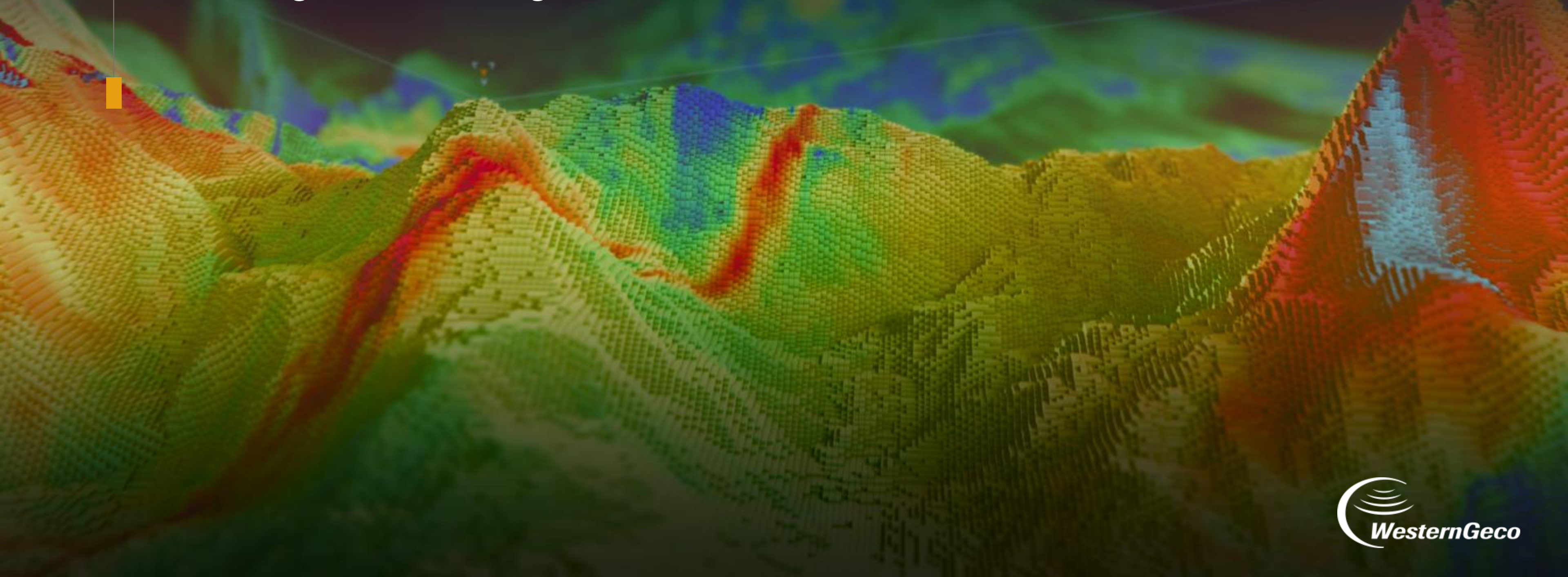
Utilizing full waveform inversion from shallow to deep.

Denes Vigh Schlumberger WesternGeco

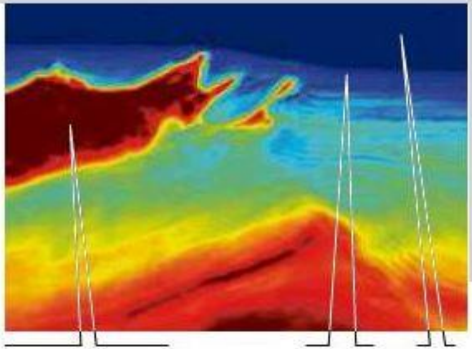


FWI in the forefront of Production

A more detailed look at what's down there

Original rendering drawn by hand guesstimating data on salt dome.

Source: BP



Salt dome more Ocean Sea accurately rendered bed

Houston Chronicle

In 2004, scientists had to guess at the size and shape of the salt dome beneath Atlantis, and knew little about the earth under the dome. Then, last year, BP scientists developed a new algorithm and used the company's supercomputer to produce a more accurate image of the salt dome and minerals under it.

British oil major BP has discovered 200 million barrels of oil in a hidden cache in the Gulf of Mexico, thanks to a technological breakthrough allowing the company to see beneath geological formations that had befuddled oil exploration for decades.

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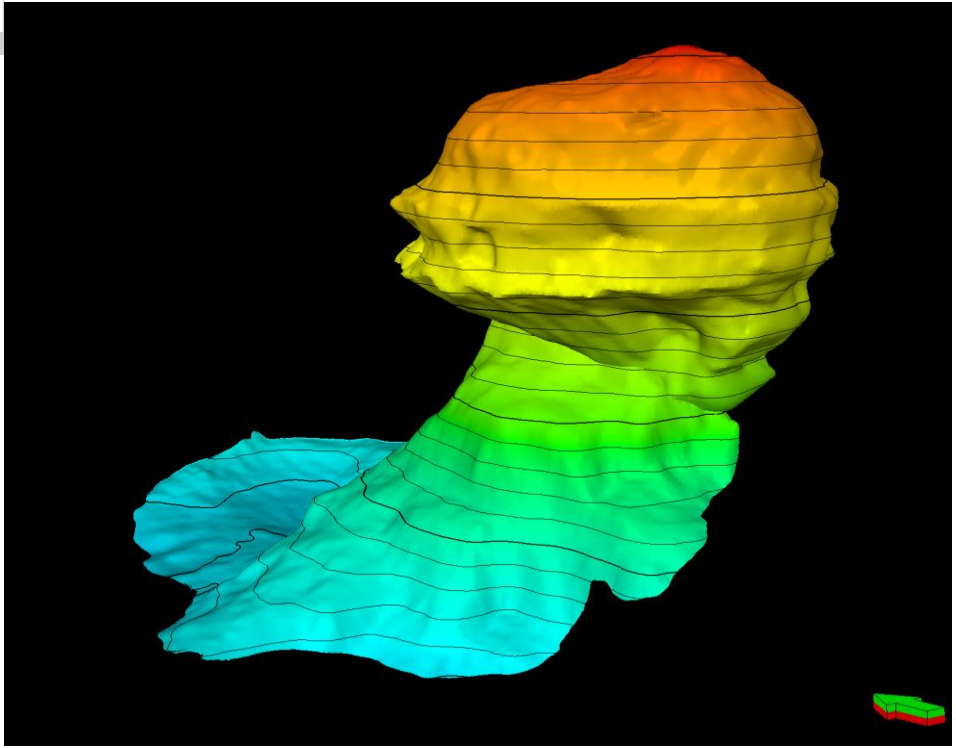
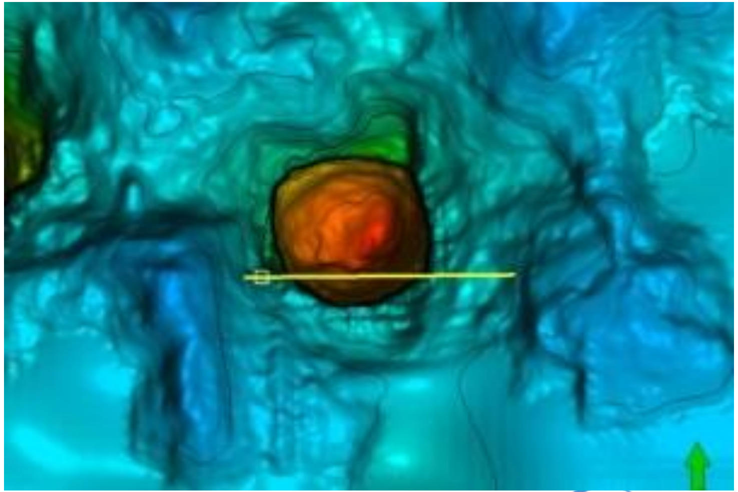
3-Dimensional Problem of Subsalt Imaging



- Full Azimuth Acquisition
- Accurate Structural Picture
- Best imaging of Salt-Sediment Interface



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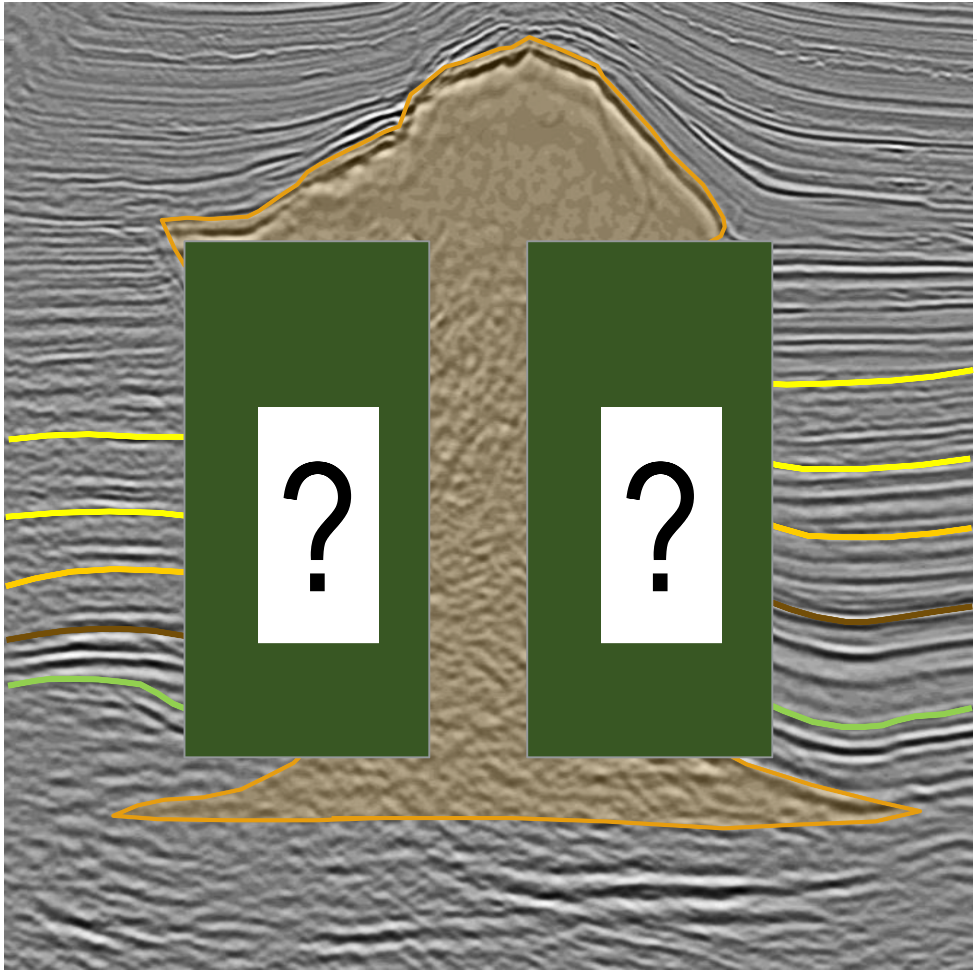
Prospecting Without Seismic and Depth Imaging

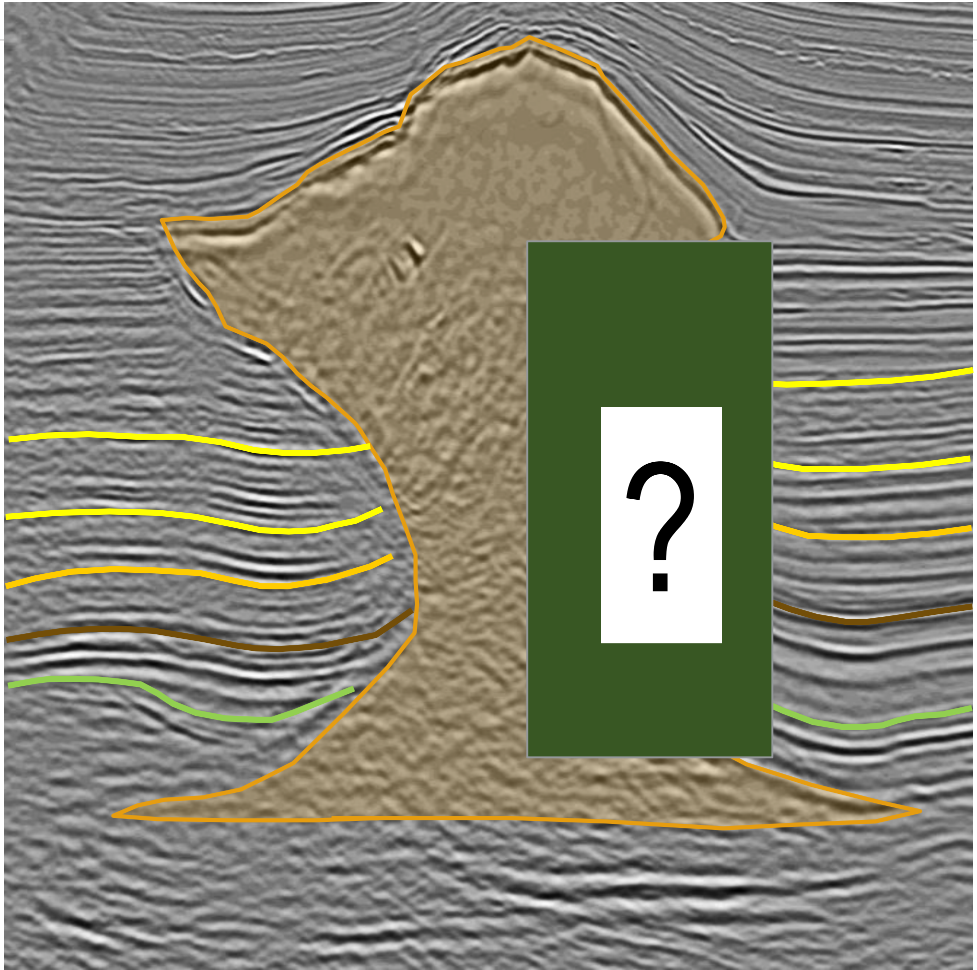
What will you find?



Prospecting Without Seismic and Depth Imaging

What will you find?

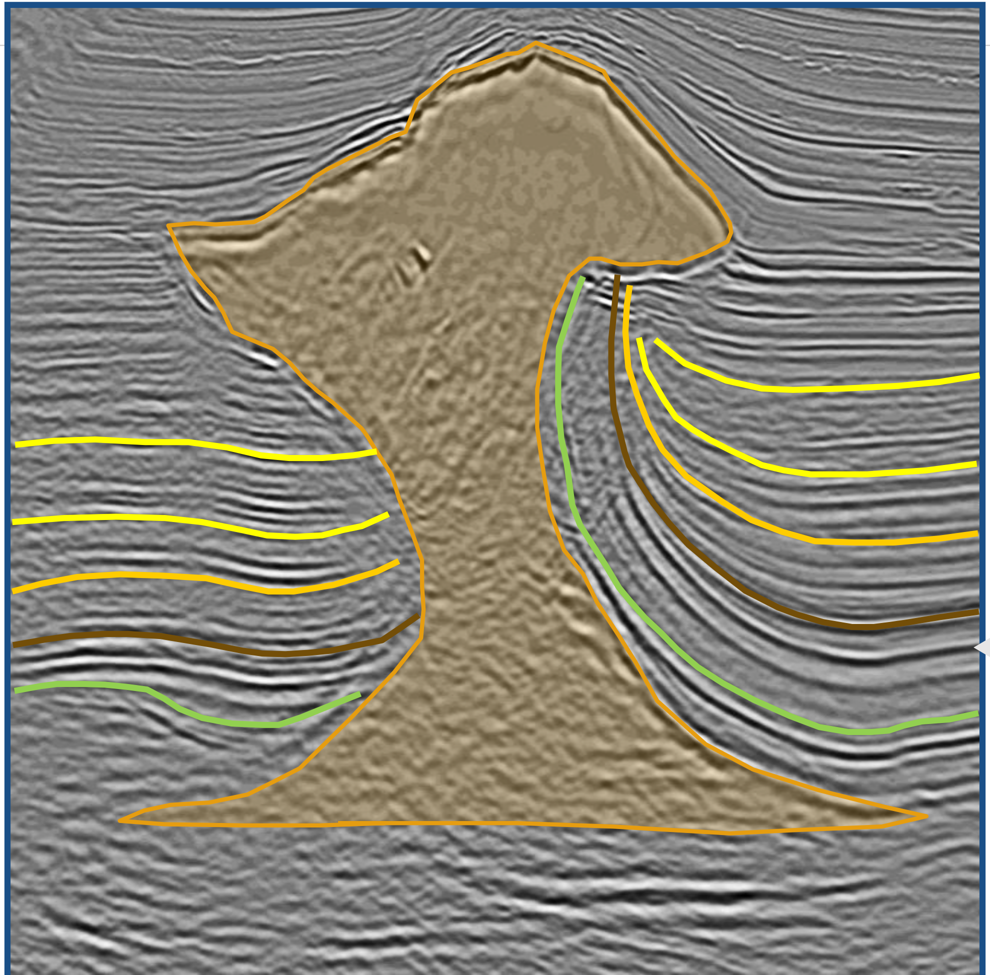
This



Prospecting Without Seismic and Depth Imaging

What will you find?

This



or This

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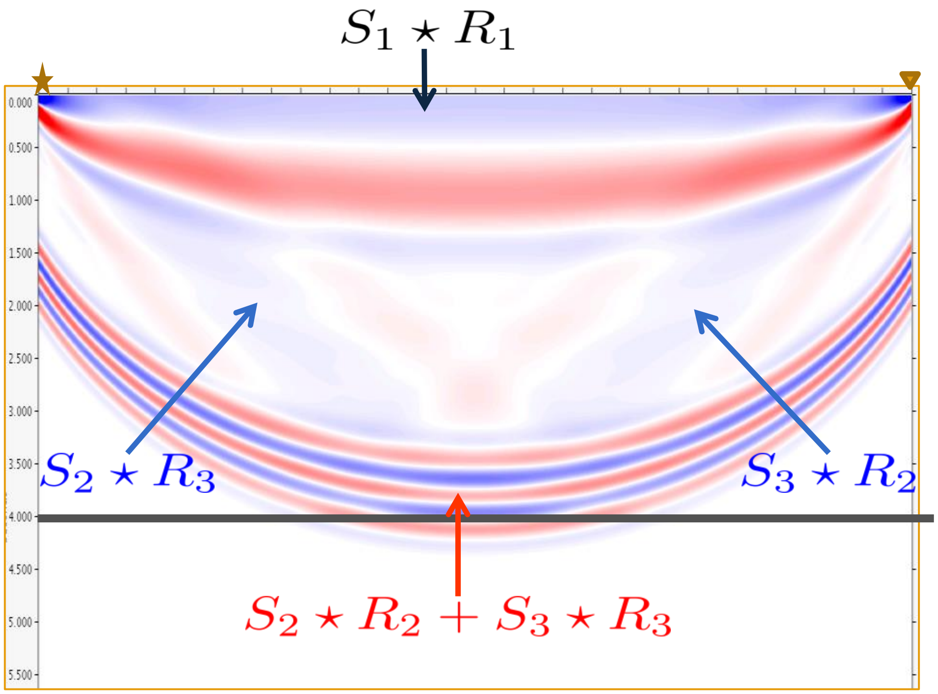
Full Waveform Inversion (FWI)

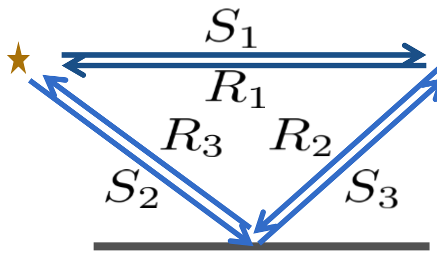
FWI: data fitting based model building process

- applicable to data with rich transmission (long-offset)
  - ✓ plenty successful FWI applications in field
  - × limited penetration depth
- **more challenging with reflection**, mainly because:
  - reflection-driven gradient not amenable for kinematic update
  - strong nonlinearity & many false local minima

Two Modes of FWI Gradient

- FWI gradient has both **low- & high-wavenumber** components





transmitted energy $S_1 \star R_1$
reflected energy $S_2 \star R_2 + S_3 \star R_3$ $+ S_2 \star R_3 + S_3 \star R_2$

Key Challenges to Successful Inversion

- Key to inversion with transmission:

  How to mitigate local-minima issue? (objective selection)

- Keys to inversion with reflection:

  (1) How to promote low-wavenumber updates?

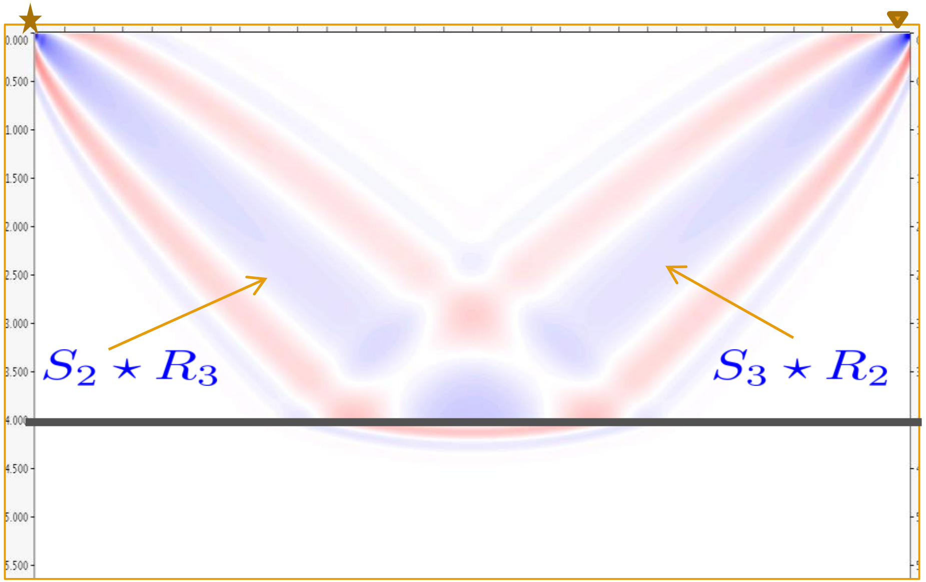
  (2) How to mitigate local-minima issue?

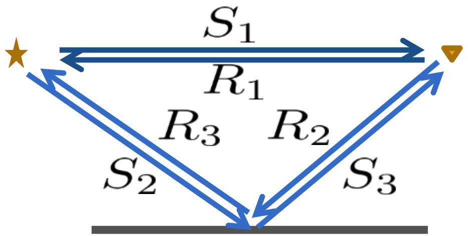
Method: Reflection based FWI (RFWI)

Two essential components:

- Born modeling based gradient kernel
  - ✓ to explicitly compute low-wavenumber components from reflection
- Kinematics oriented objective functions
  - ✓ to achieve correct updating direction

Low-wavenumber Gradient from Reflection





Gradient based on Born modeling

$$\left(\frac{\partial \delta p}{\partial v}\right)^T d_r = S_2 \star R_3 + S_3 \star R_2$$

$$\left(\frac{\partial \delta p}{\partial v}\right)^T d_r = \texttt{src\_bg} \star \texttt{rcv\_scat} + \texttt{rcv\_bg} \star \texttt{src\_scat}$$

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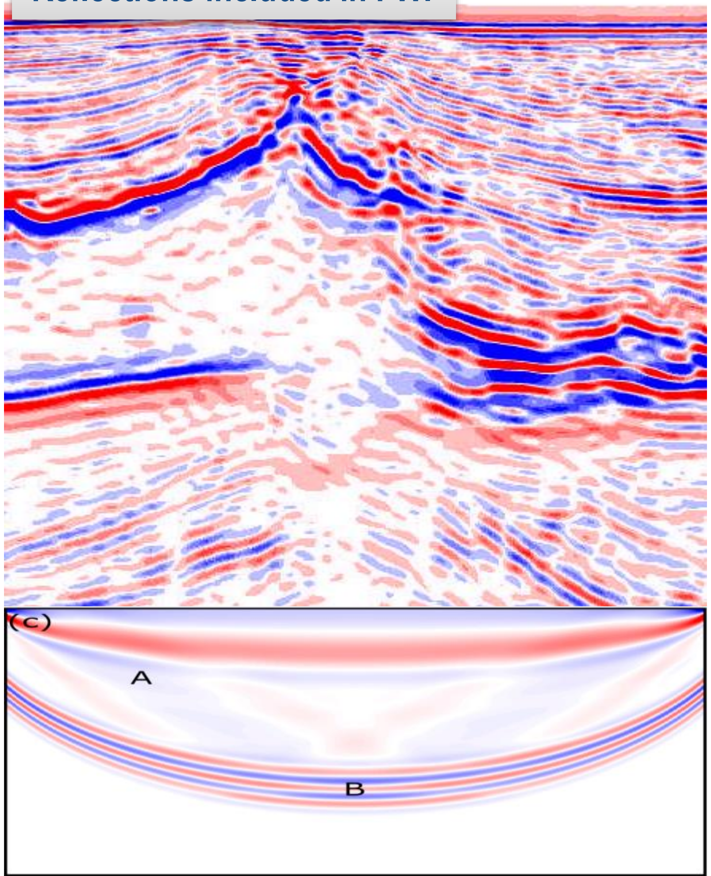
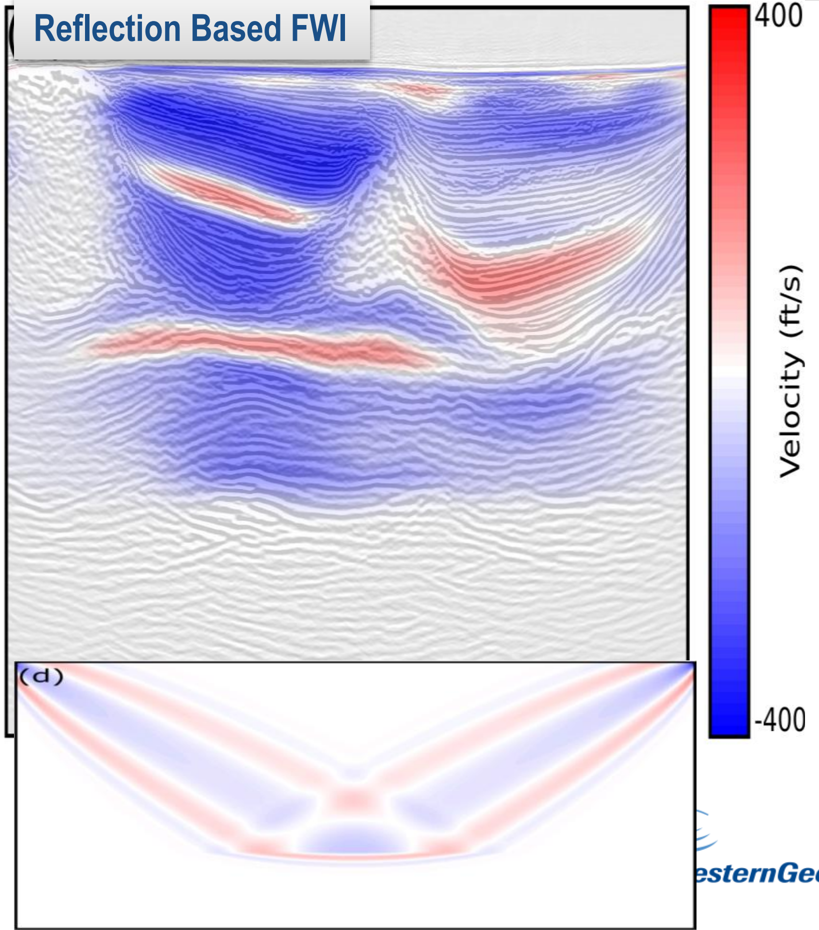
Difference between FWI approaches

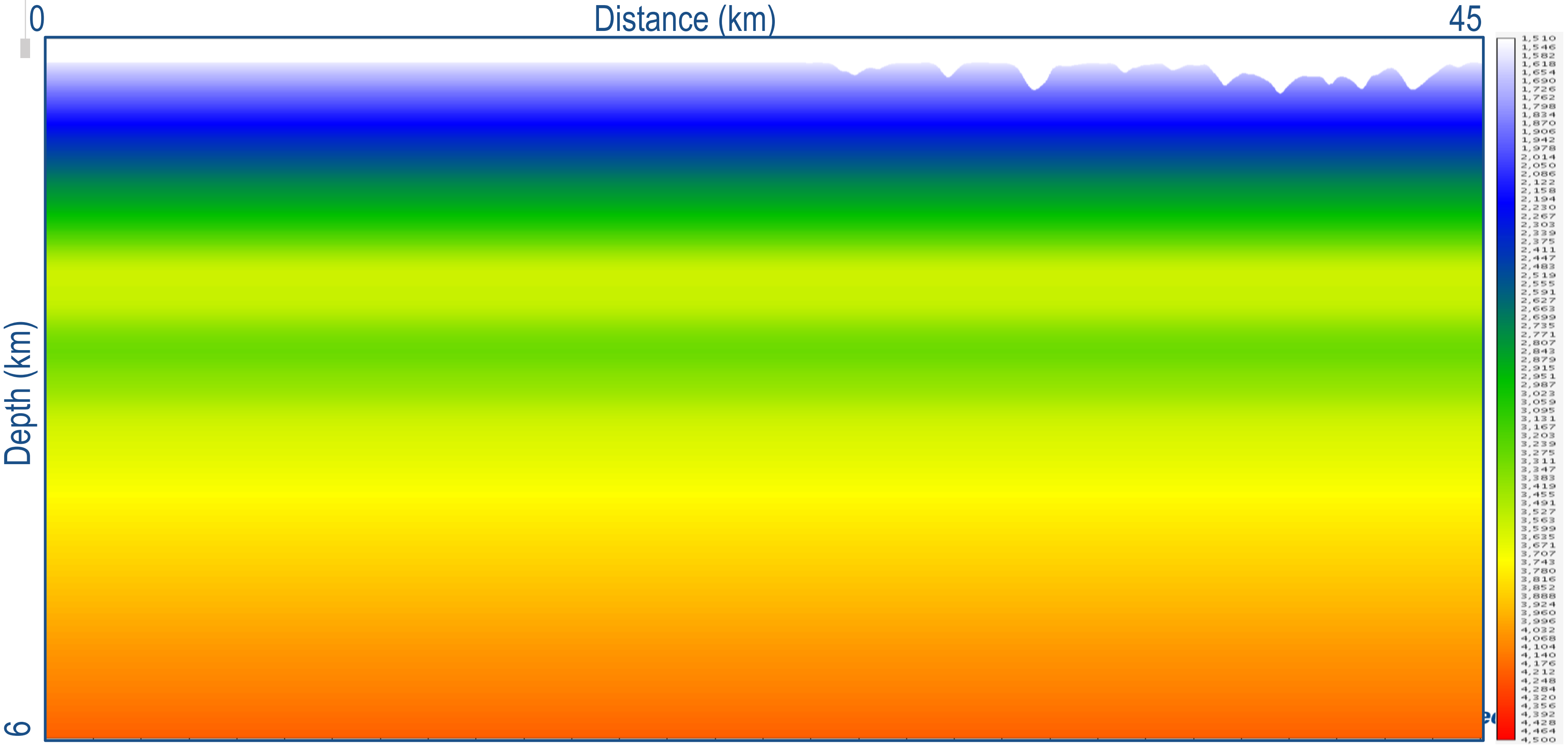
Reflections included in FWI



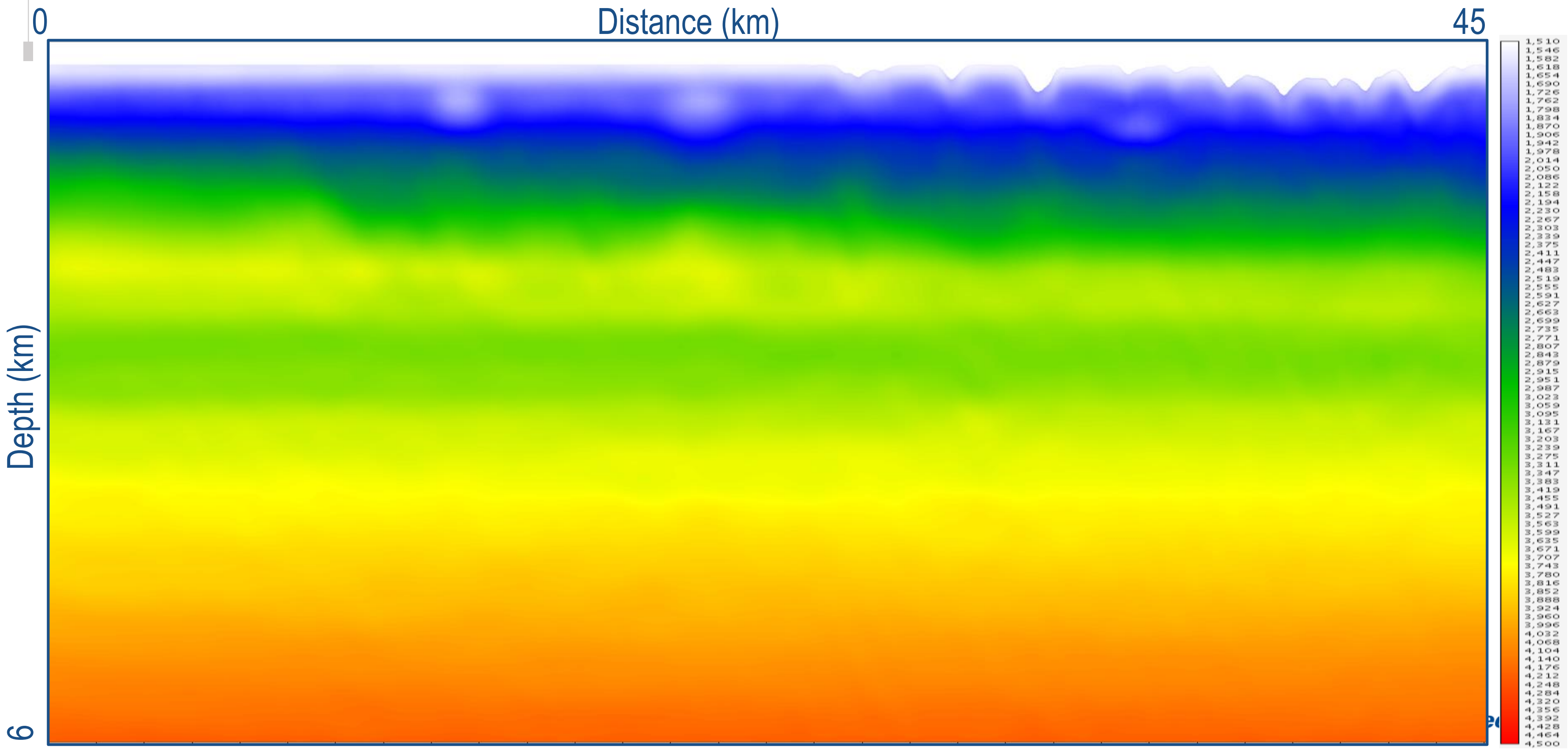
Reflection Based FWI



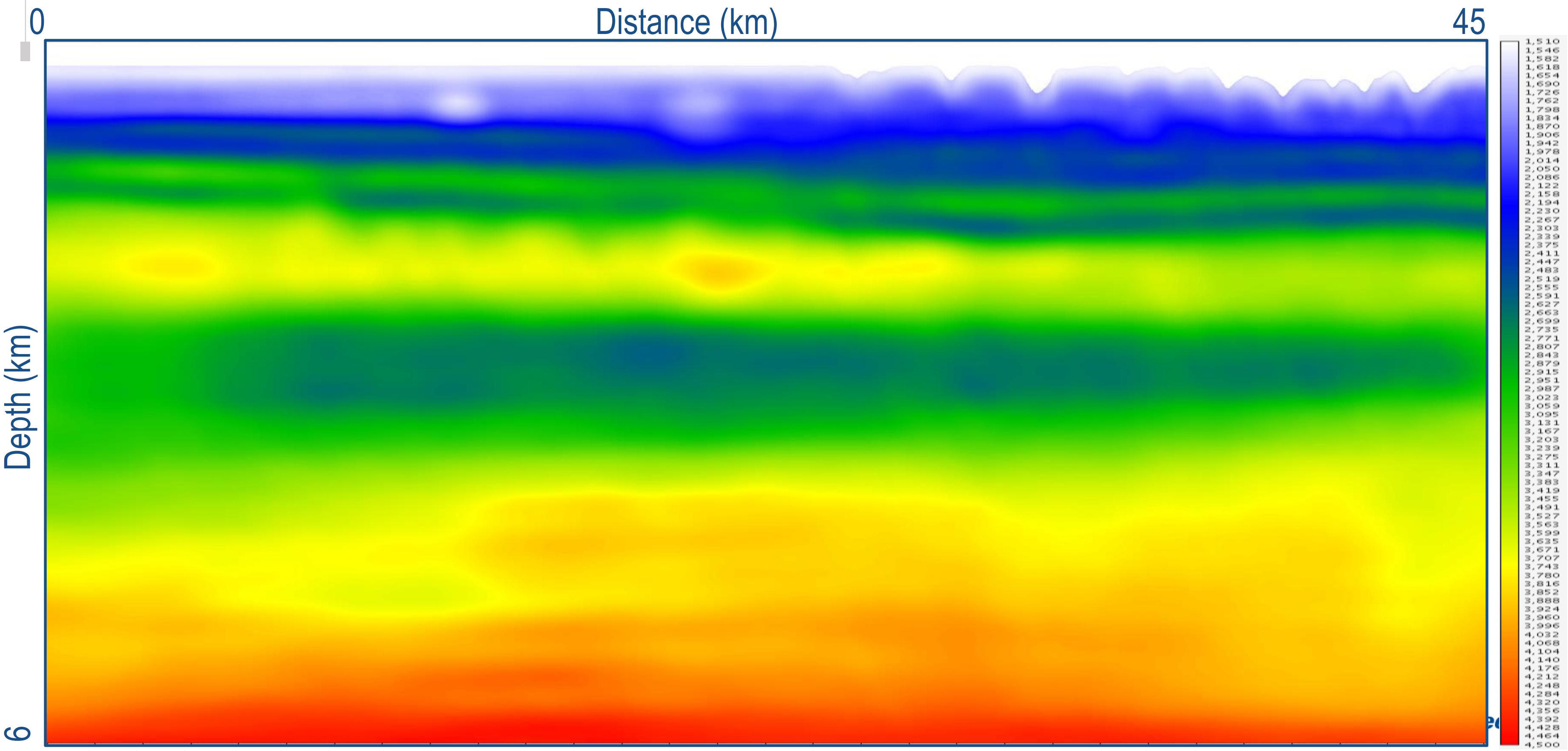
Initial Velocity Provided



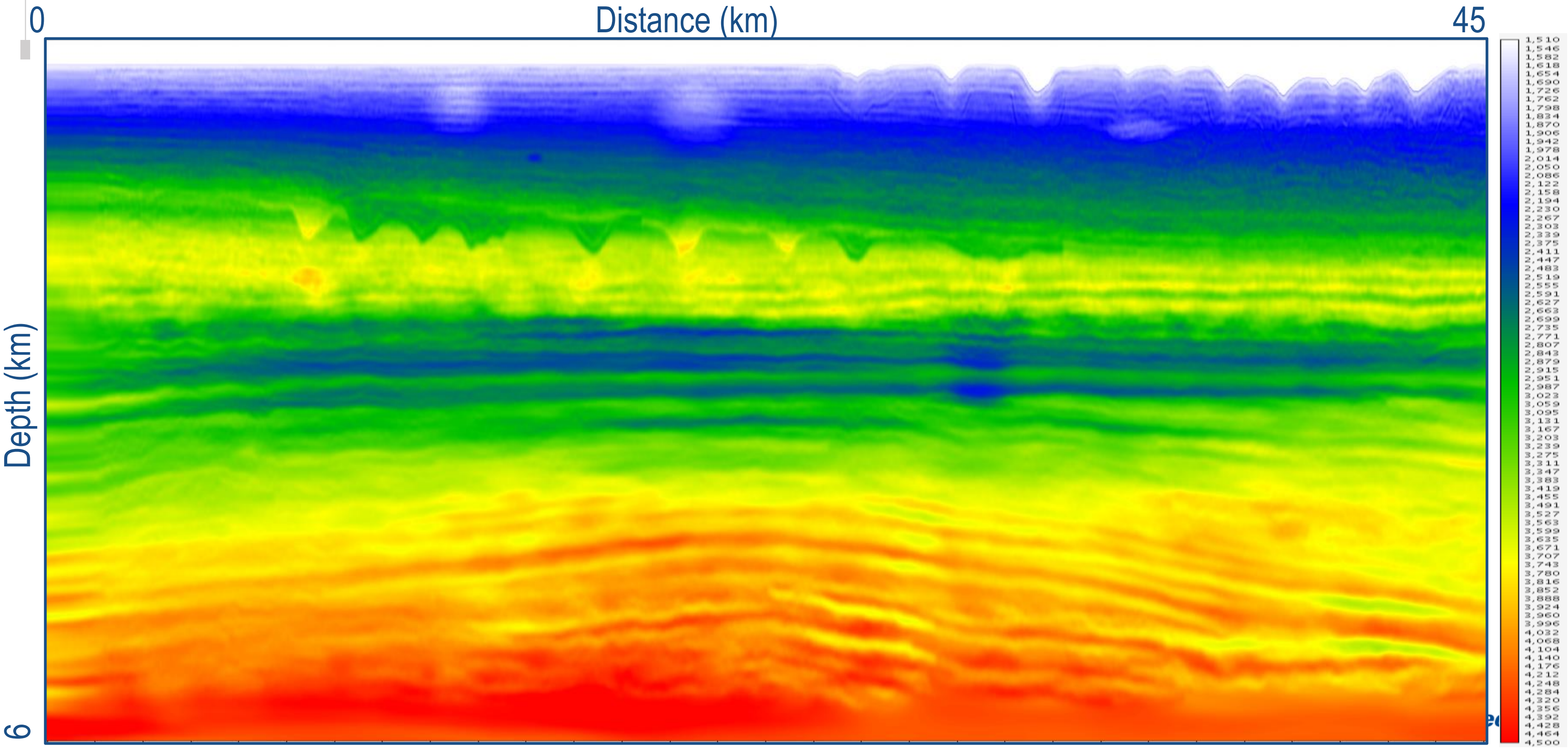
Adjustive FWI Inverted Vp (up to 5 Hz)



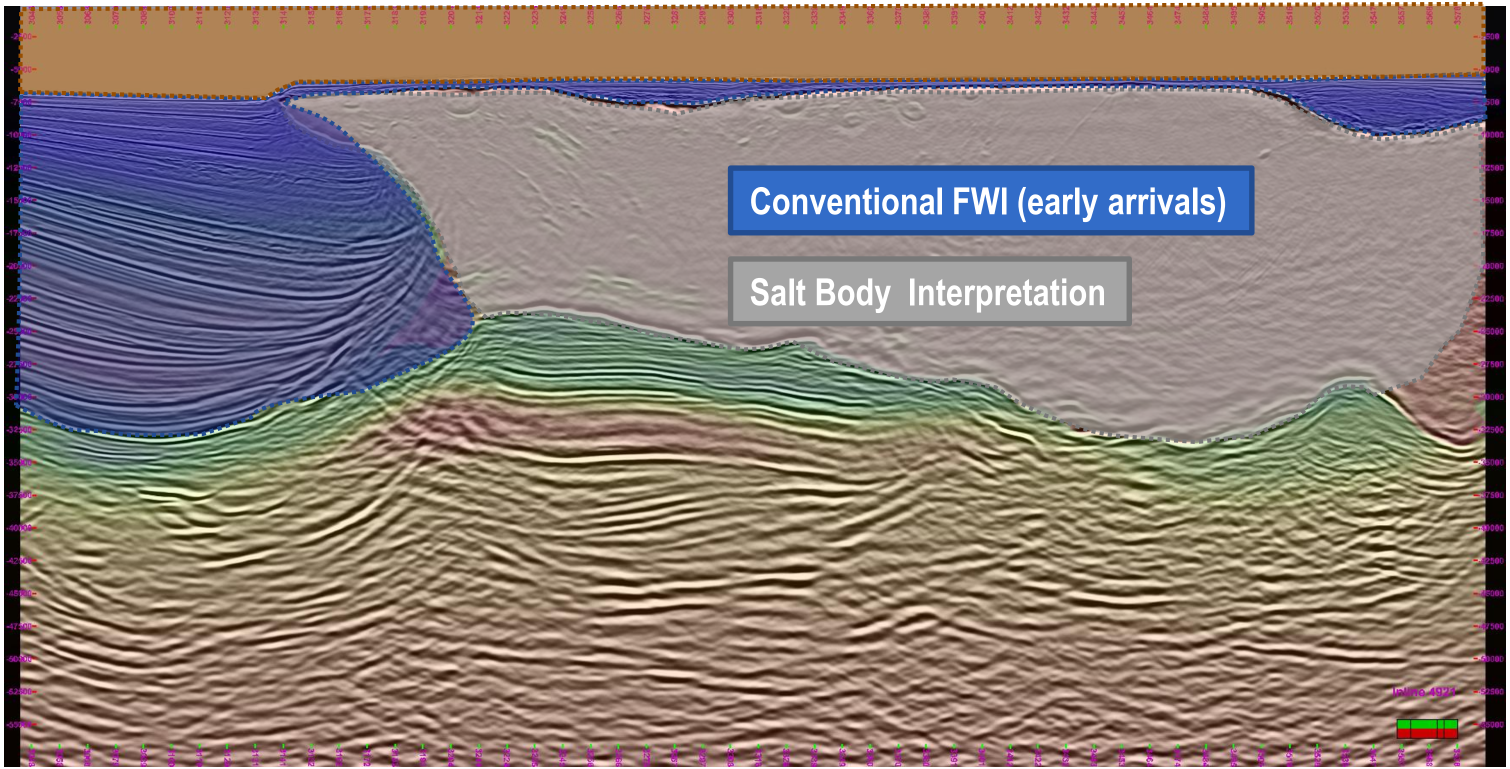
Adjustive RFWI Inverted Vp (5 and 7 Hz)



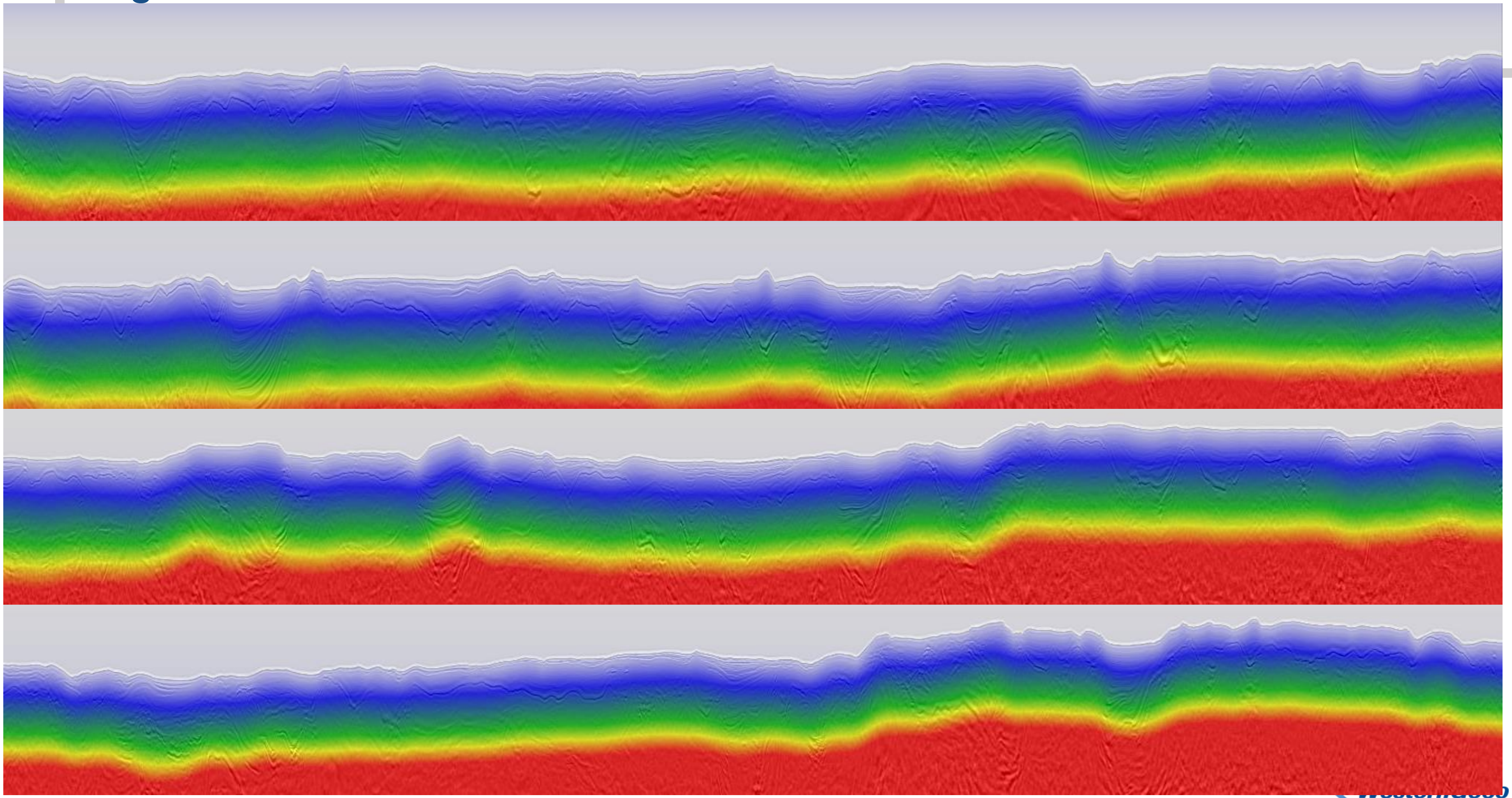
LS-FWI Inverted Vp (7 and 10 Hz)



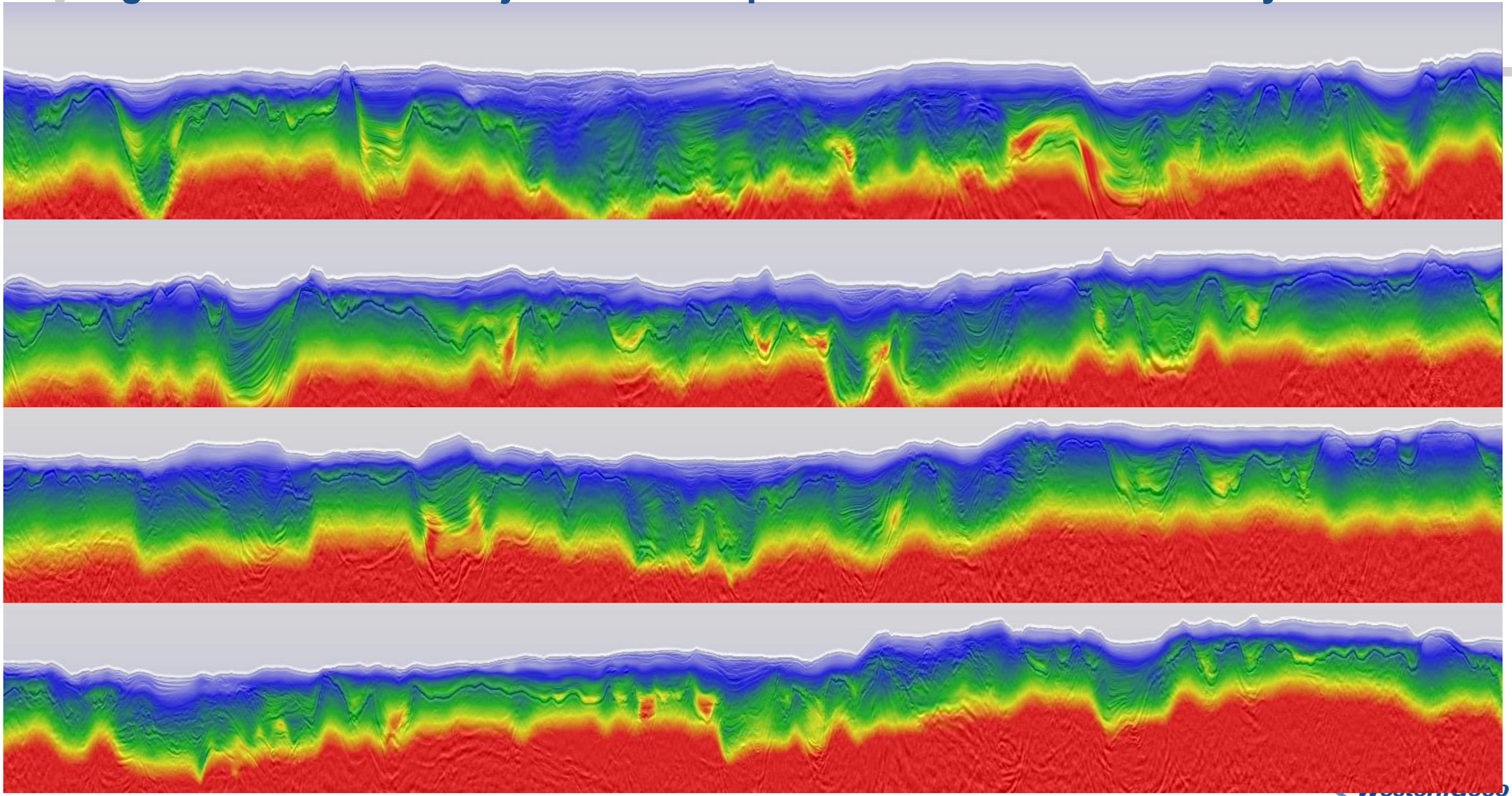
Velocity Model Building Approach



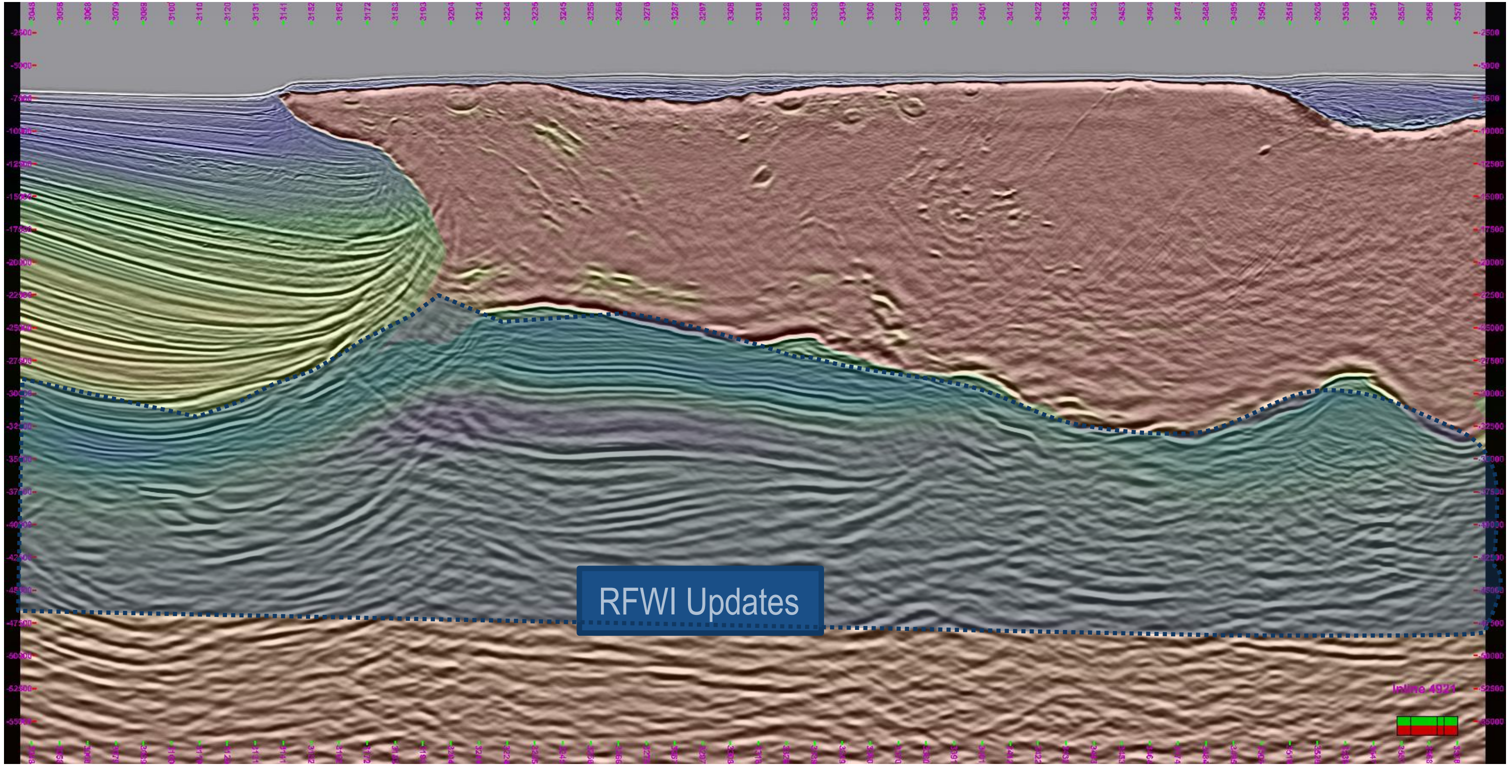
Regional Lines with 1D initial model for FWI



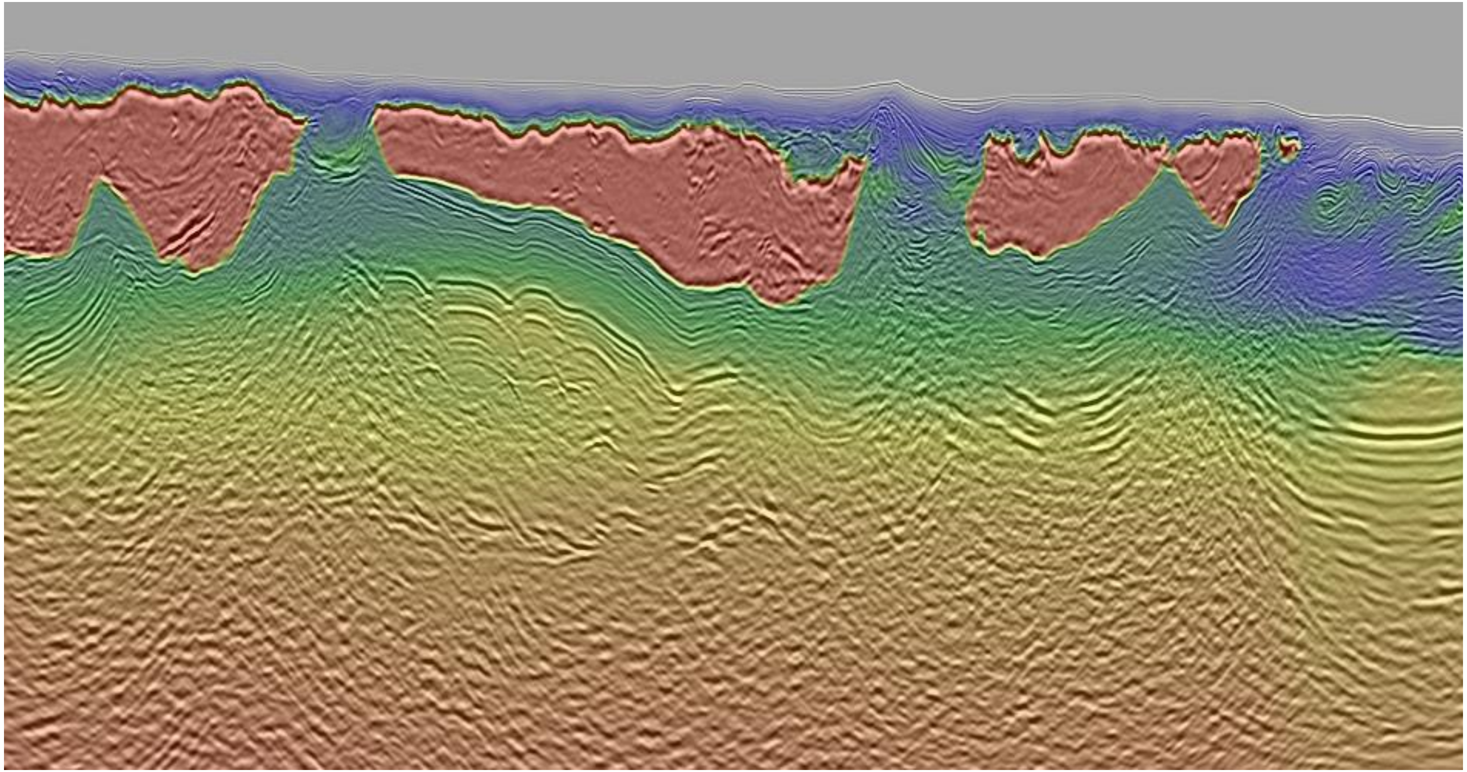
Regional Lines with Adjustive FWI update from 1D initial velocity model



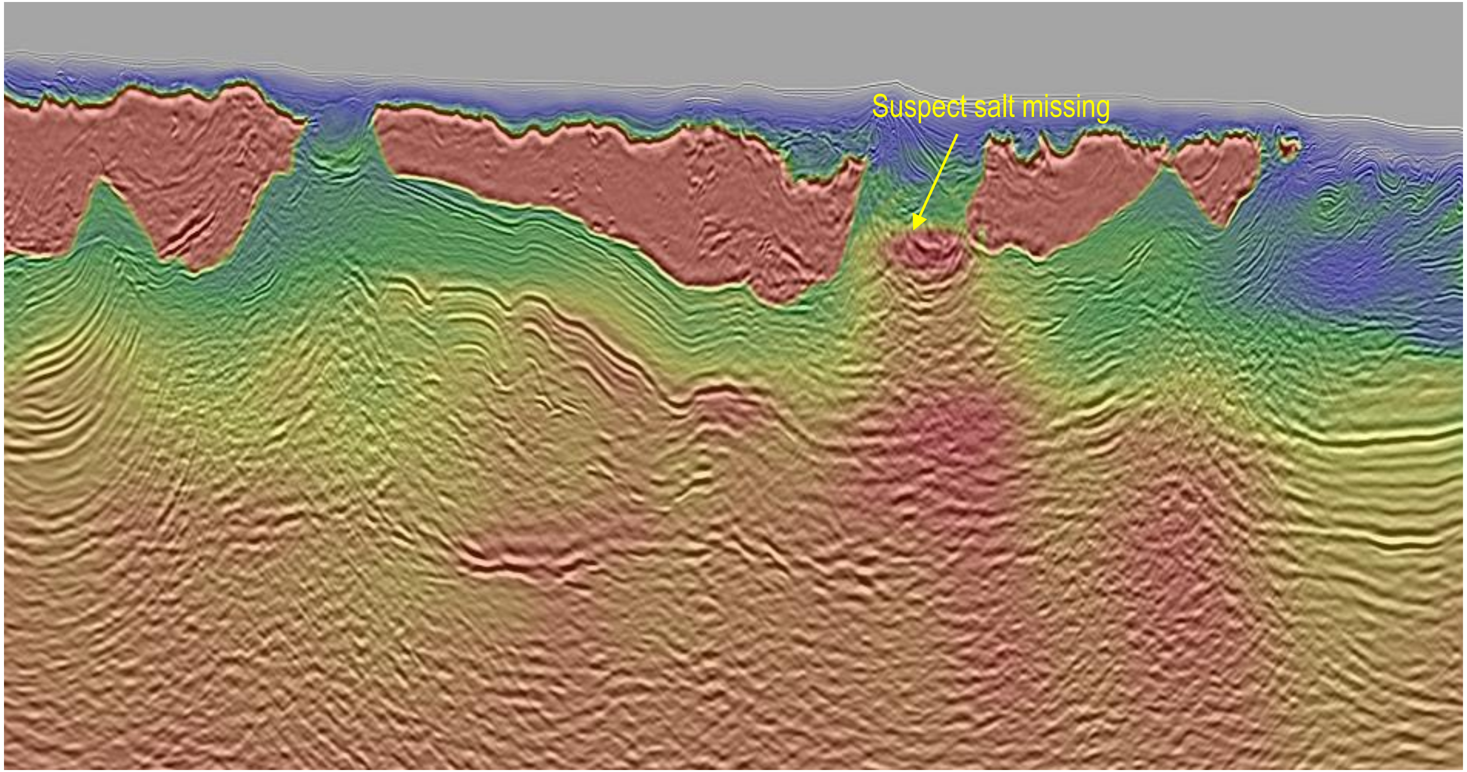
Velocity Model Building Approach



Input velocity to RFWI



RFWI Update with Velocity Overlay



Summary & Conclusion

- Two essential components of RFWI:
  1. model decomposition & Born modeling based optimization
  2. objective function: emphasize on measuring kinematic difference between observed and predicted reflections
- Reflections can be used to build macro model
- Robust inversion workflow (Cycle skip mitigation {FWI + RFWI} + LS FWI)

  for velocity model determination.

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