Low-frequency seismic: The next revolution in resolution

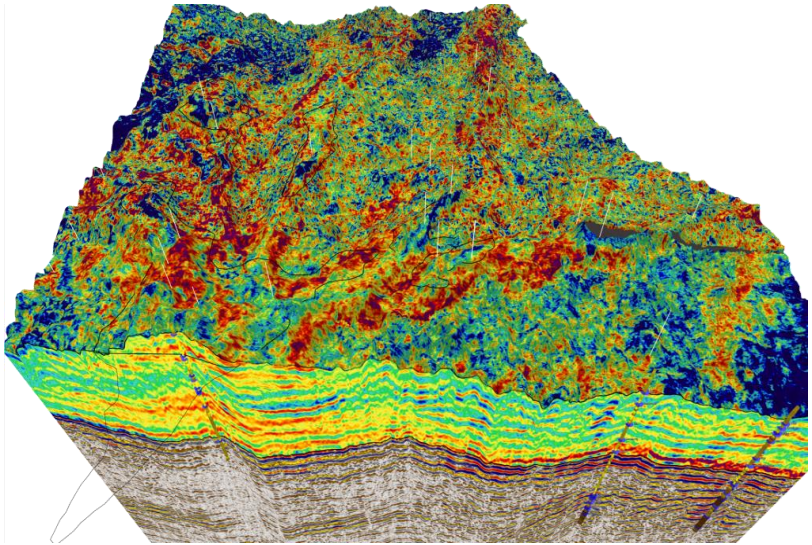
Andrew Long and Cyrille Reiser,

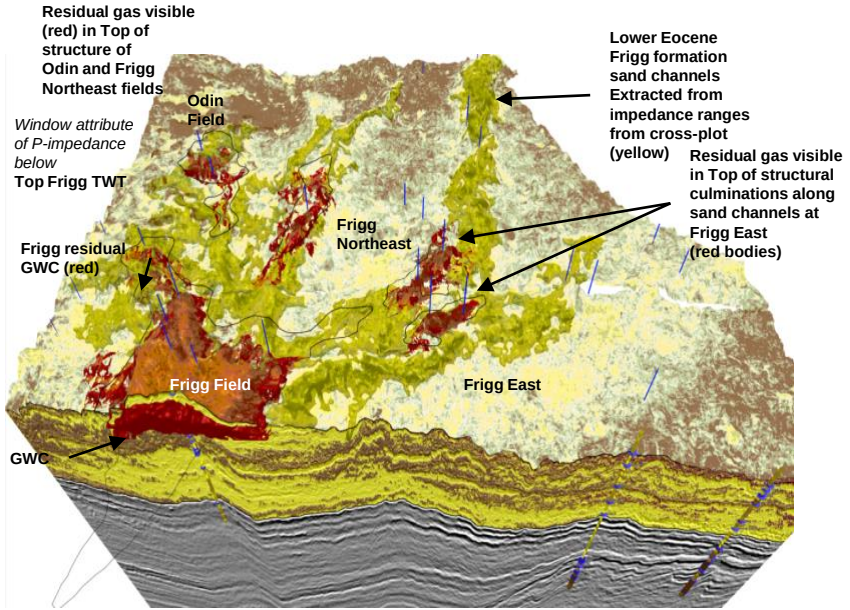
8 April 2014, APPEA Conference

- **The low frequency challenge**
- **What could we do with low frequency amplitudes?**
- **The “ghost”: Not all of the story**
- **A solution not (directly) involving acquisition hardware**
- **Summary**

Optimizing static models and predicted reservoir properties

Better ultra-low frequency information will enable better prediction of reservoir lithology and fluid properties with less reliance upon well control and calibration factors for relative impedances.



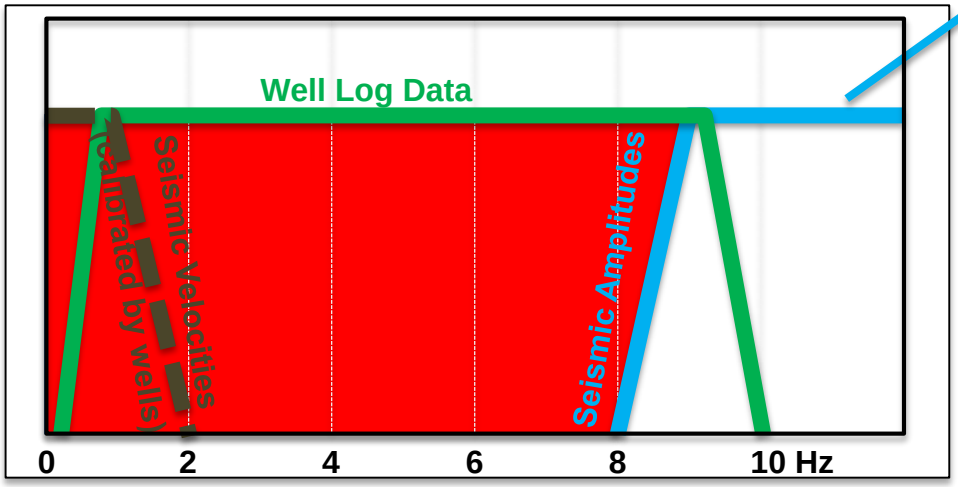


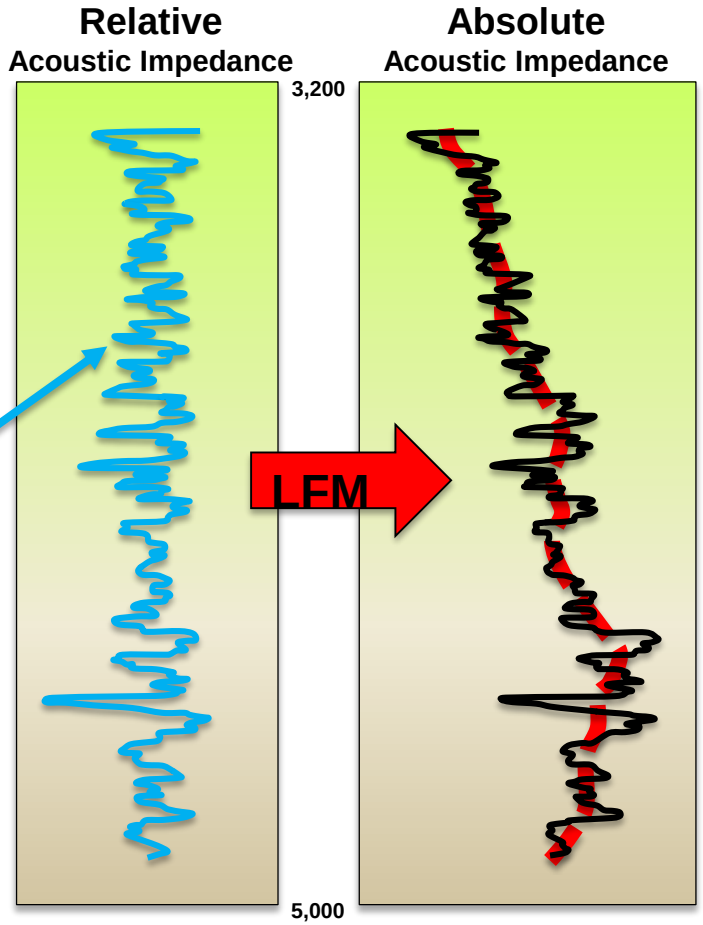
“Ultra-low” = 0 – 8 Hz

Relative and absolute impedance: The low frequency model

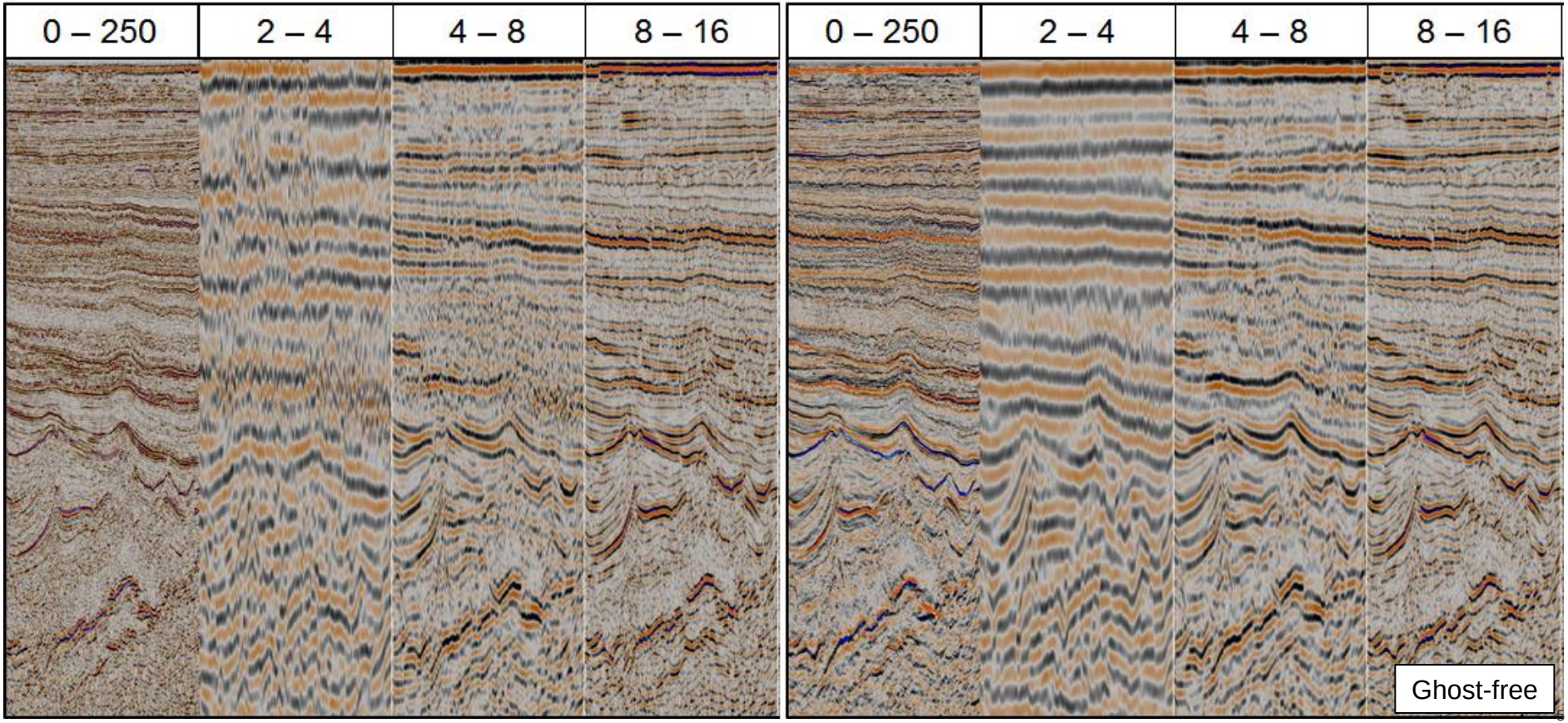
"LFM" = Low Frequency Model

- Built from available **velocity and well log data** to address "low frequency gap".
- Provides background trend for **quantitatively accurate** estimate of elastic impedances.

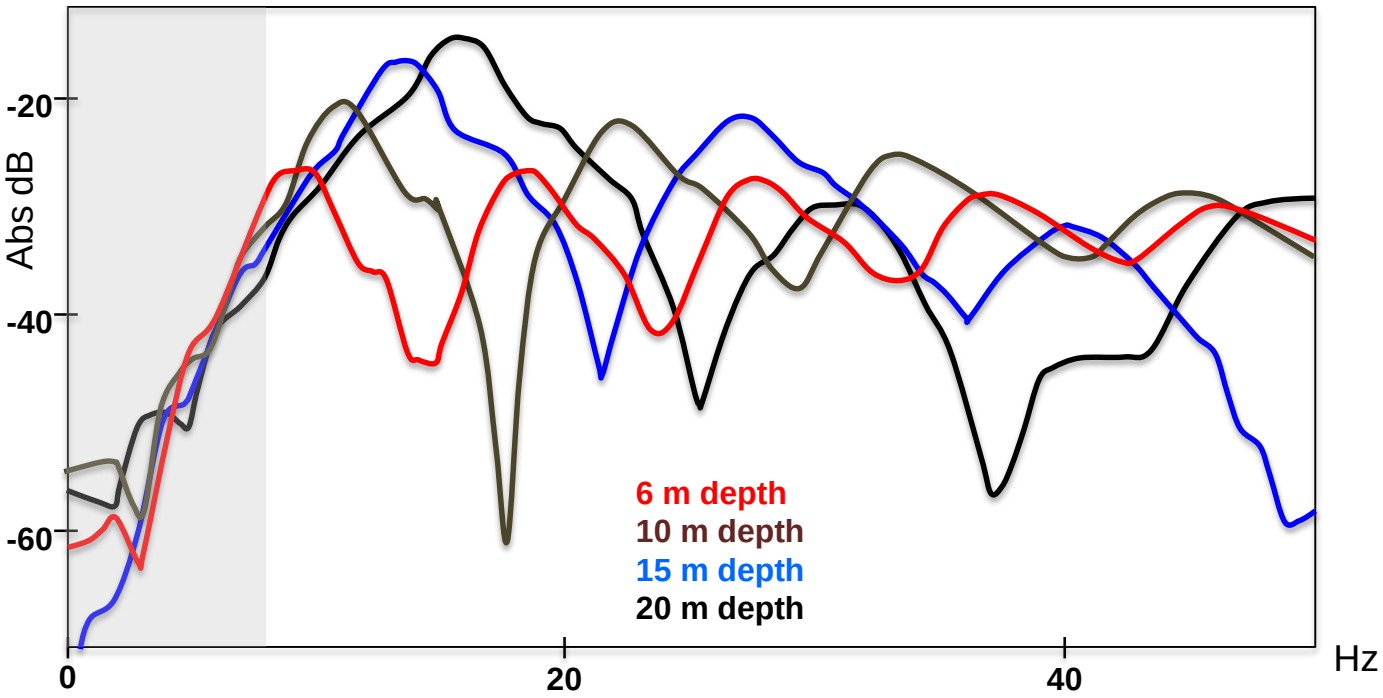




Removal of source-side and receiver-side ghosts



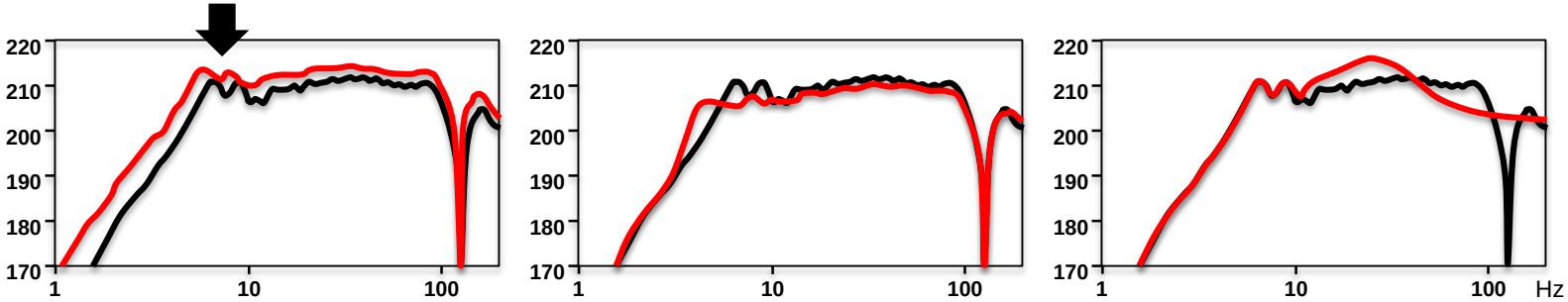
Air gun output (250 in^3 gun)



“Ultra-low” = 0 – 8 Hz

- As air gun depth increases the hydrostatic pressure increases.
- The bubble period will decrease.
- The “characteristic frequency” will move towards higher values!
- There is no low frequency benefit in towing air guns very deep.

Air gun array configurations



Bubble period ∝ $V^{1/3}P^{1/3}$

Increase volume:

Hypercluster

Longer bubble period:

Multi-level source (MLS)

Decouple source wavefields:

- An increased bubble period translates to a lower characteristic frequency.
- In practice, it is not feasible to significantly increase air gun volume or firing pressure.
- Multi-level/over-under source arrays fill in source ghost notch and primarily extend the recovered bandwidth **towards the high end**.

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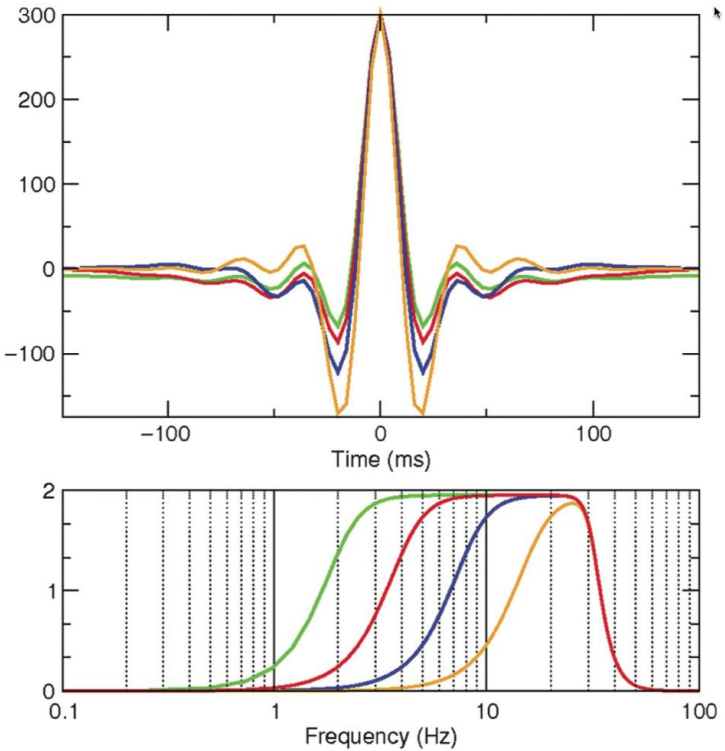
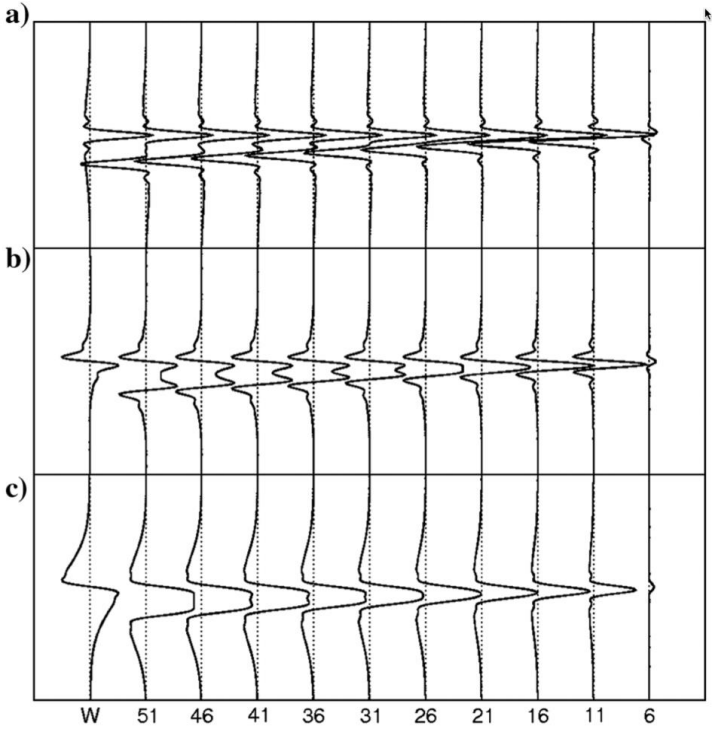
Temporal resolution vs. frequency content





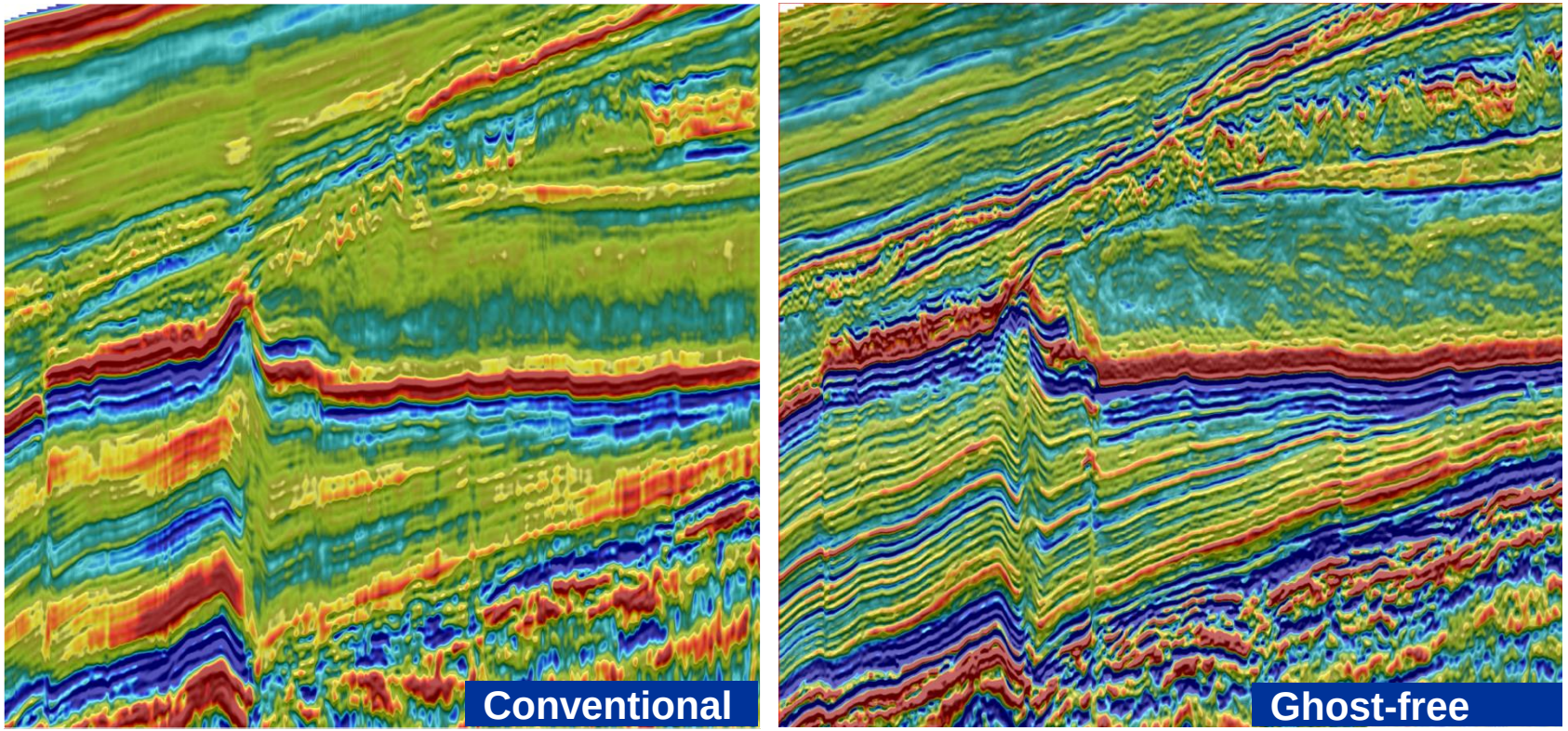
Input wavelet

90° phase rotation

+6 dB/octave low frequency boost

From ten Kroode et al. (2013), *Geophysics*

Temporal resolution vs. frequency content



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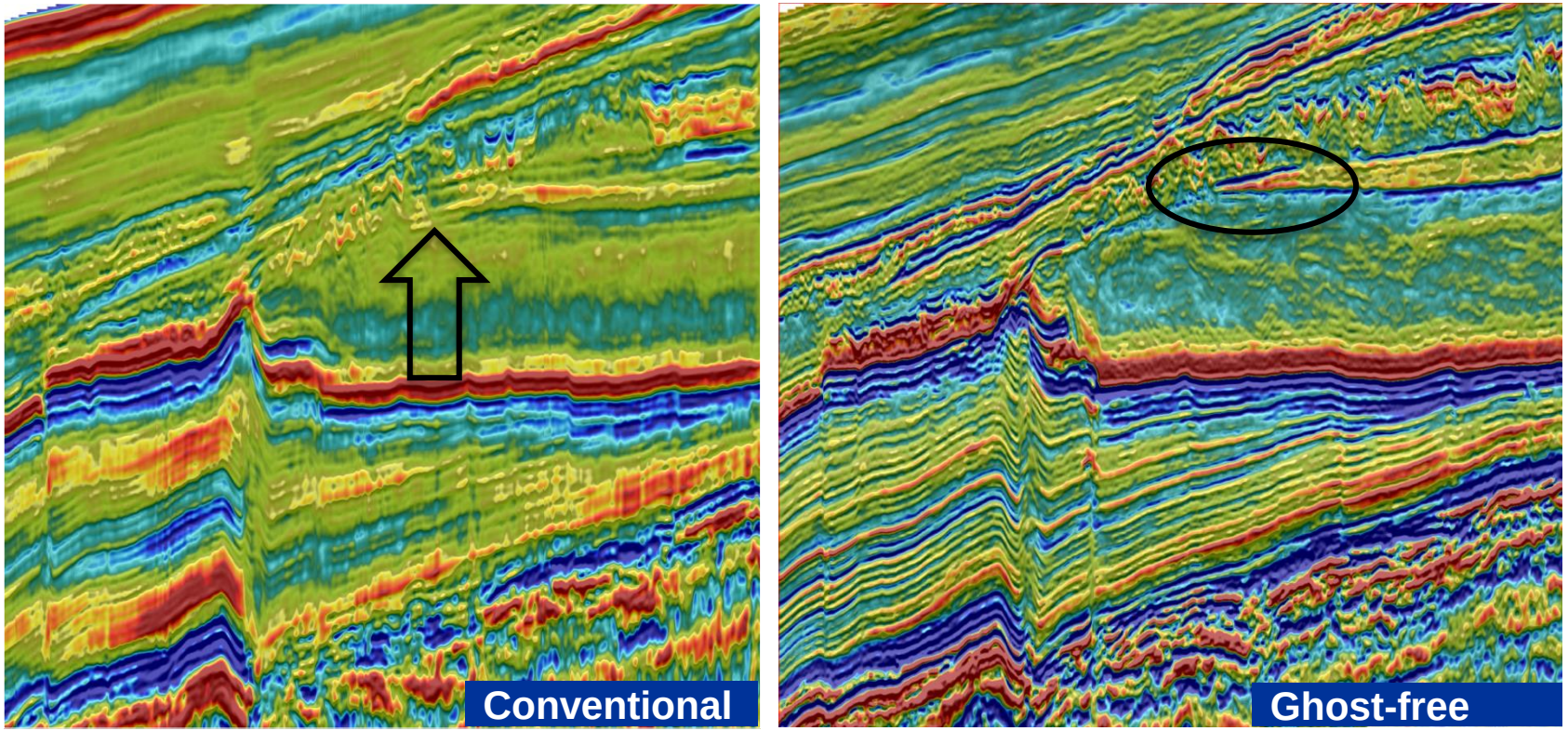
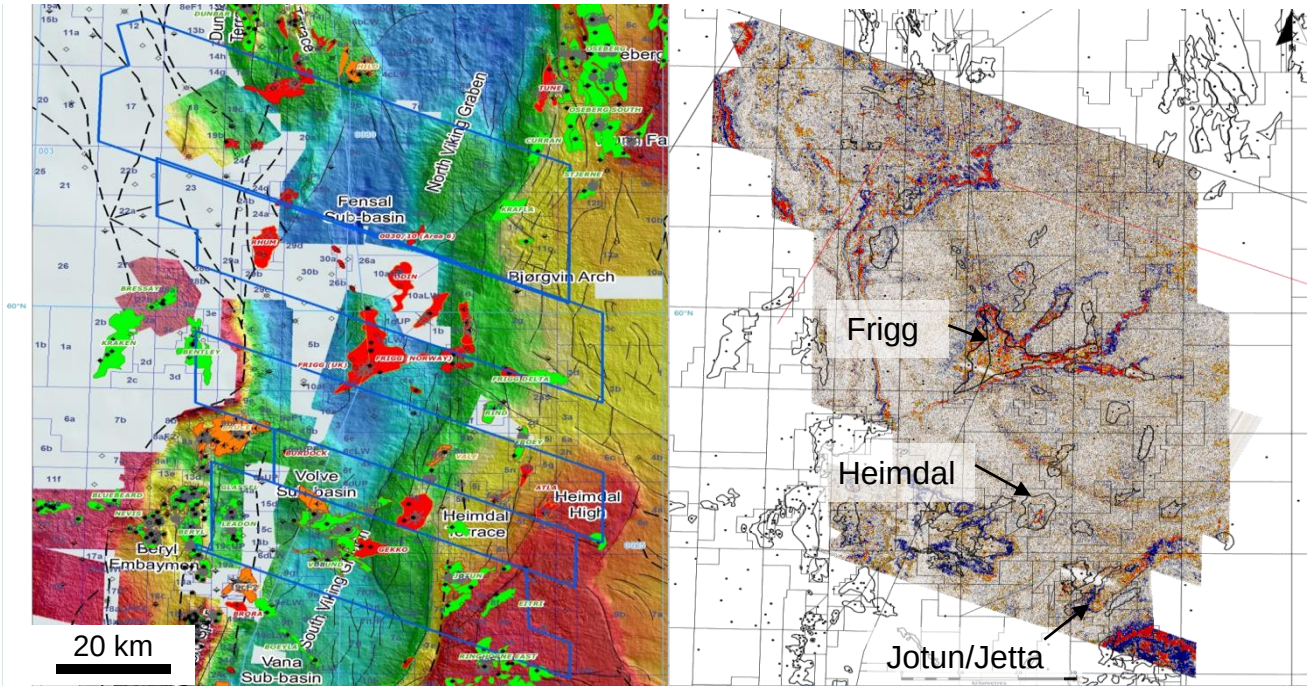


North Viking Graben



Fields of note on the survey:

- Heimdal
- Frigg
- Jotun

Key facts on **Heimdal**

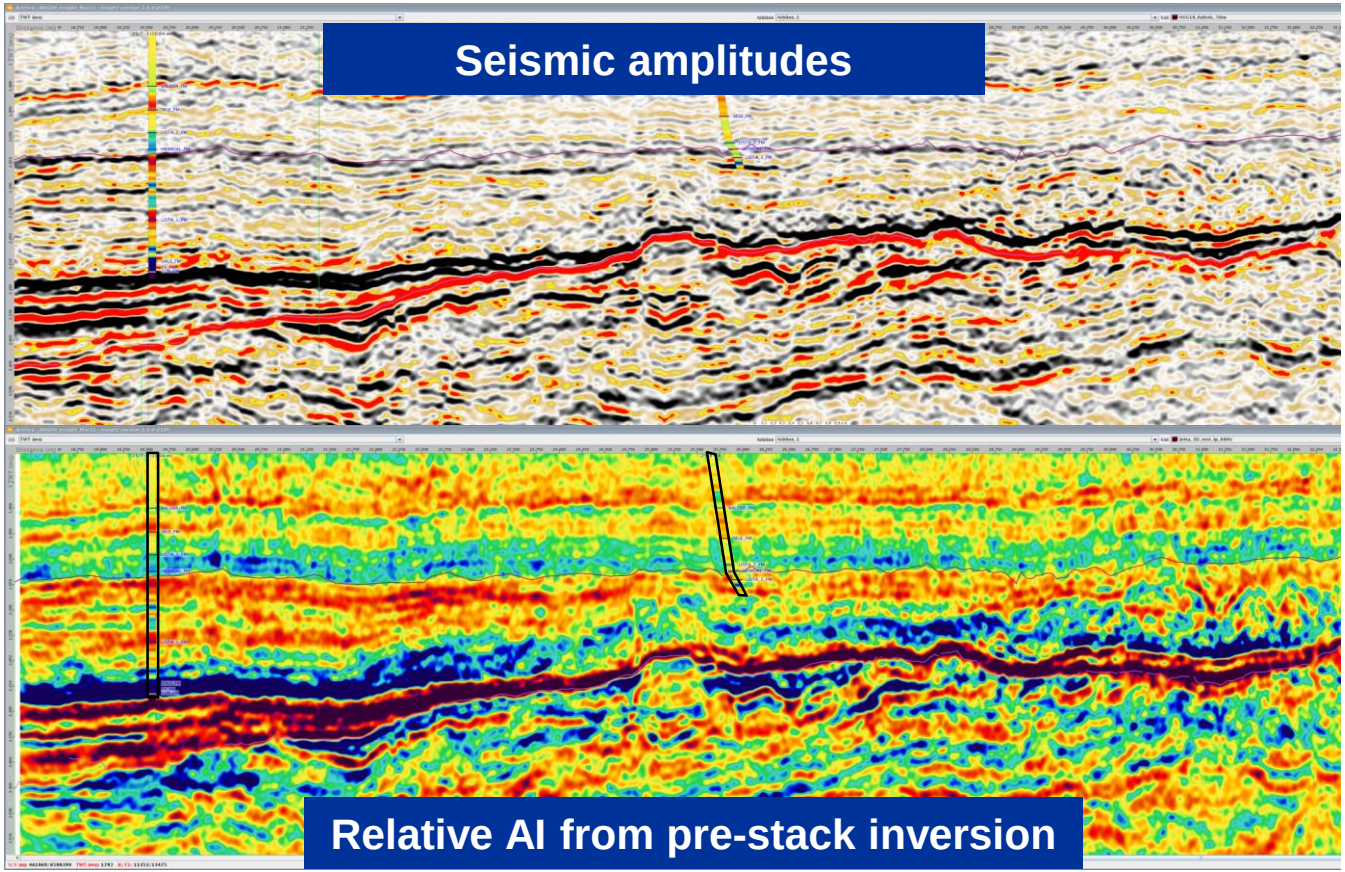
- Gas field - depleted
- Production ceased
- Reservoir depth ~ 2.1 km / 1.9 s TWT
- Sandstone reservoirs
- Palaeocene deep-marine

Key facts on **Frigg**

- Gas field
- Production ceased
- Reservoir depth ~ 2.0 km / 1.9 s TWT
- Sandstone reservoirs
- Eocene deep-marine environment

Oil Field
Gas Field
Condensate Field

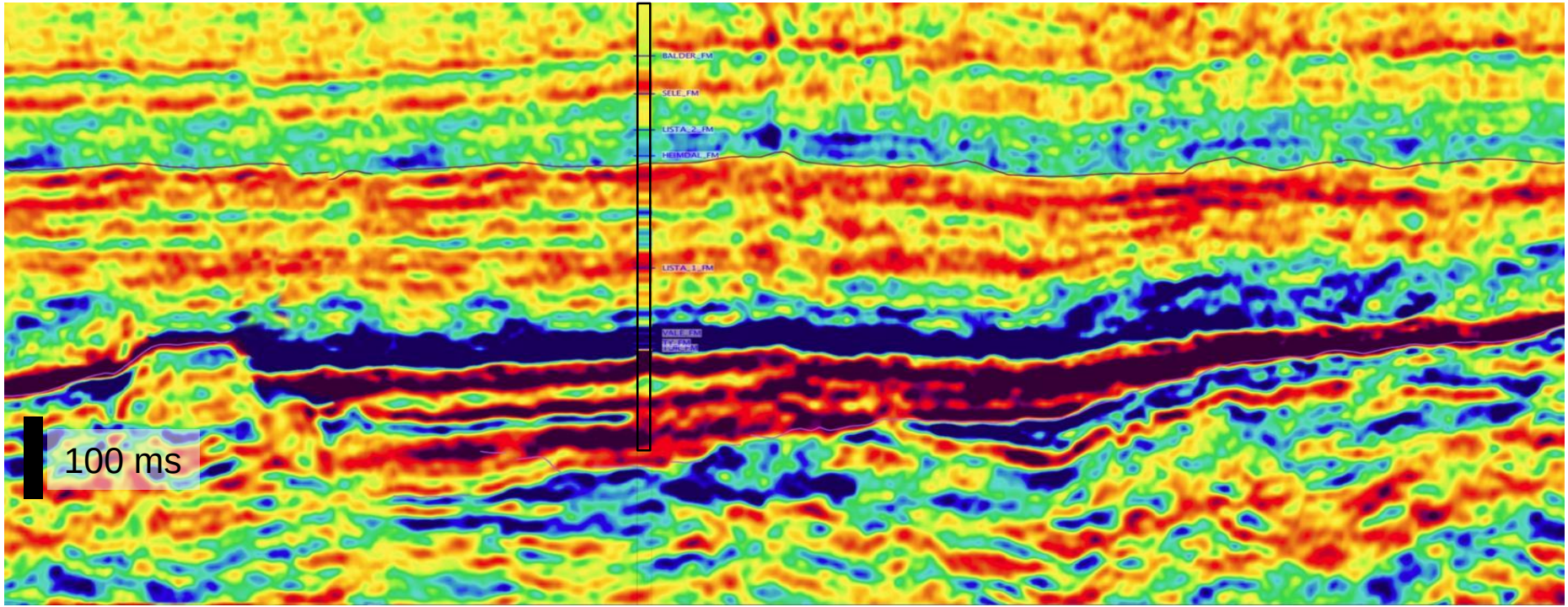
Receiver-side deghosting: Relative inversion (no well information)



- Fairly flat geology.
- Laterally consistent properties.

- No well control/LFM used in the inversion.

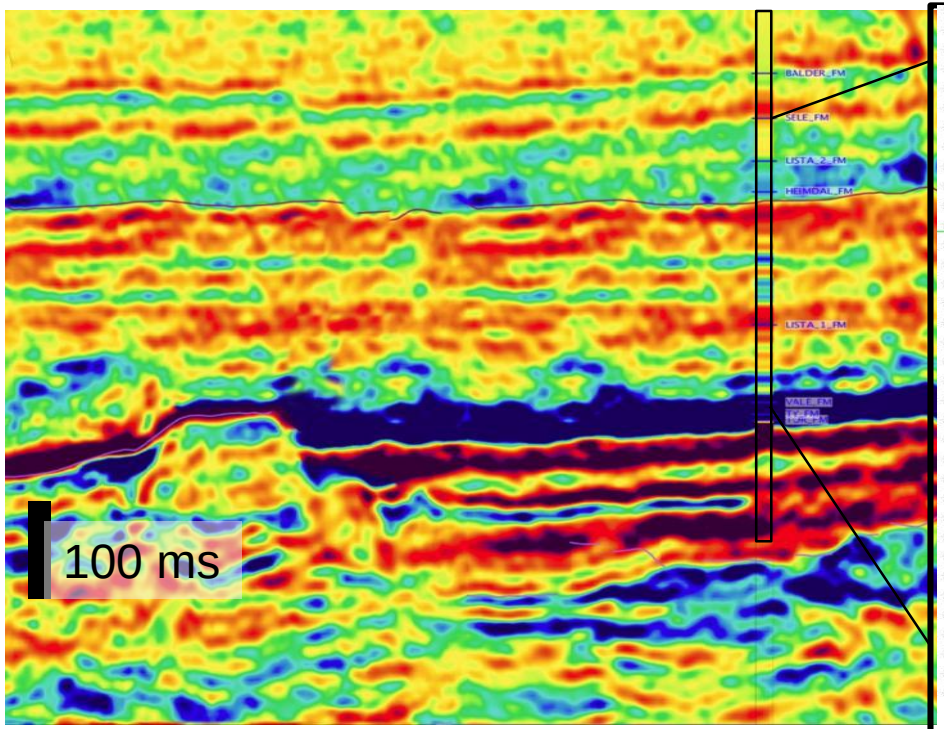
Receiver-side deghosting: Relative inversion

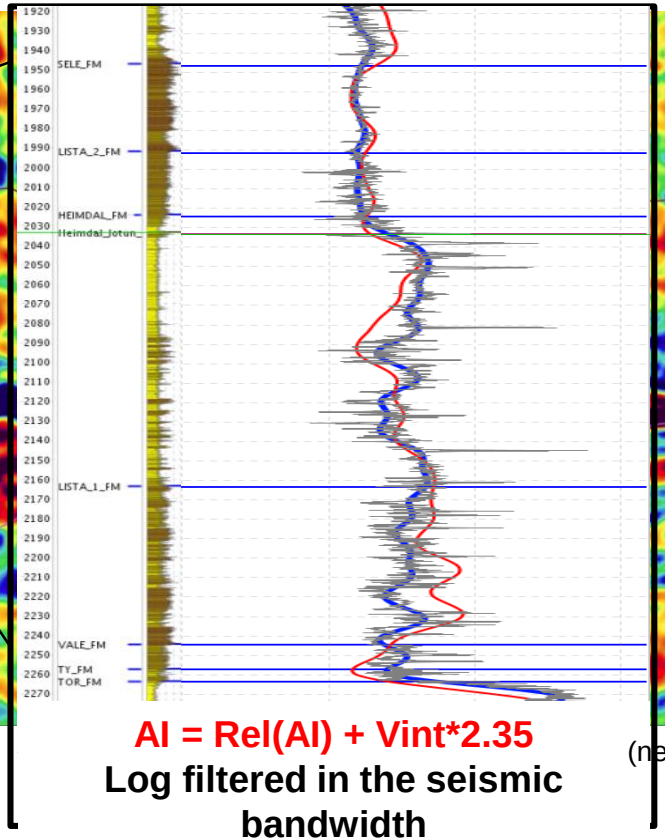


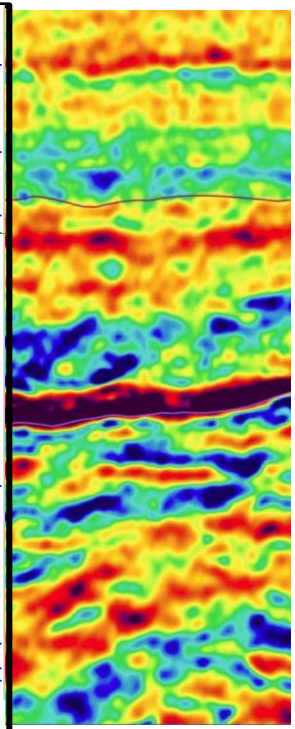
Low frequency model (LFM) derived using only seismic velocity ***= NO WELL INPUT to LFM***

(near Jotun field, NVG10)

Receiver-side deghosting: Relative inversion







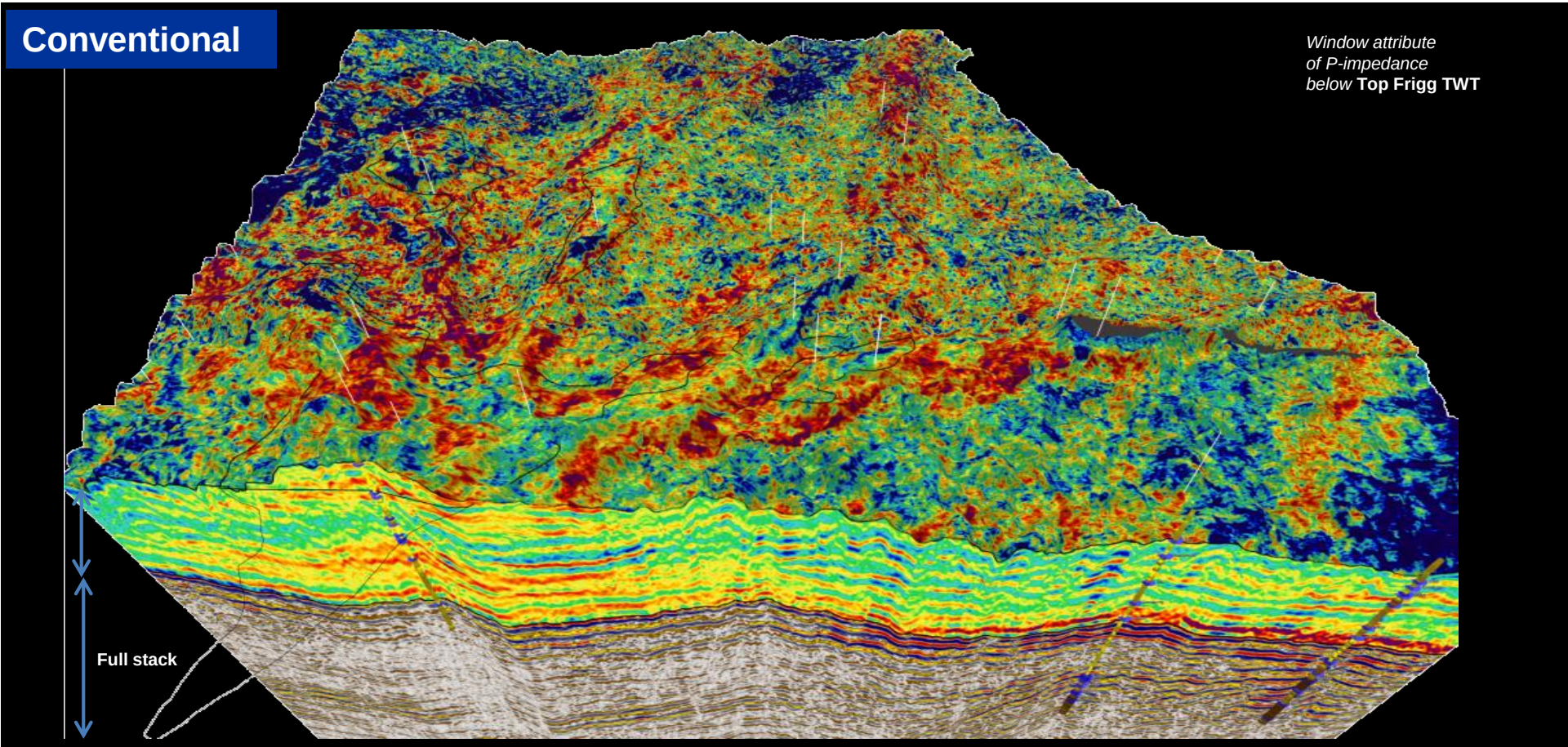
Low frequency model (LFM) derived using only seismic velocity ***= NO WELL INPUT to LFM***

AI = Rel(AI) + Vint*2.35

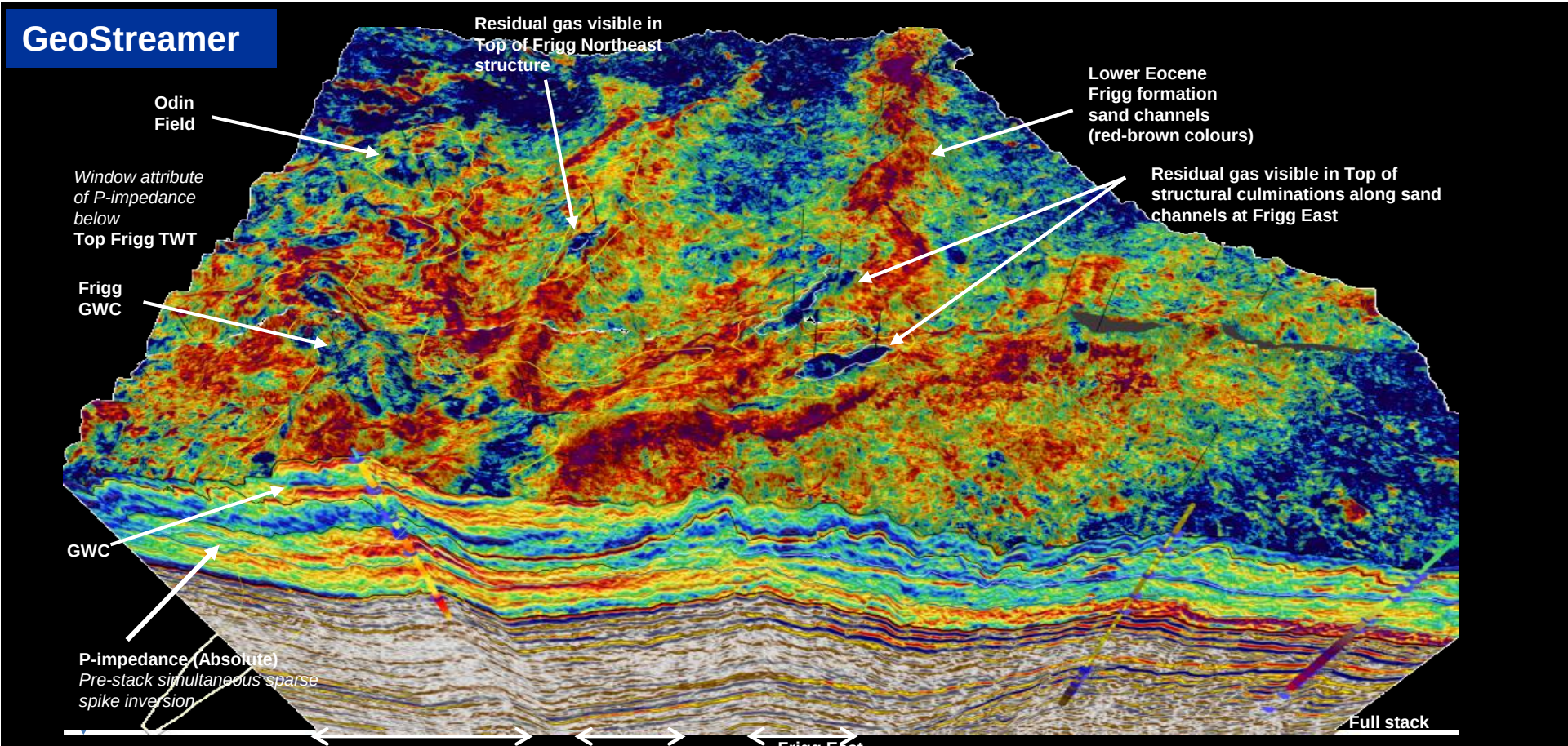
Log filtered in the seismic bandwidth

(near Jotun field, NVG10)

Conventional streamer 3D



GeoStreamer 3D



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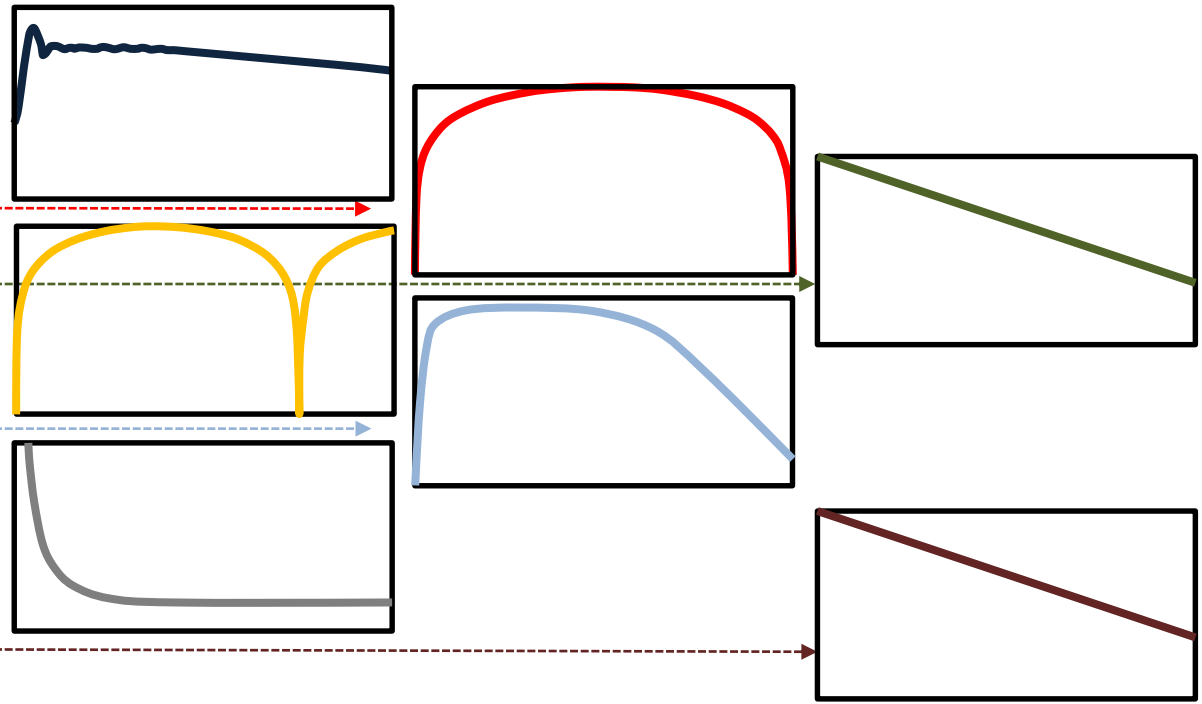
Seismic data amplitude spectra

The convolution of:

- Source signature
- Source-side ghost
- Earth reflectivity
- Attenuation (“Q”)
- Receiver-side ghost
- Recording system
- Mechanical/ environmental noise
- Spatial sampling/processing/imaging
- Induced artifacts



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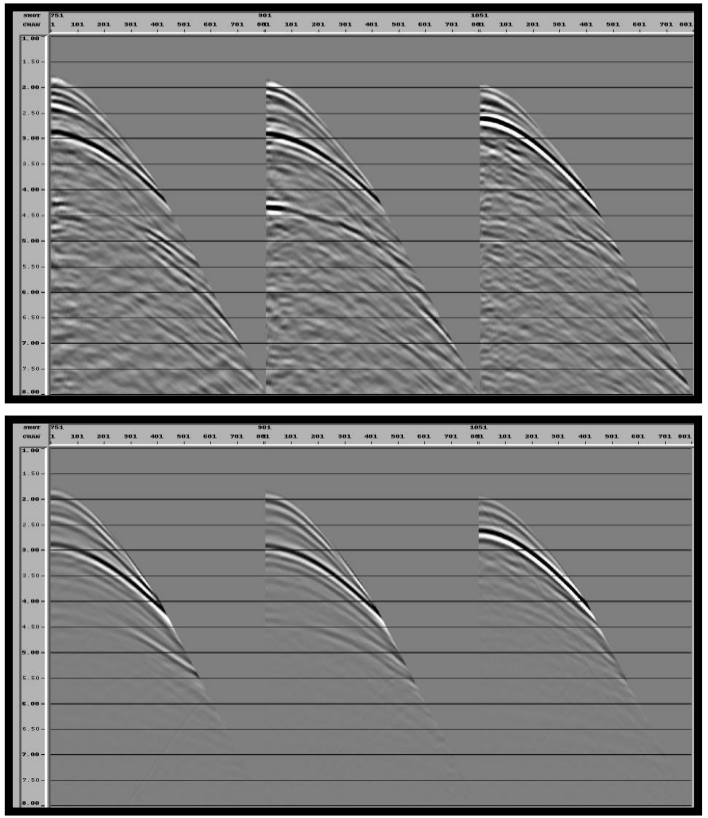
Full Waveform Inversion (FWI)

FWI performs iterative forward modeling to compute the differences between acquired seismic data and some model of either diving waves/refractions or reflections.

The output is a high resolution velocity model.

Very long offsets and/or very low frequencies are required for robust results and deep velocity models, particularly for the diving wave/refraction scenario.



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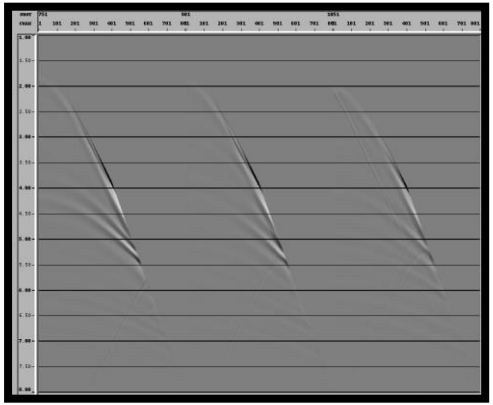
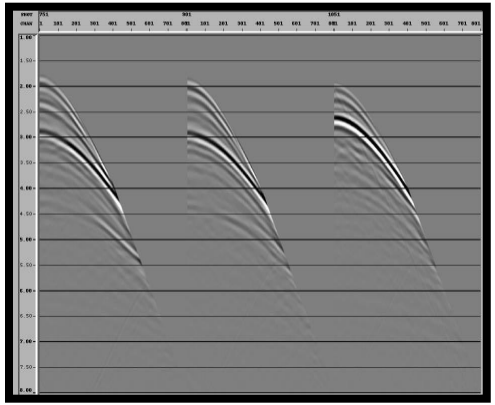
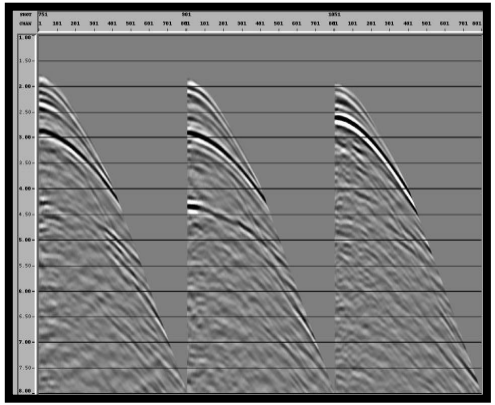
$FWI_{initial}$

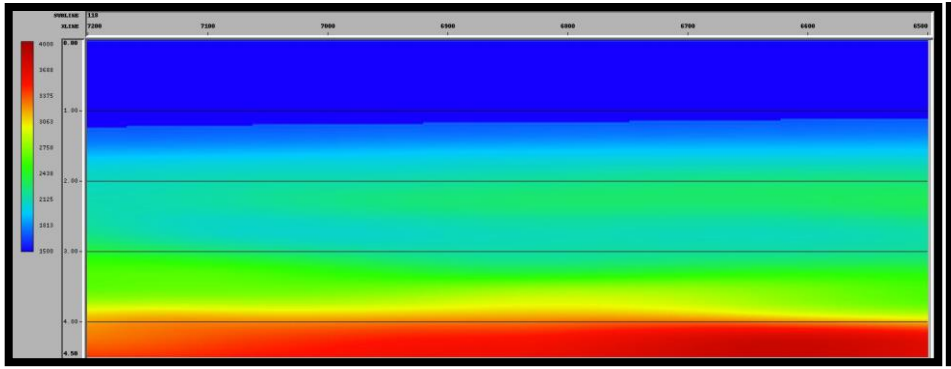


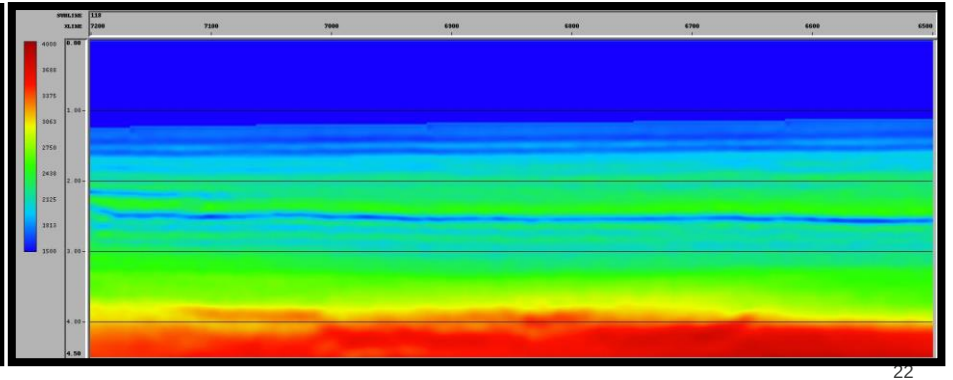
FWI_{final}



Field Gathers







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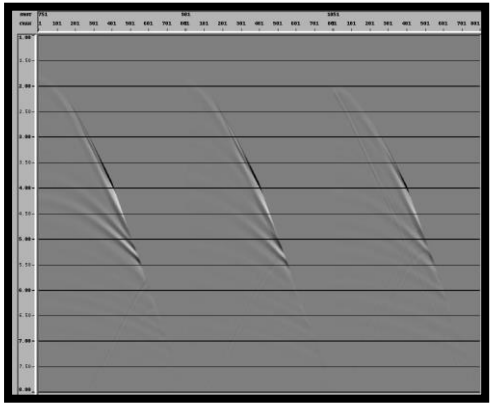

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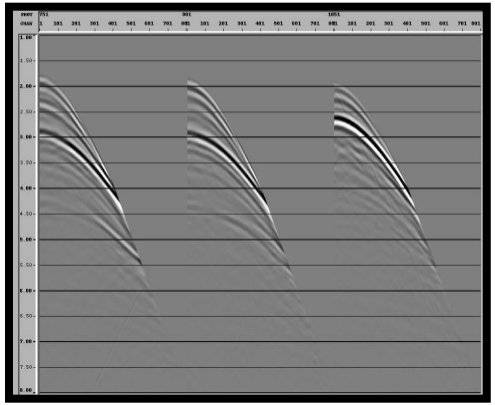

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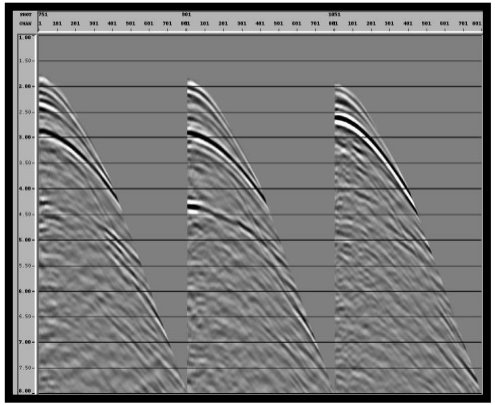
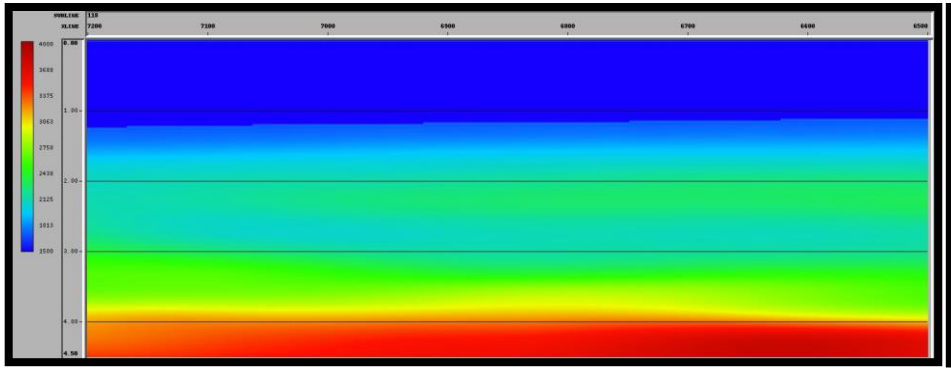
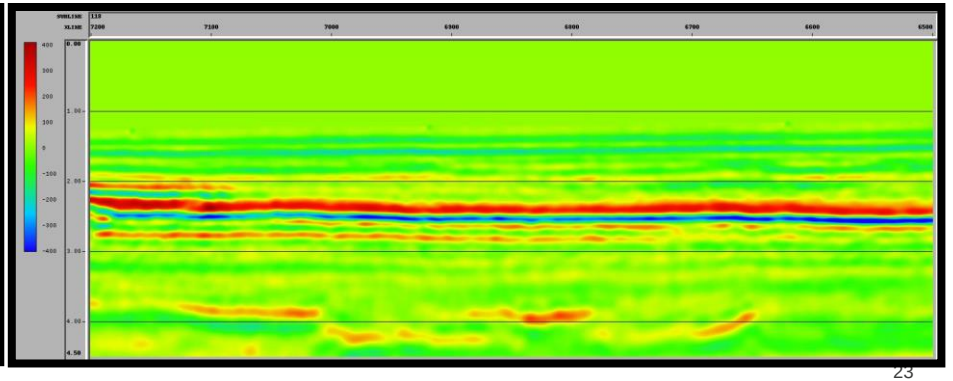


Difference





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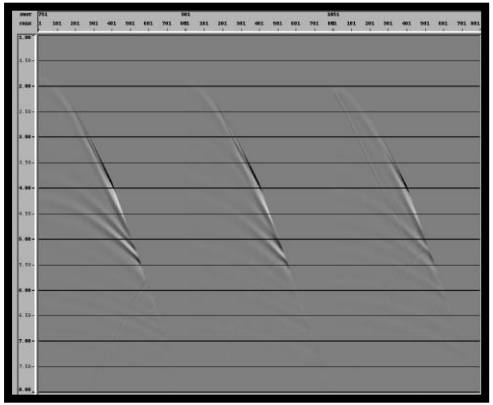

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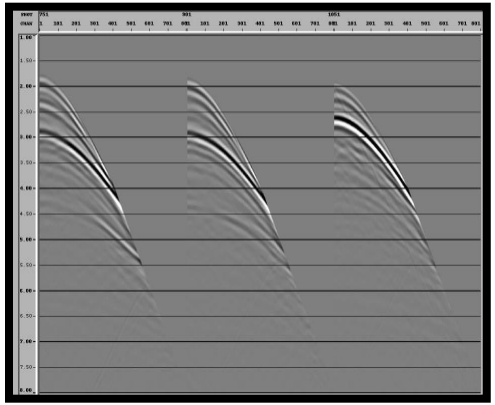

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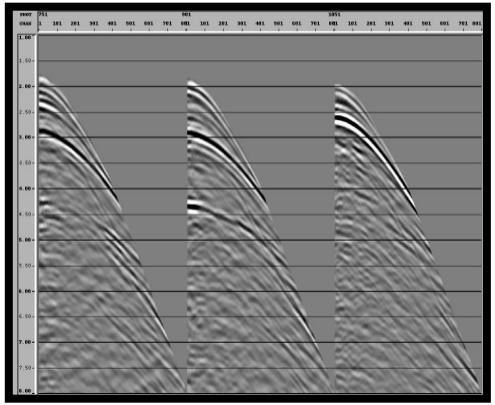

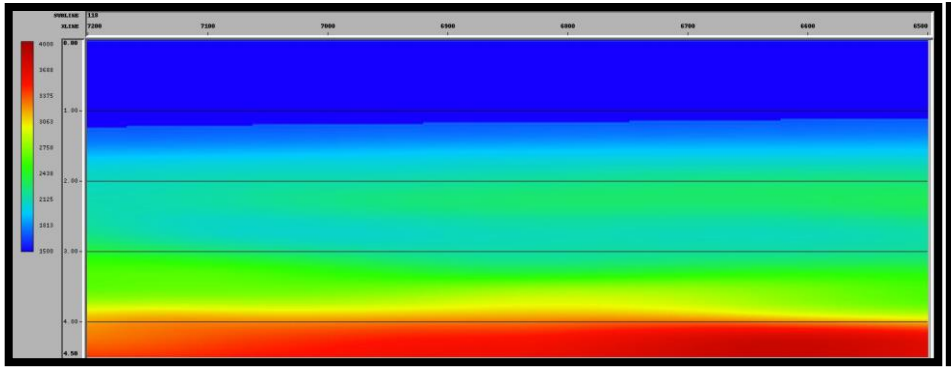

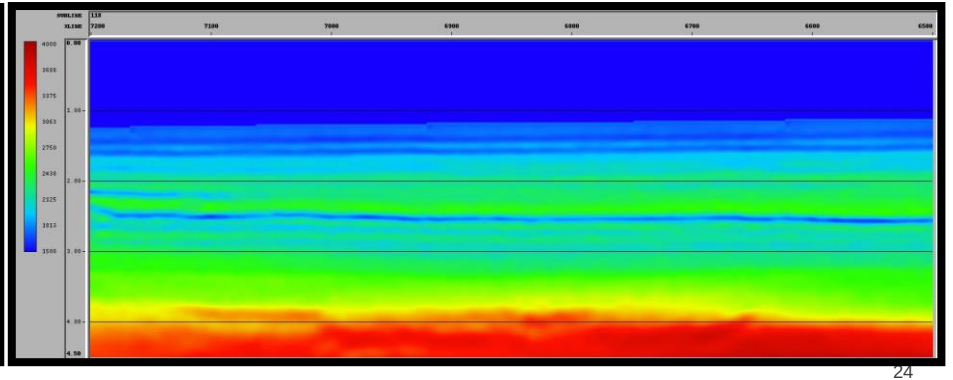

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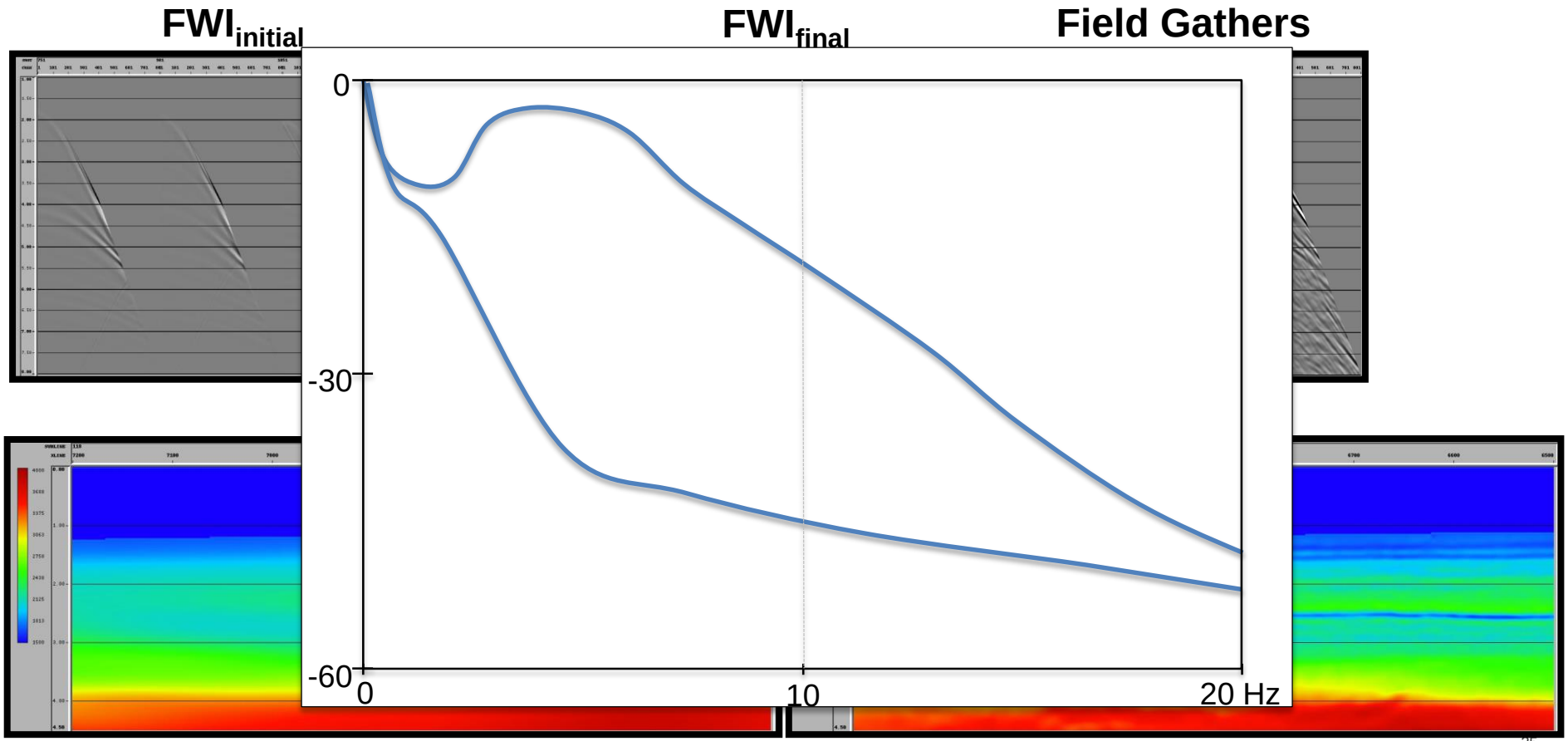

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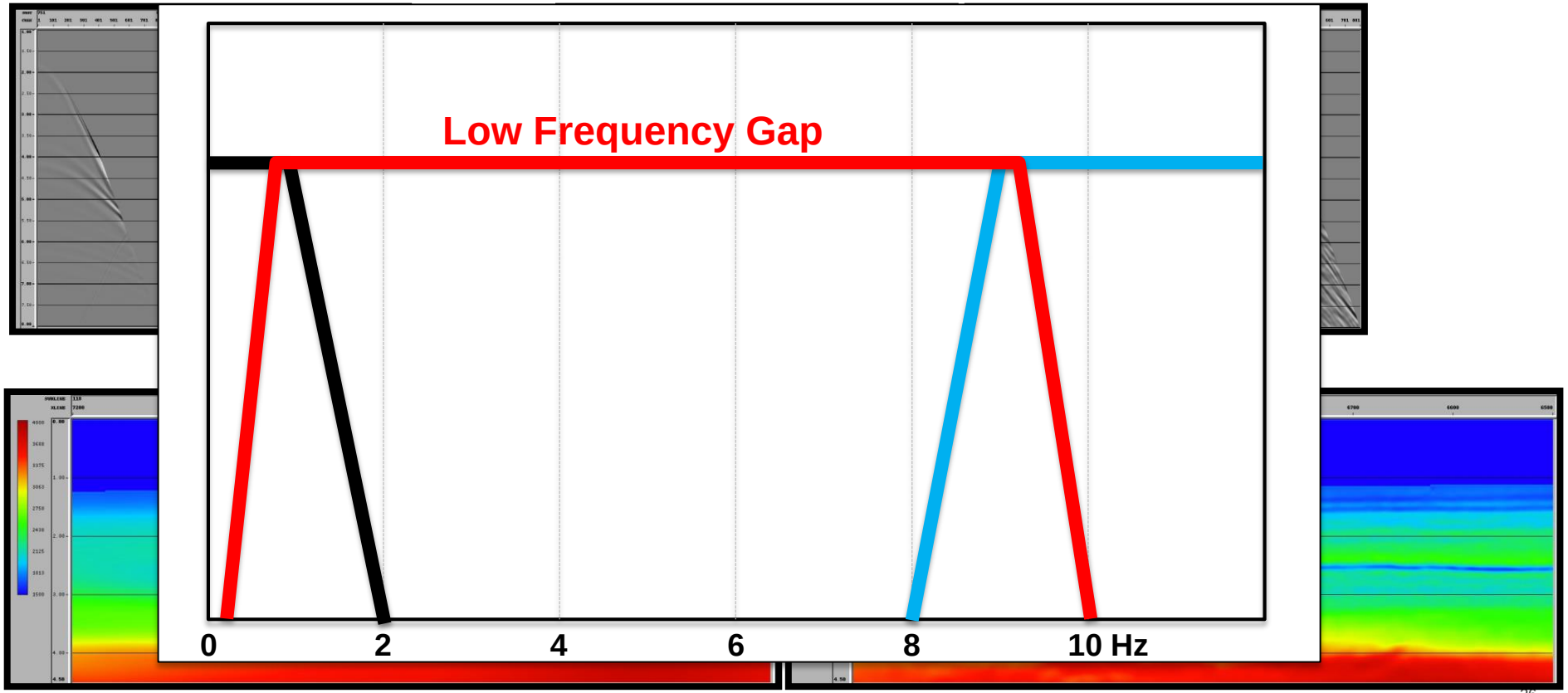

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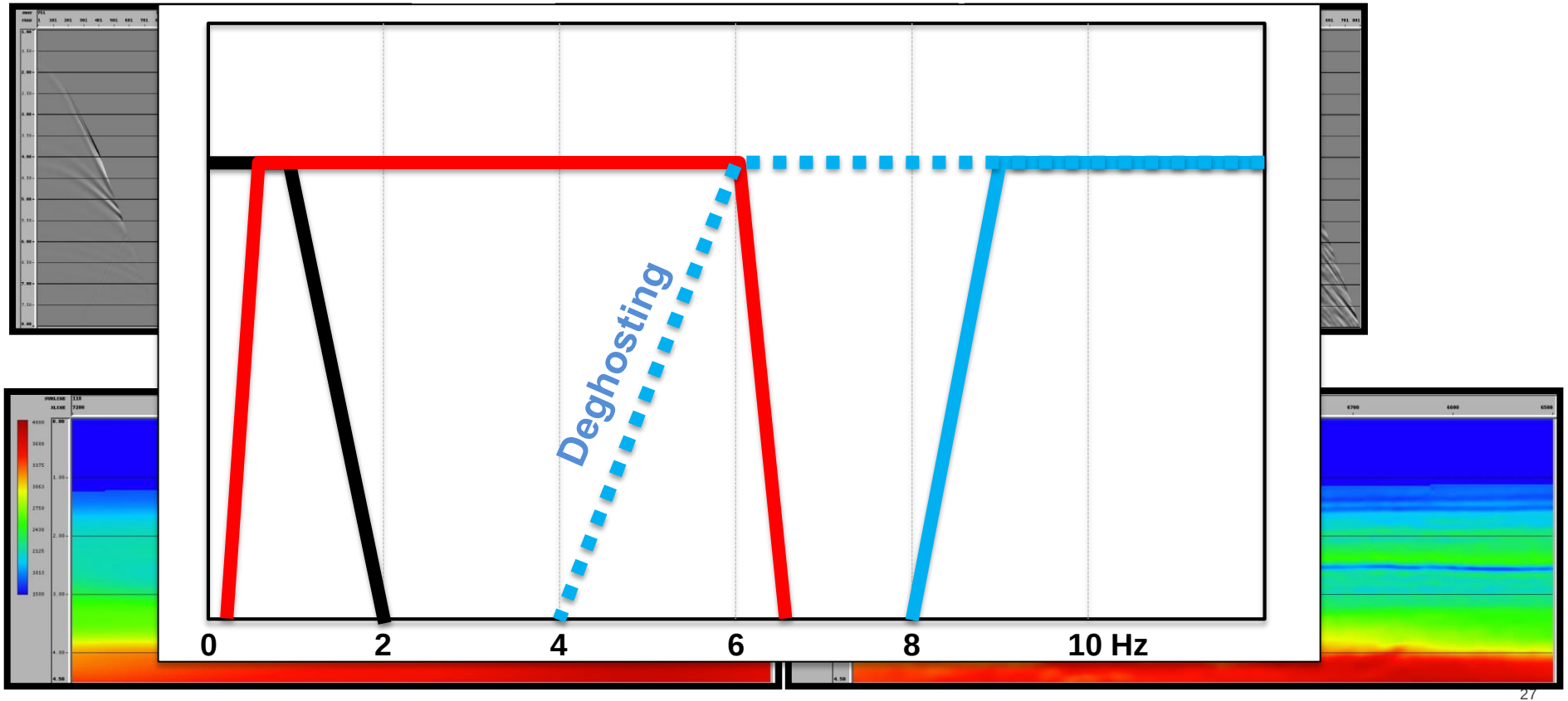

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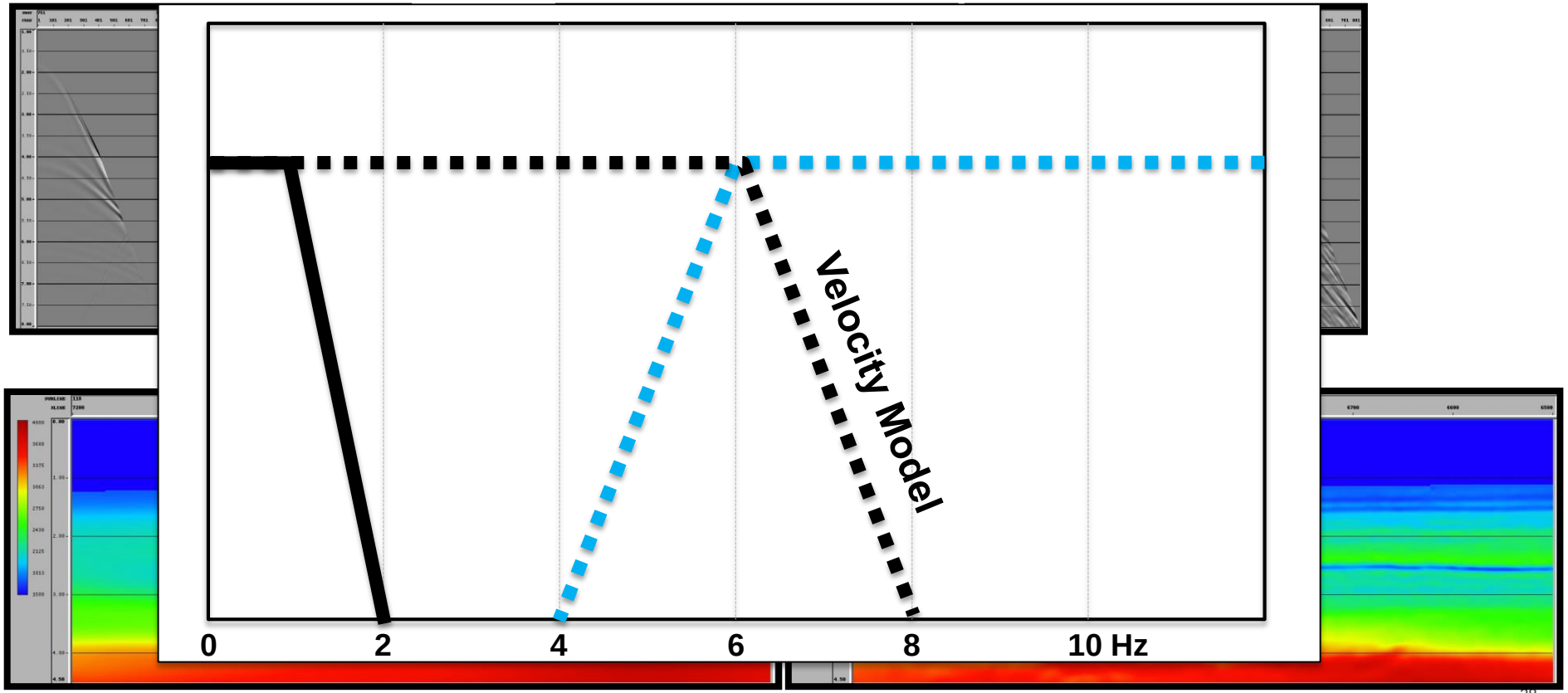

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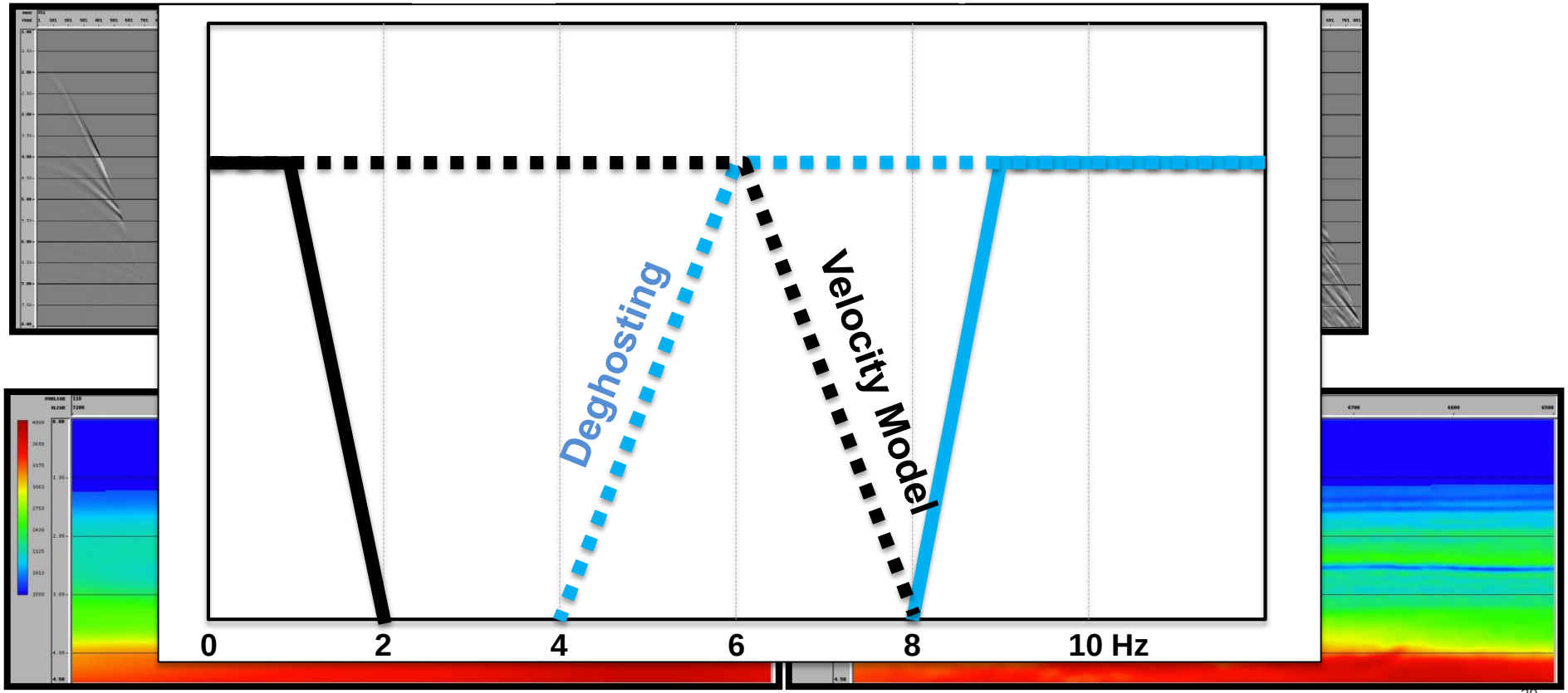

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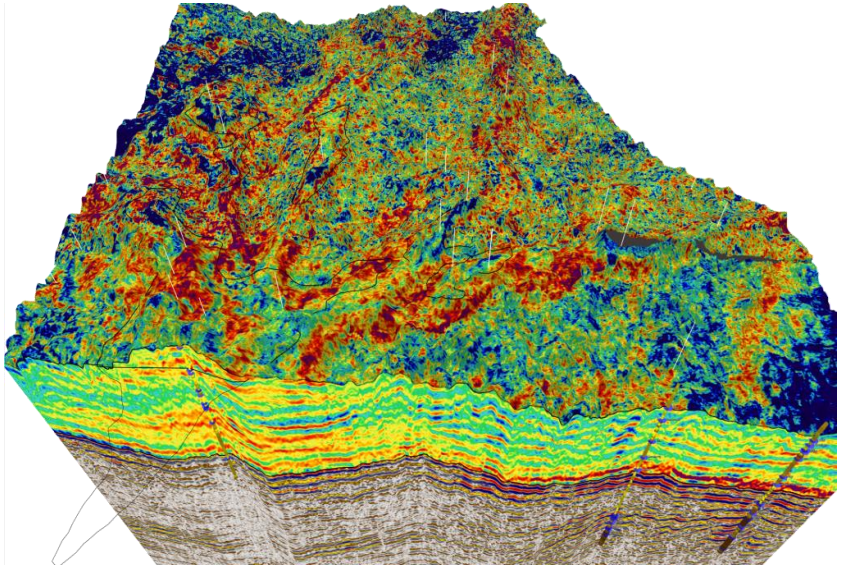

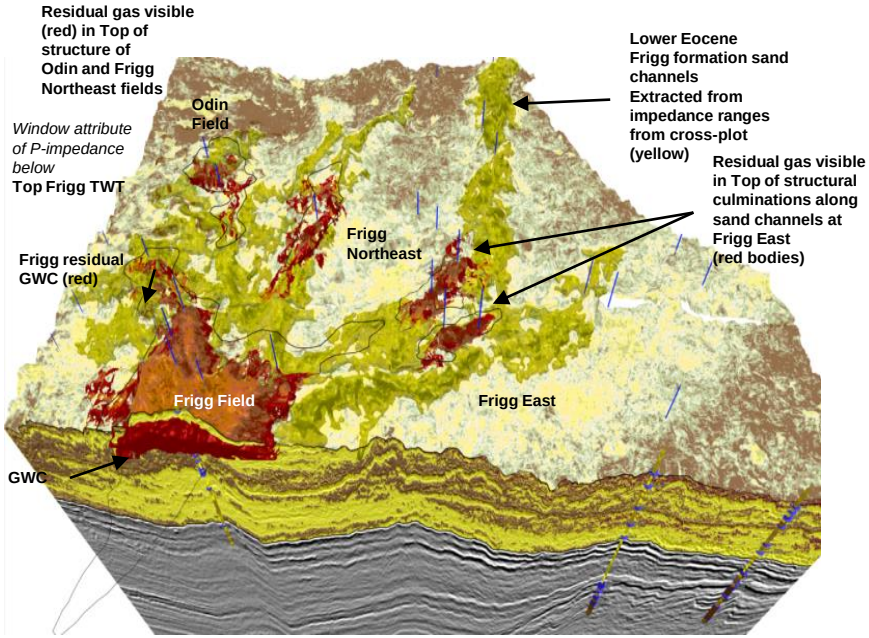

Summary

- There **are** ultra-low frequency amplitudes in towed streamer seismic data
  - They are **weak** (air gun physics, lo-cut filters, ghost effects) and have **poor S/N**
  - They can be **boosted in processing** (**beware!**)
  - They need to be **balanced** otherwise the data is overwhelmed with “wormy” events

- **In the absence of processing tricks, consider the amplitudes < 8-10 Hz as deficient**
  - Assisted by deghosting (must be AVO- and phase-compliant)
  - An extra octave (or more) of ultra-low frequency amplitude content is an excellent step towards quantitative accuracy! Must be AVO- and phase-compliant!
  - No real source hardware solution with air guns or other approaches

- Full Waveform Inversion (FWI) offers a robust platform to address the “low frequency gap”
  - Optimal trend model
  - Gets starting impedances close to their true values (helps inversion convergence)
  - A step towards automated seismic inversion
  - **More robust and accurate prediction of lithology and fluid properties**

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