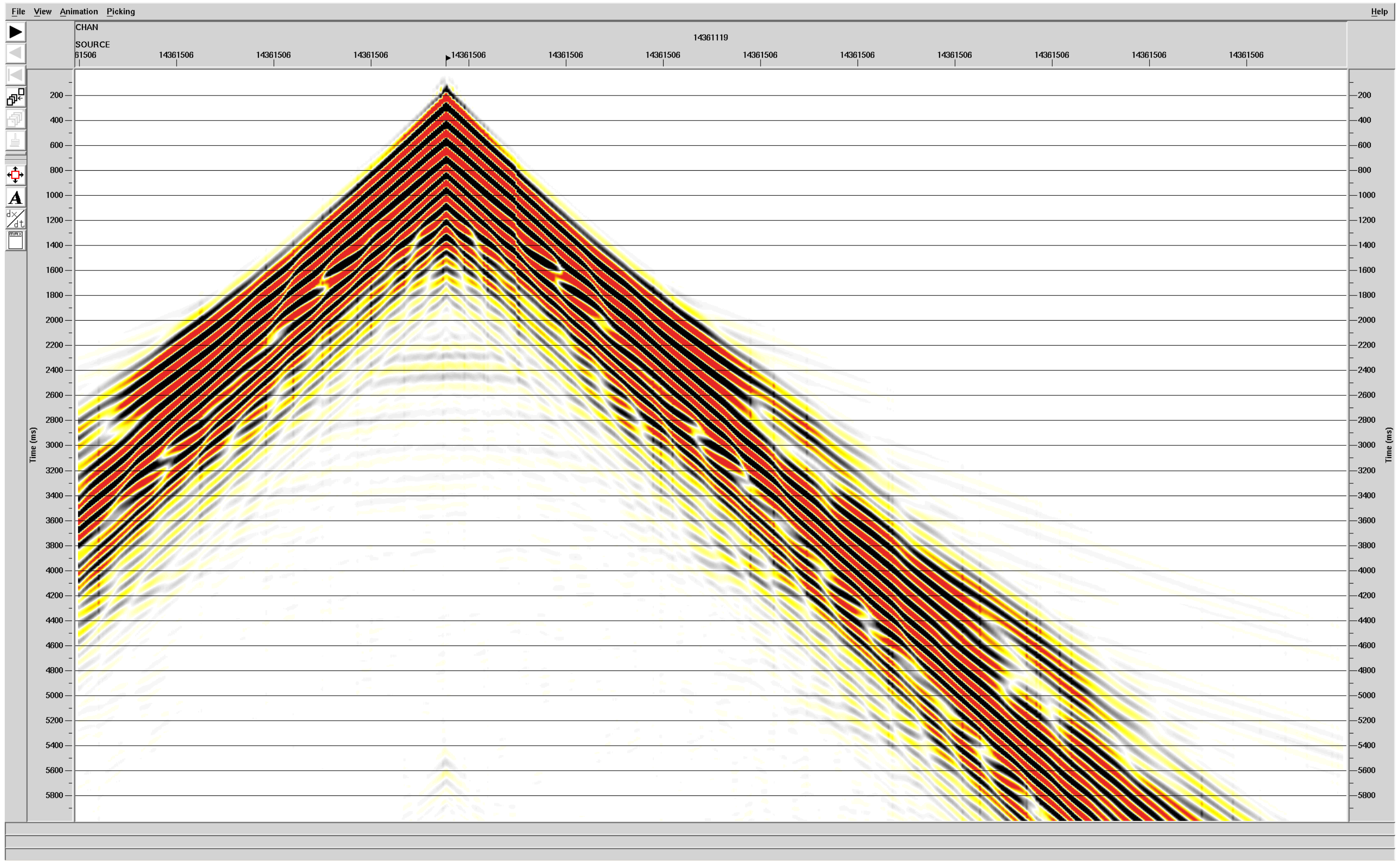
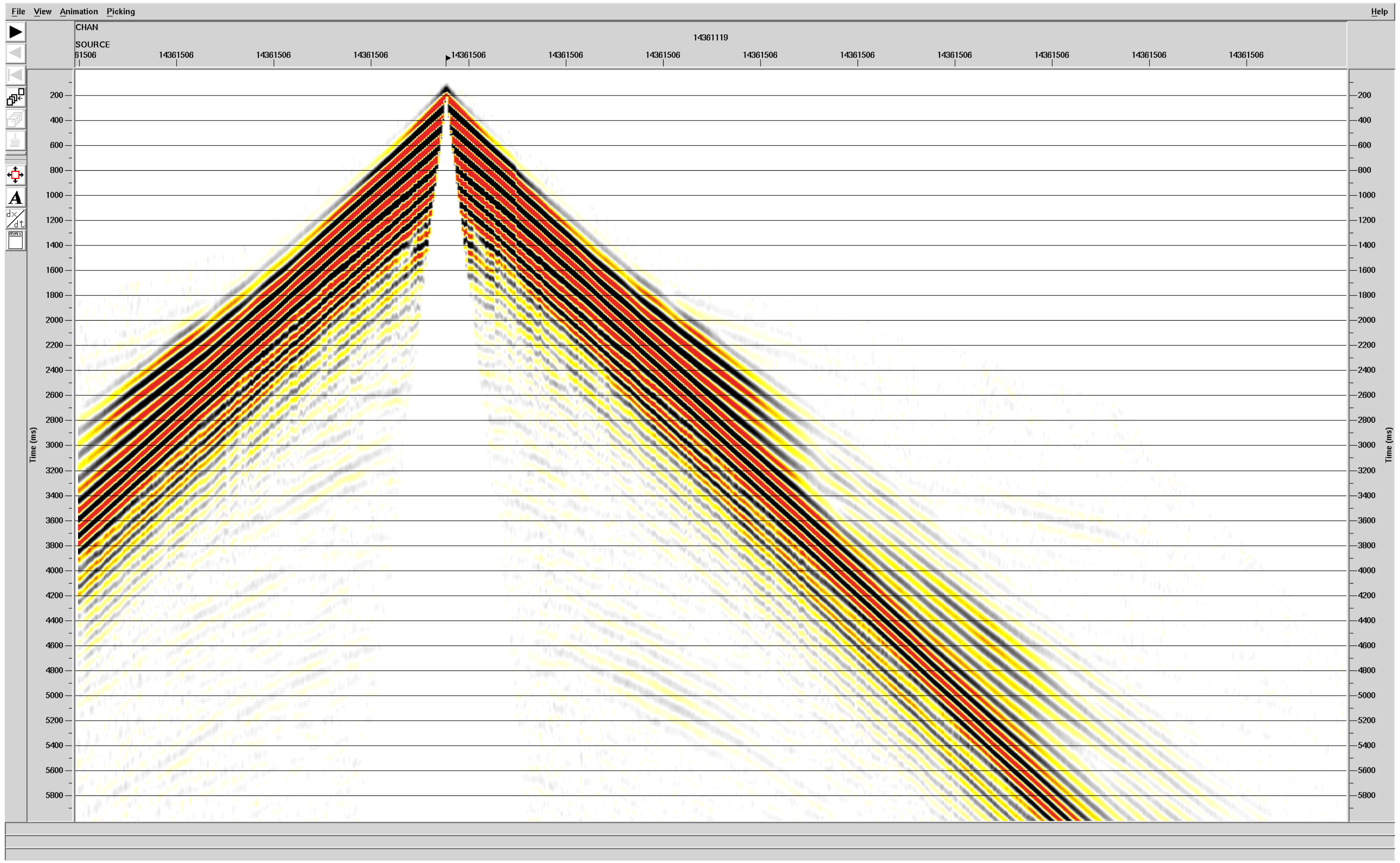


Start-model data



Field data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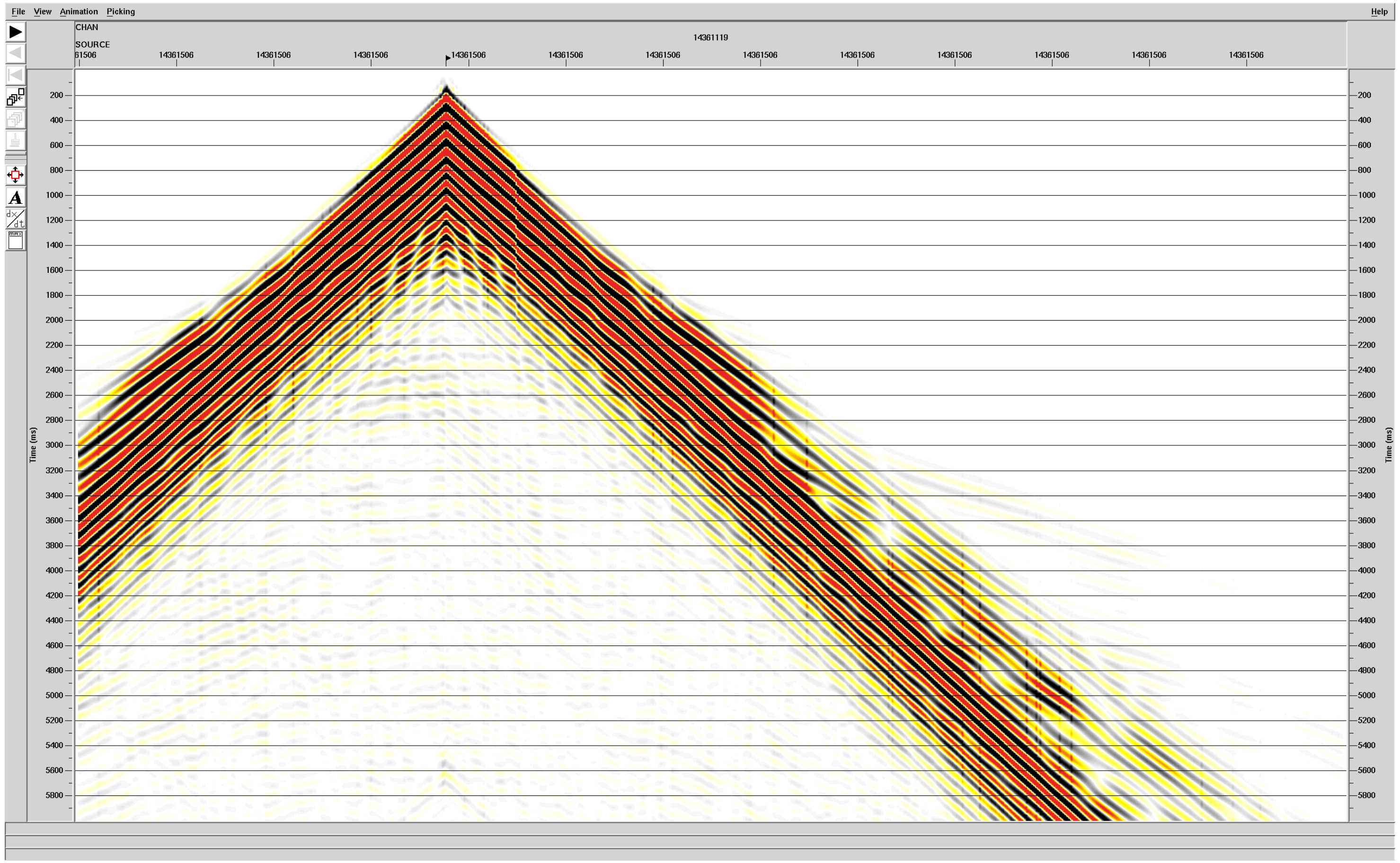
Final-model data



FWI behaviour

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- FWI tries to supress or remove the chalk
- This is consistent independent of:
  - parameterisation
  - pre-processing
  - anisotropy model
  - density model
  - data selection
  - flavour of FWI ...

Field data, f-k filtered

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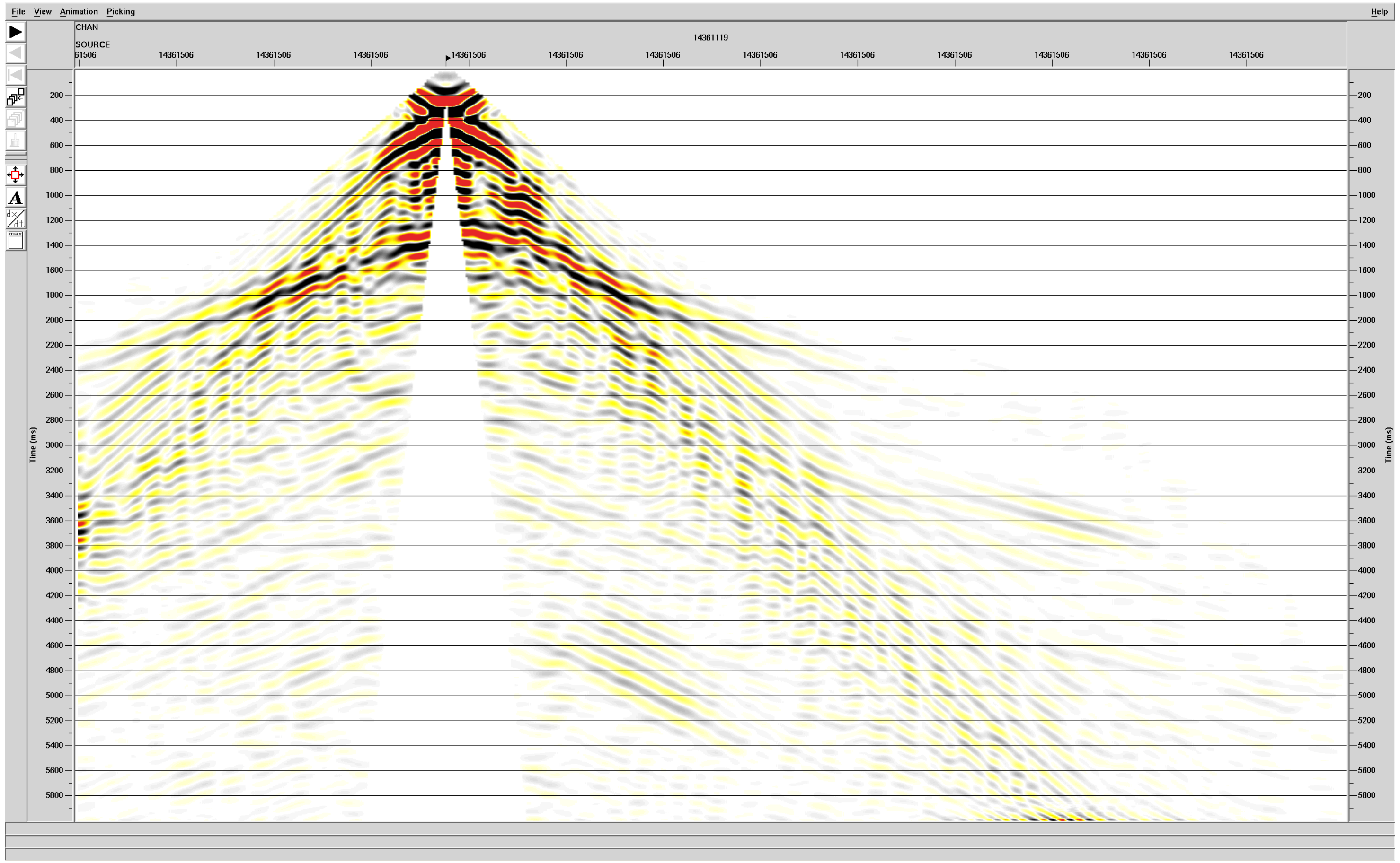
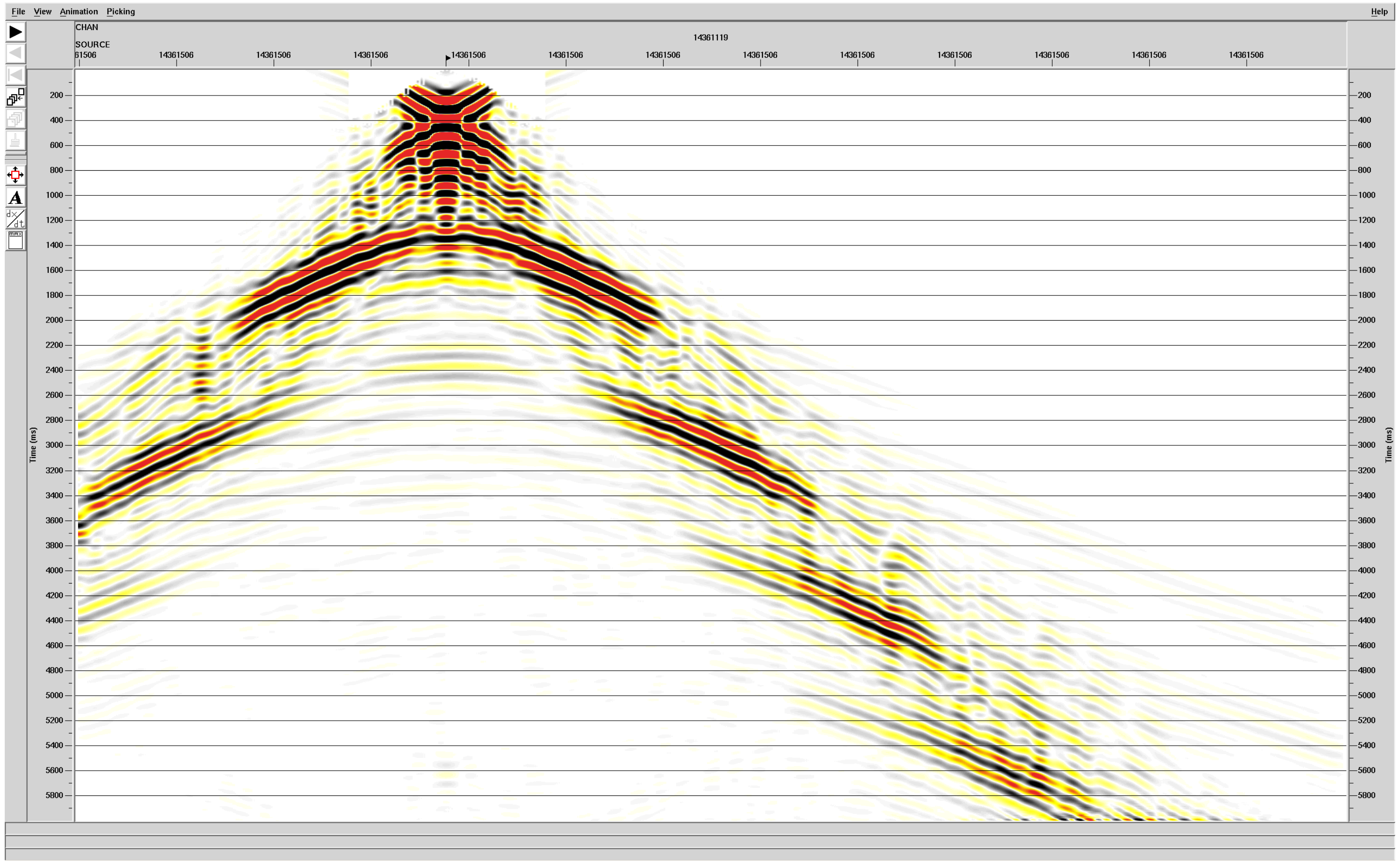


Start data, f-k filtered



Final data, f-k filtered

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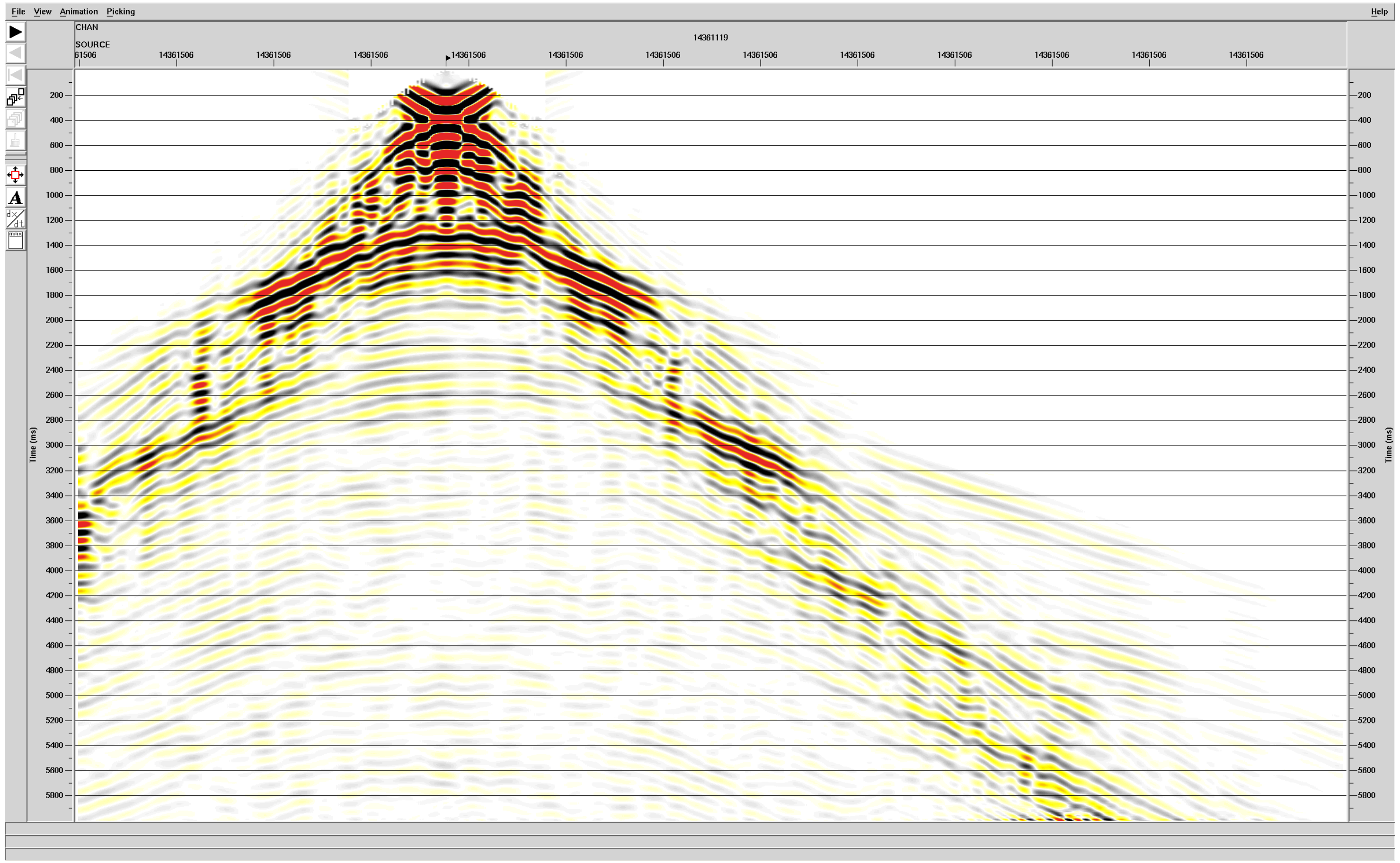
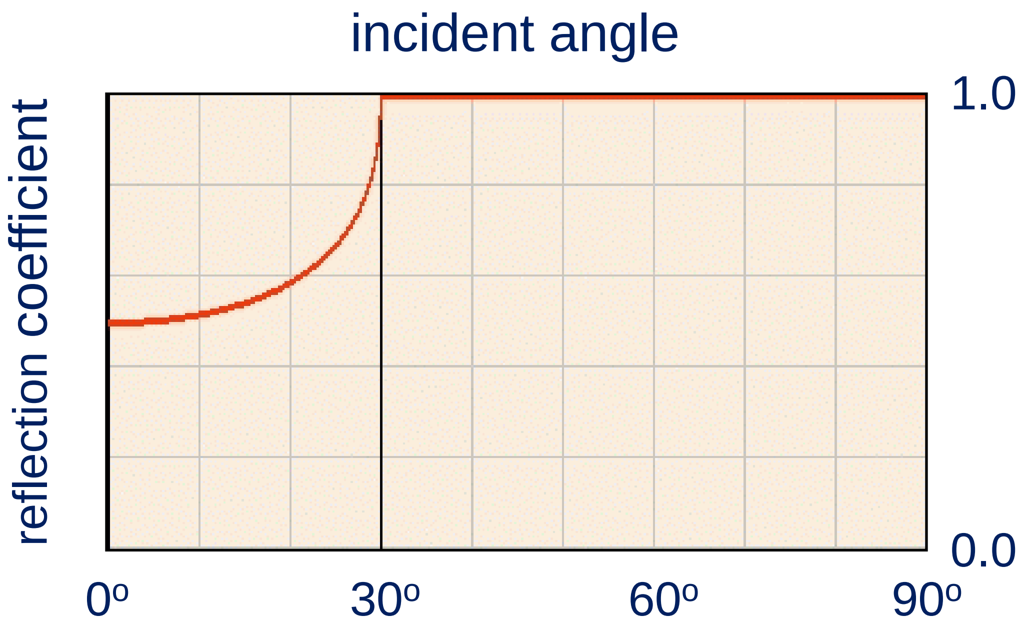


Acoustic effects

- FWI is trying to kill post-critical top-chalk reflections and their multiples
- The inversion is acoustic, so post-critical p-wave reflection coefficients are ~100%
- Surface multiple is also 100%
- So little energy is lost from post-critical primaries and multiples in acoustic simulations

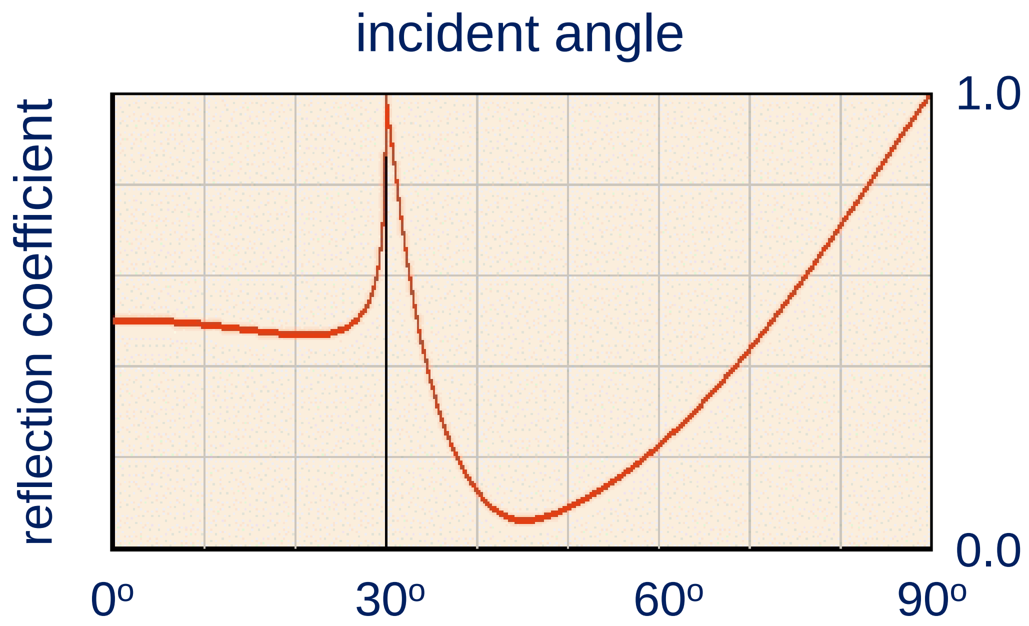
Top chalk acoustic reflection coefficient

	Vp	Vs	density
clastics	2000	0	2000
chalk	4000	0	3000



Top chalk elastic reflection coefficient

	Vp	Vs	density
clastics	2000	400	2000
chalk	4000	2000	3000



Top chalk reflection coefficient

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- In elastic models, the post-critical top-chalk reflection coefficient is similar or less than the post-critical coefficient
- Post-critical multiples are now much weaker

$\longrightarrow$ purely acoustic FWI is not good enough

Why not a problem everywhere?

- Requires a sharp simple boundary
- Requires large Vs contrast
- Requires large Vp contrast
- Helped by large density contrast
- Helped by shallow top-chalk
- Chalk here buried, uplifted, eroded, subsided...
  ...giving exactly these circumstances
- We do not see this in Central North Sea

Solutions

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1. Elastic inversion – but typically unaffordable when Vs is low
2. Affordable acoustic inversion:
   - Add post-critical primaries and multiples to field data, or
   - Supress post-critical primaries and multiples in predicted data

Summary

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Commercial FWI with cycle-skipping protection works out of the box at least 80% of the time

- still needs insight and experience for the remaining 20%
- not always obvious if a dataset will be in the 20% *a priori*