(1) Estimating intrinsic attenuation

Gary Margrave, Sylvestre Charles (Suncor), and Hossein Aghabarati (Suncor)

(2) Post-stack Iterated modelling, migration and inversion (IMMI)

Gary Margrave

Estimating intrinsic attenuation: Cumulative attenuation

Attenuation (Q^{-1}) consists of intrinsic and stratigraphic parts which combine to give total attenuation:

$$\frac{\pi(t_2 - t_1)}{Q_{eff}} = \frac{\pi(t_2 - t_1)}{Q_{intrinsic}} + \frac{\pi(t_2 - t_1)}{Q_{strat}}$$

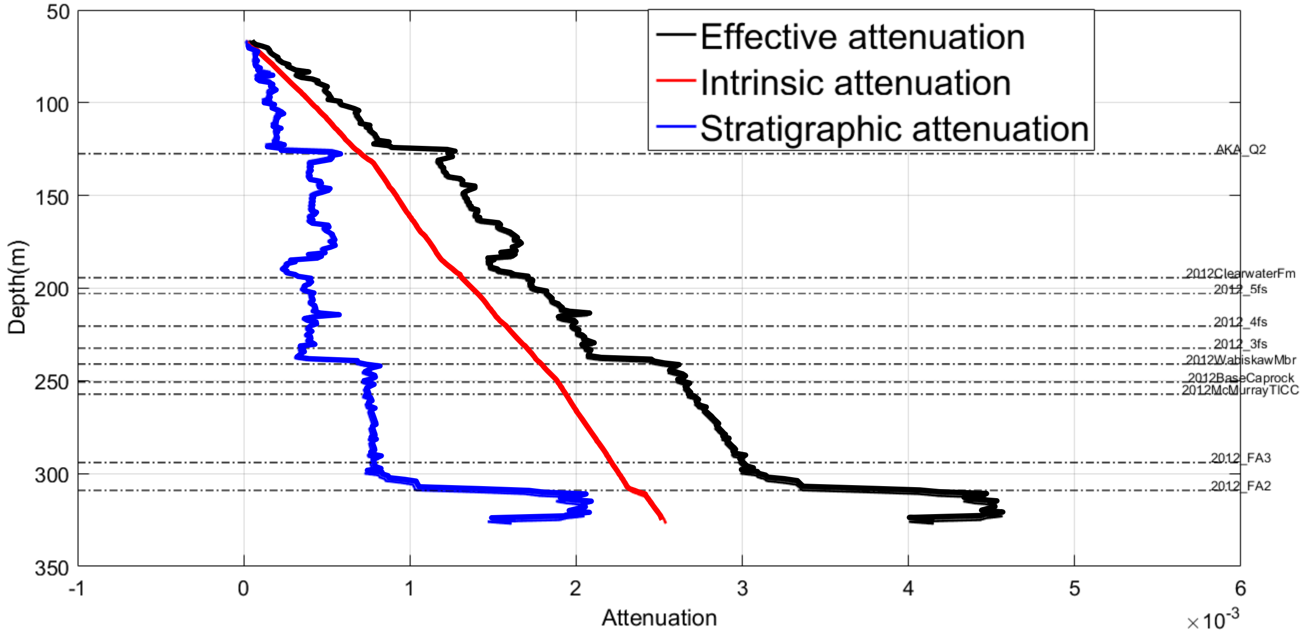
With time in the numerator, this is called *cumulative attenuation* or CA.

1. Effective attenuation is what is always measured.

2. Intrinsic attenuation is a rock or reservoir property. Monotonic.

3. Stratigraphic attenuation is a interference effect from short-path multiples (O'Doherty and Anstey 1971).

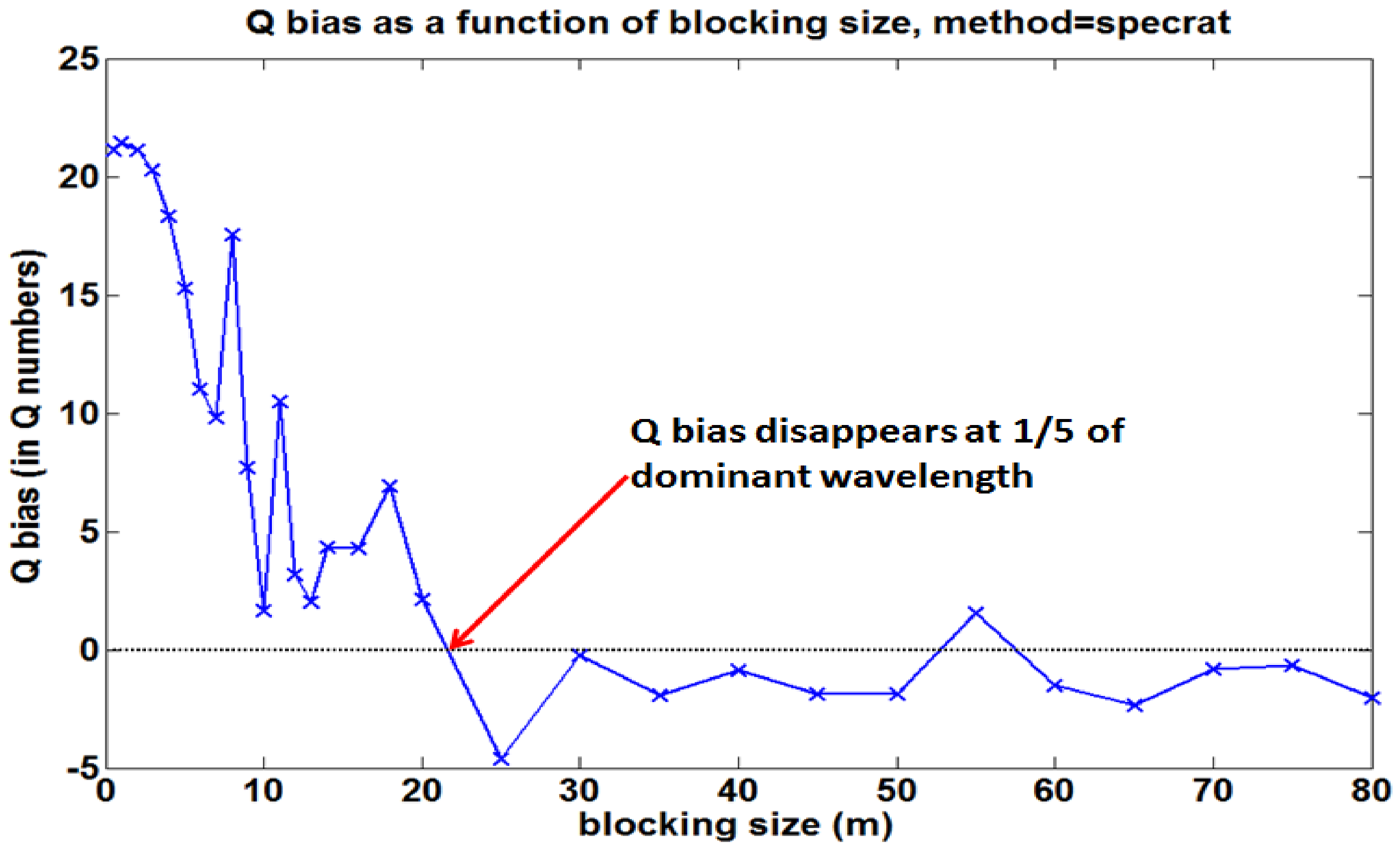
Cumulative attenuation from synthetic VSP



Estimating intrinsic attenuation: Previously Q_{bias}

Previously (Margrave, CREWES, 2014):

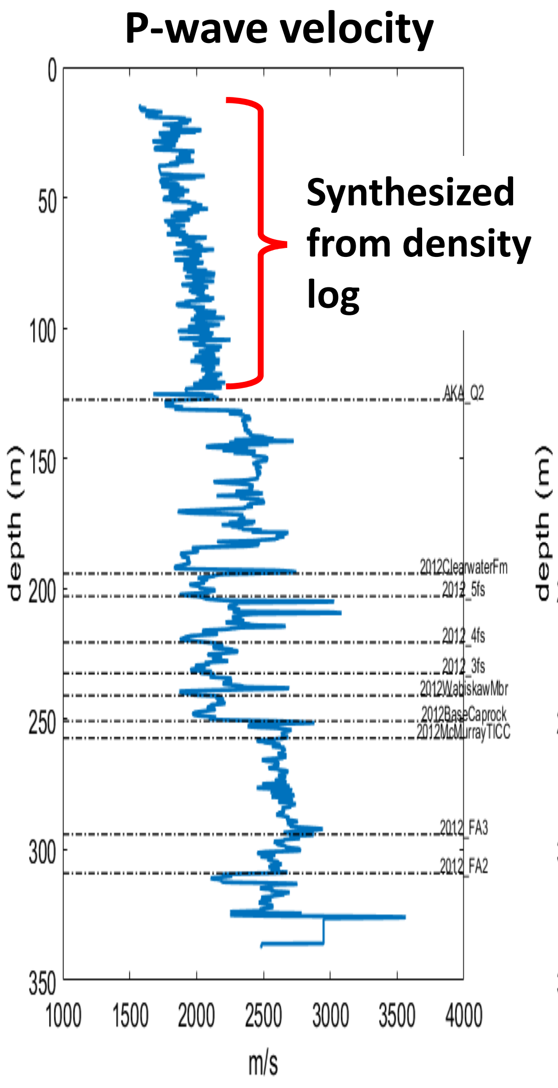
- A highly accurate 1-D VSP modelling code for acoustic waves with Q was released.
- Using this code, synthetic VSP's with both intrinsic and stratigraphic attenuation can be constructed from well logs.
- Q measurement then allows the stratigraphic attenuation to be quantified.
- A series of measurements were shown for different blocking sizes.
- Define $Q_{bias} = \overline{Q_{eff}} - \overline{Q_{intrinsic}}$ then

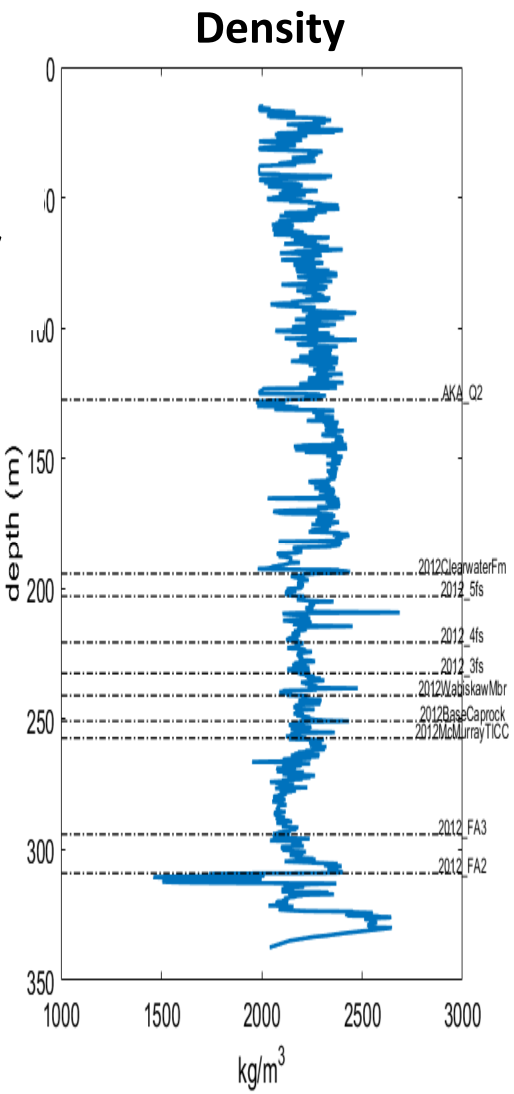


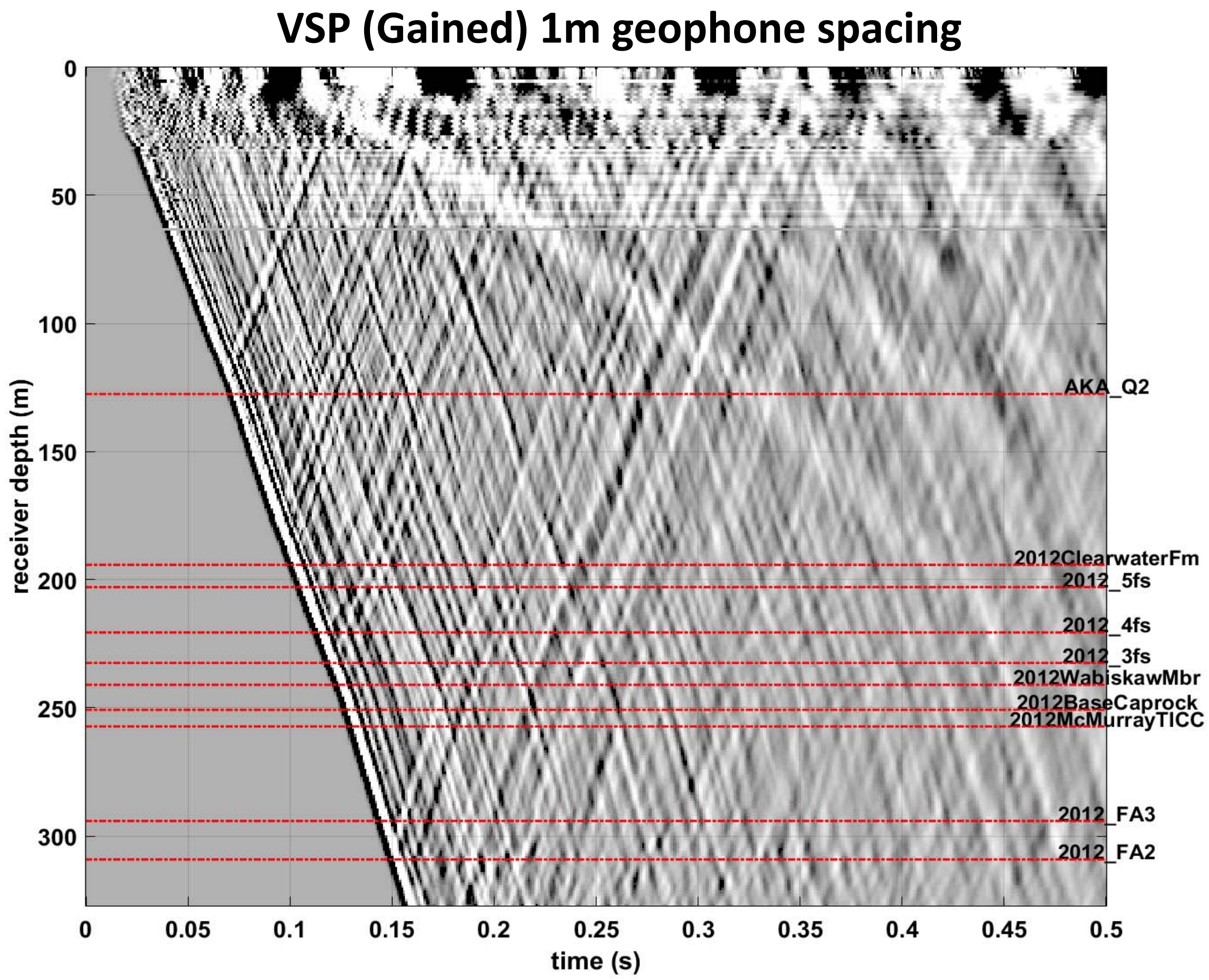
Estimating intrinsic attenuation: The Question

Given a VSP in a well with a good set of logs, can we use the logs to estimate the stratigraphic effect and then use this to correct VSP attenuation measures for stratigraphy?

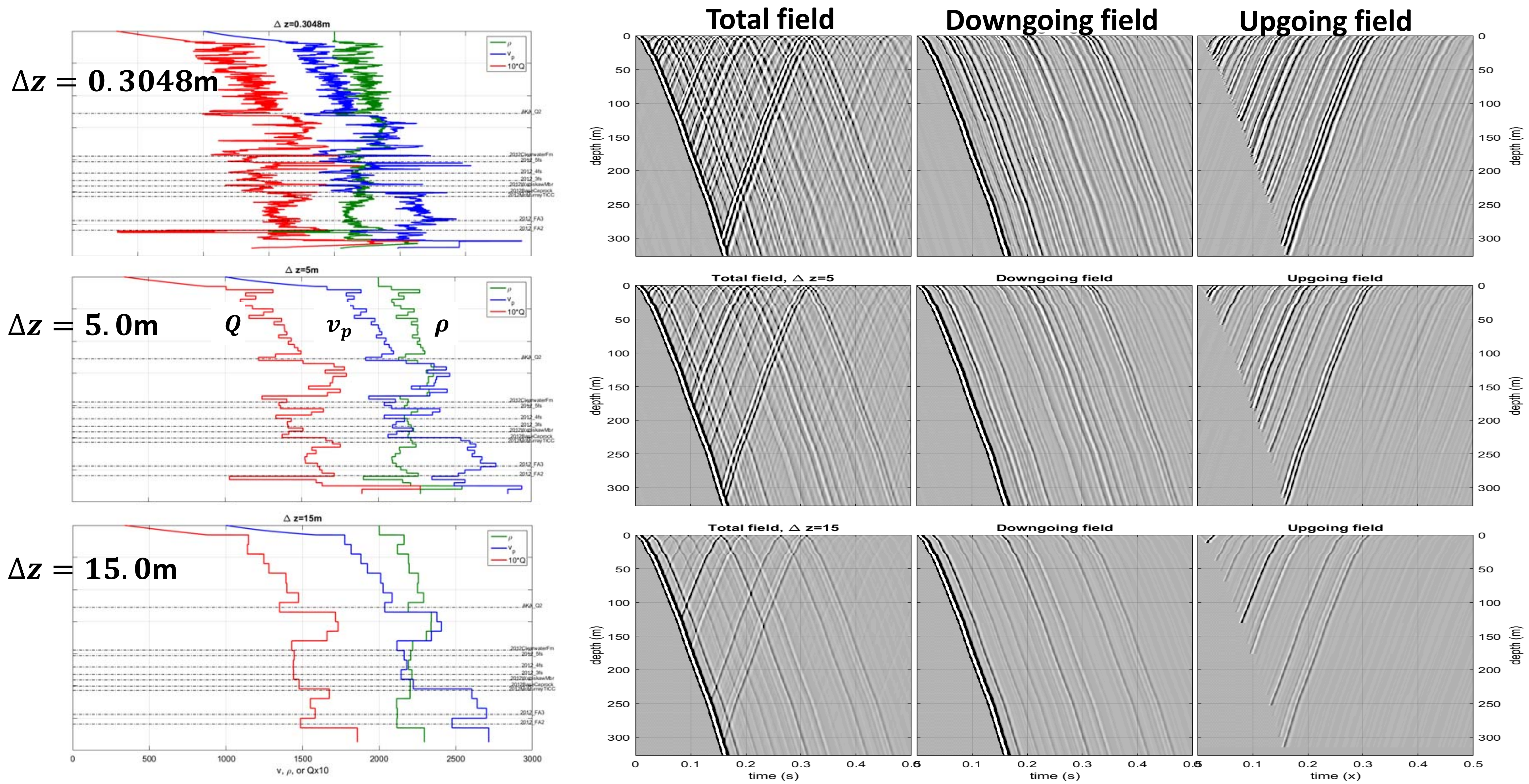
Estimating intrinsic attenuation: Suncor logs and VSP





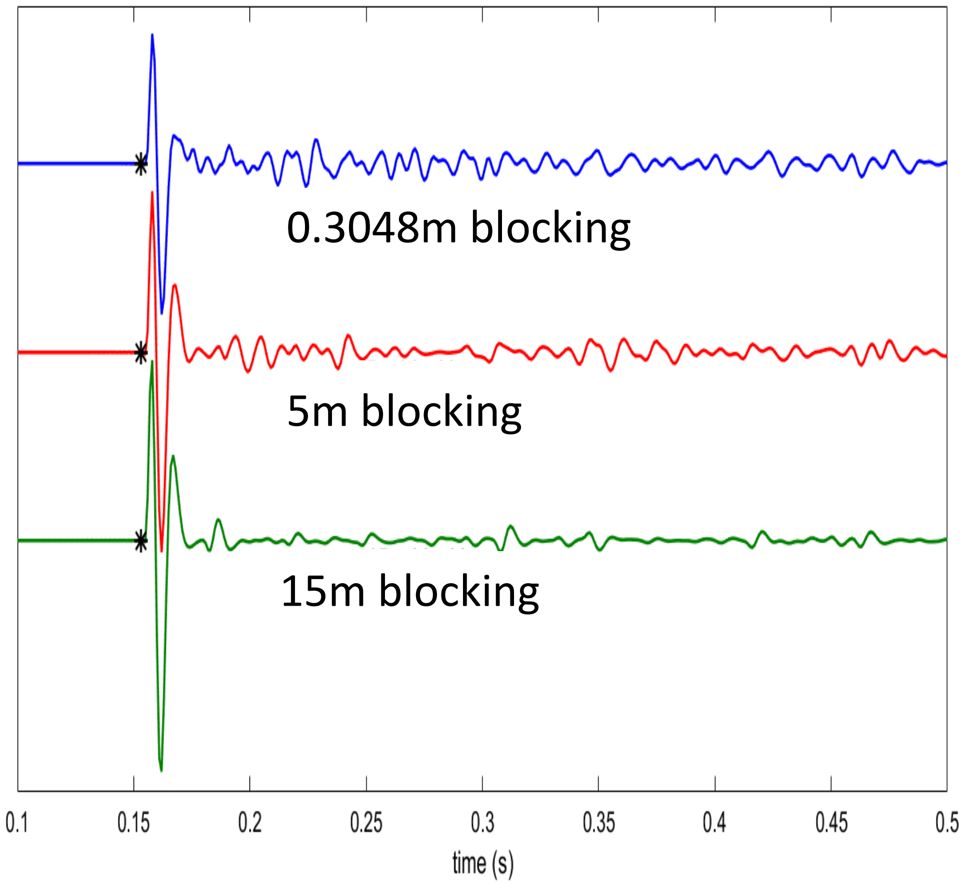


Estimating intrinsic attenuation: Synthetic VSPs

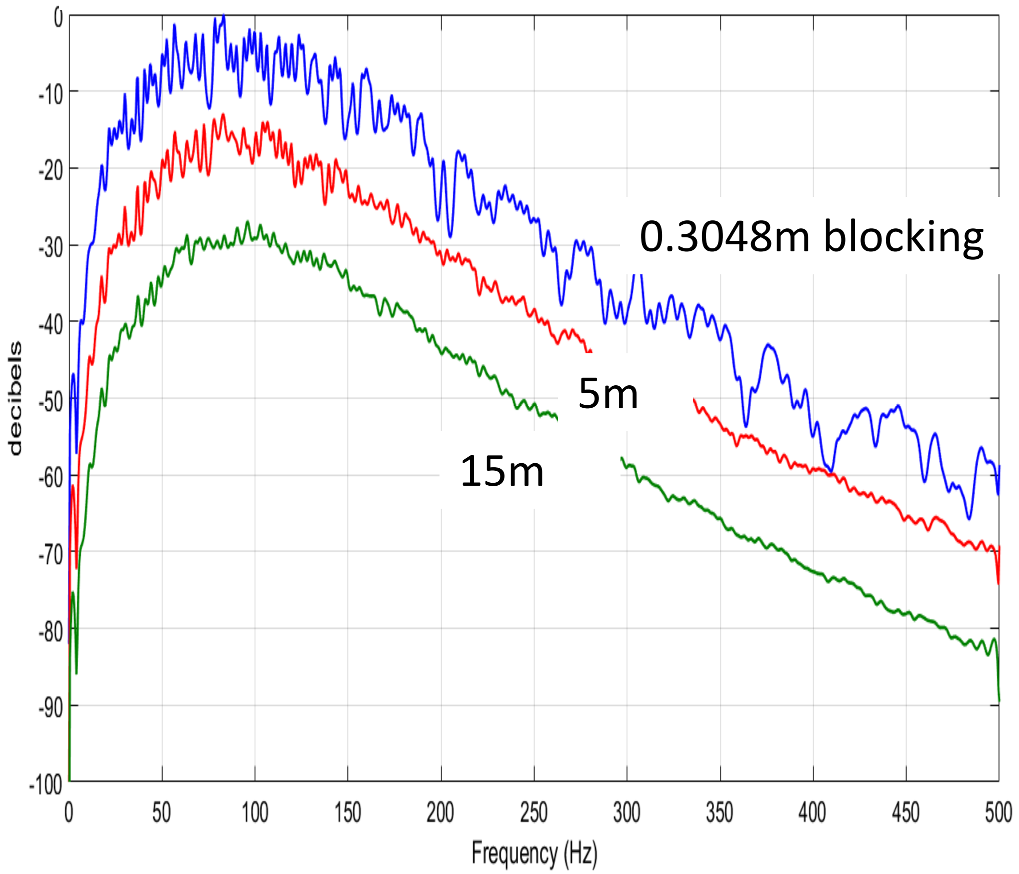


Estimating intrinsic attenuation: Single traces from synthetic VSPs

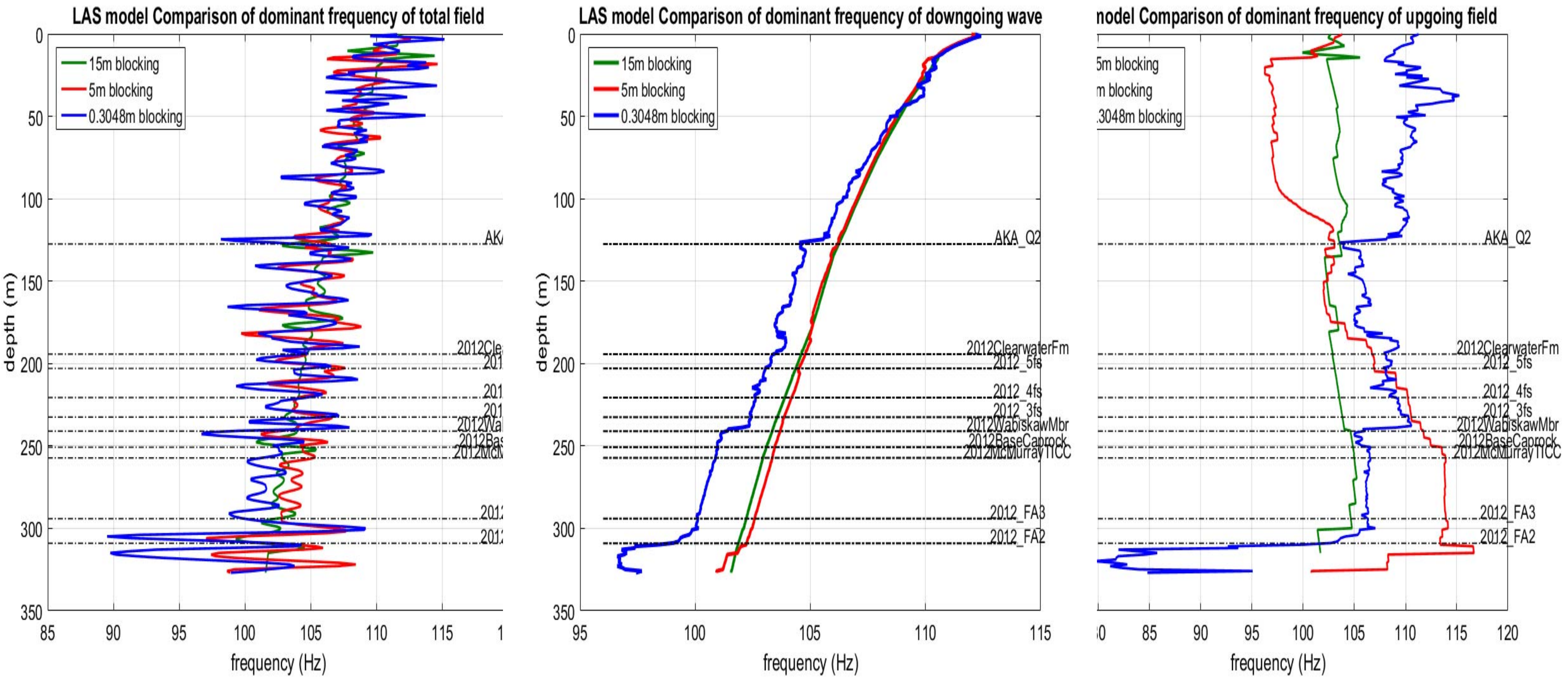
Traces at deepest receiver for different blocking sizes



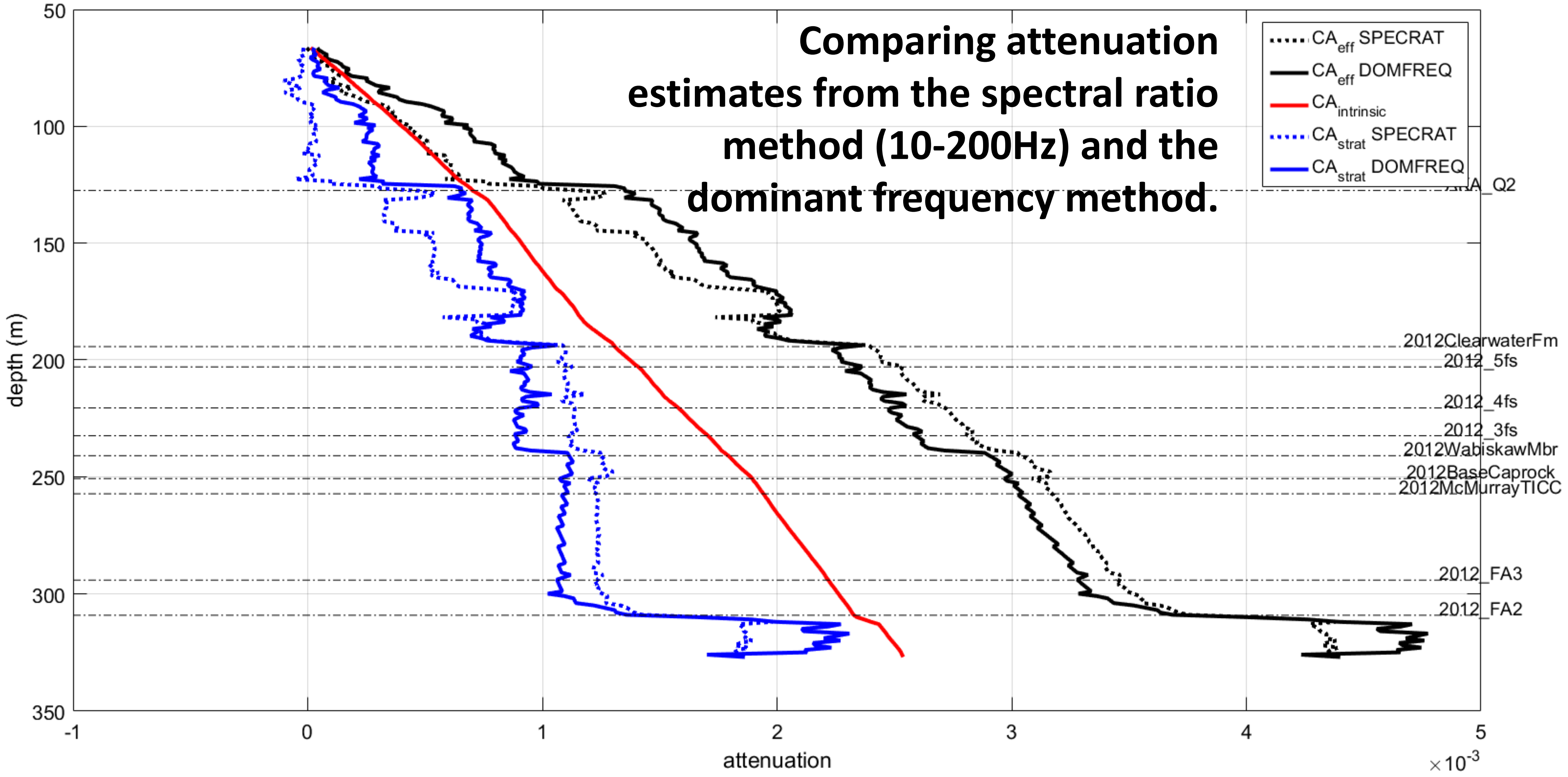
Spectra of the traces with vertical shifts applied



Estimating intrinsic attenuation: Dominant frequency (synthetics)

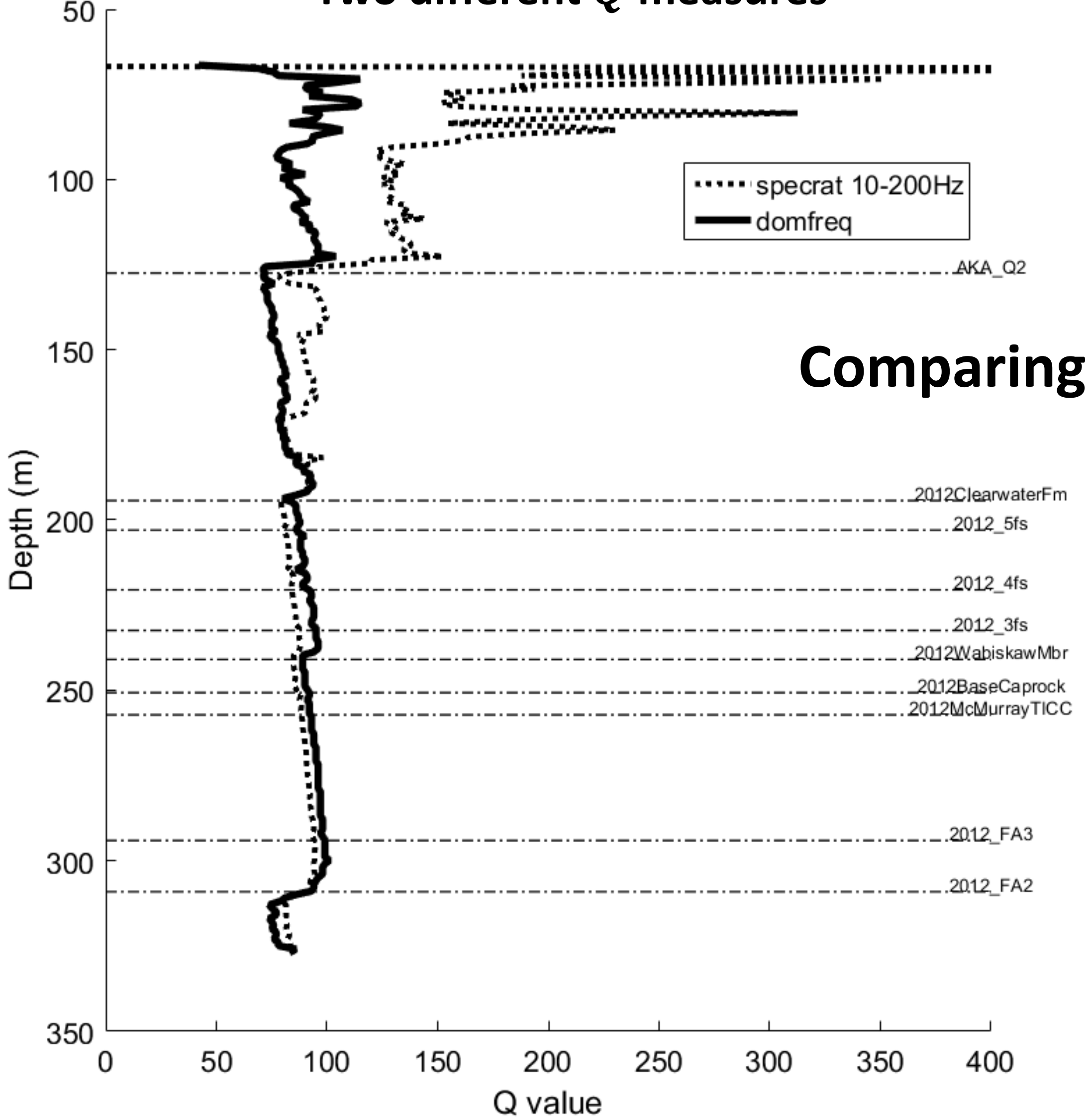


Estimating intrinsic attenuation: CA estimates (synthetics)



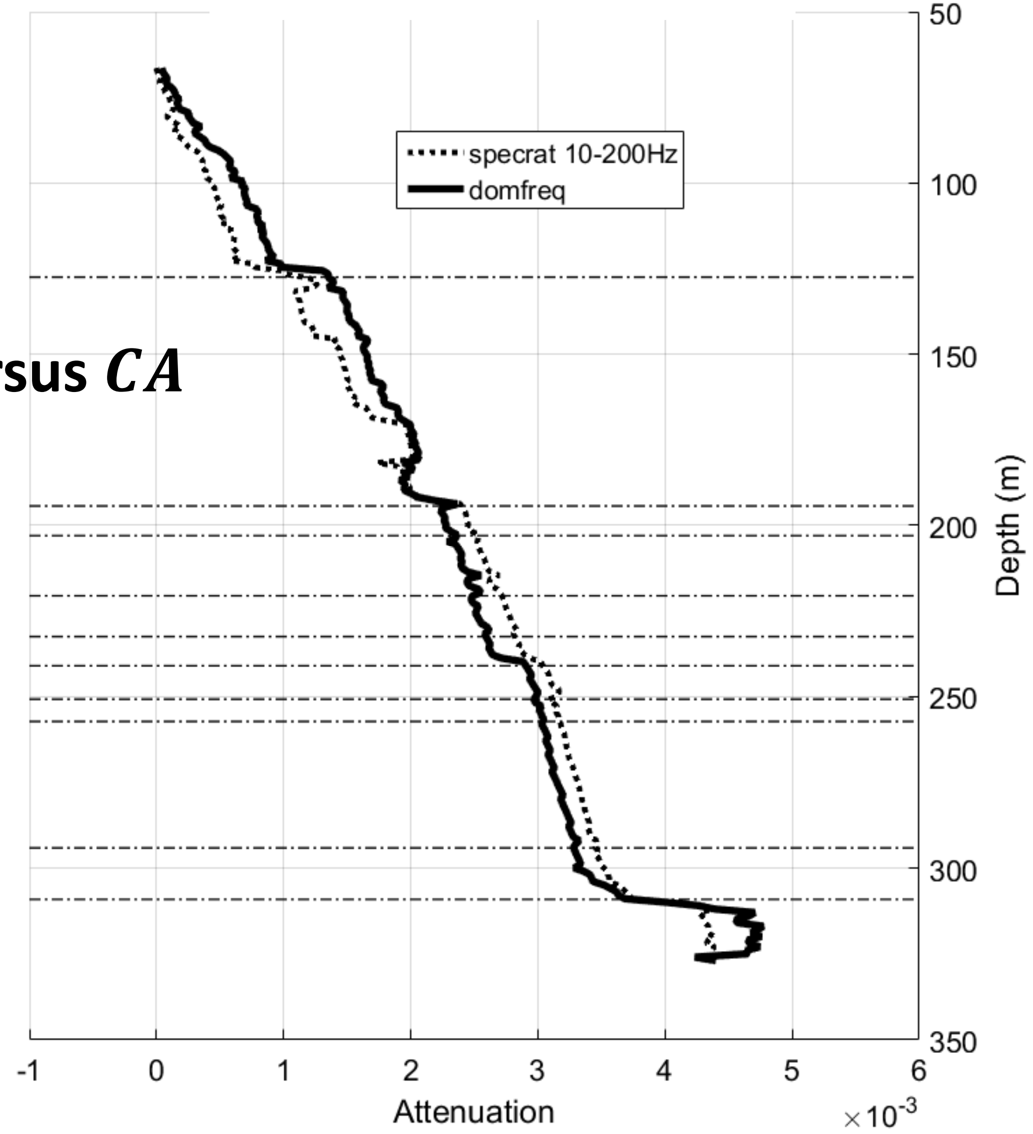
Estimating intrinsic attenuation: Q vs CA estimates (synthetics)

Two different Q measures

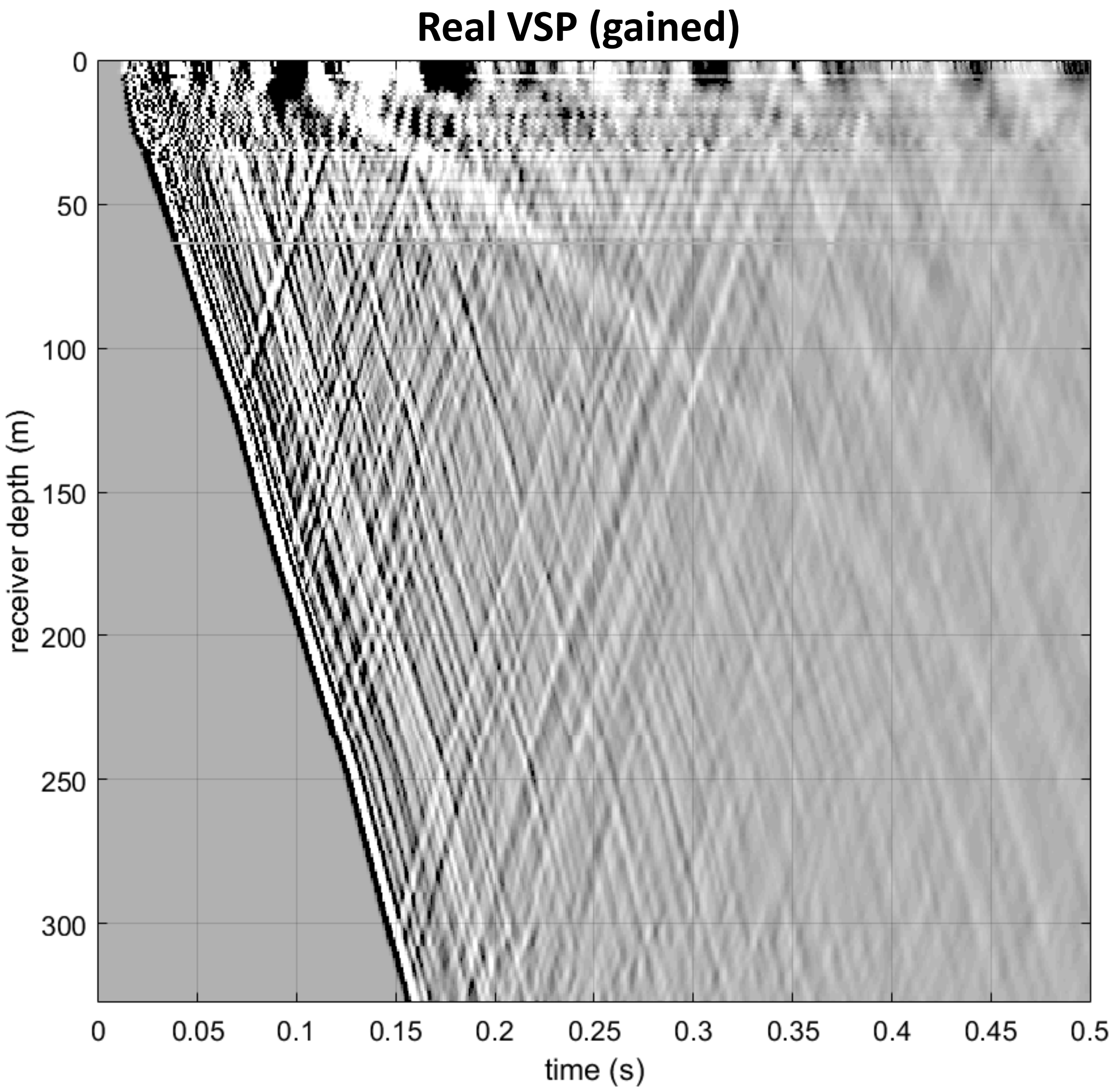


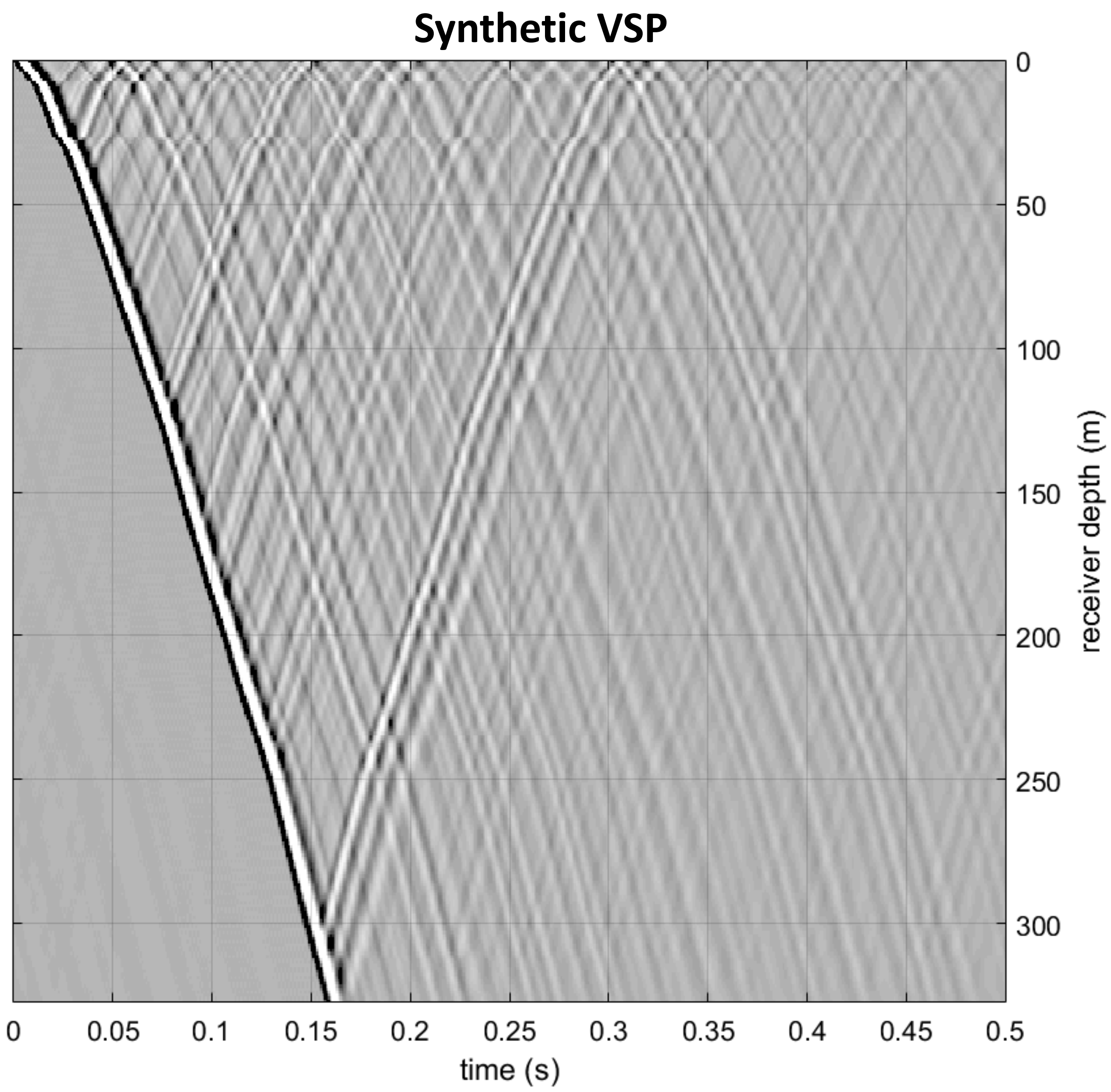
Comparing Q versus CA

Two different CA measures

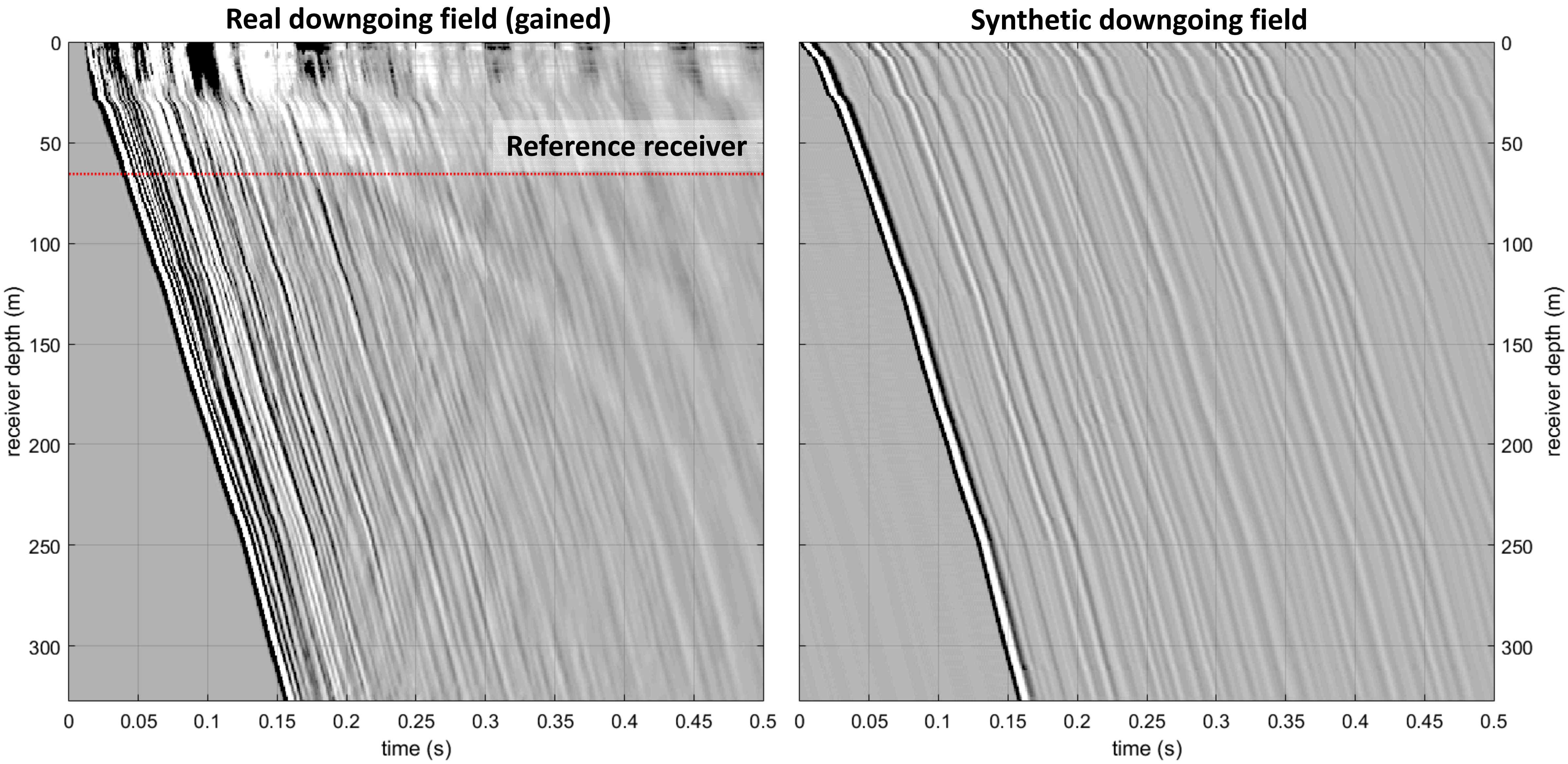


Estimating intrinsic attenuation: Synthetic versus real VSP

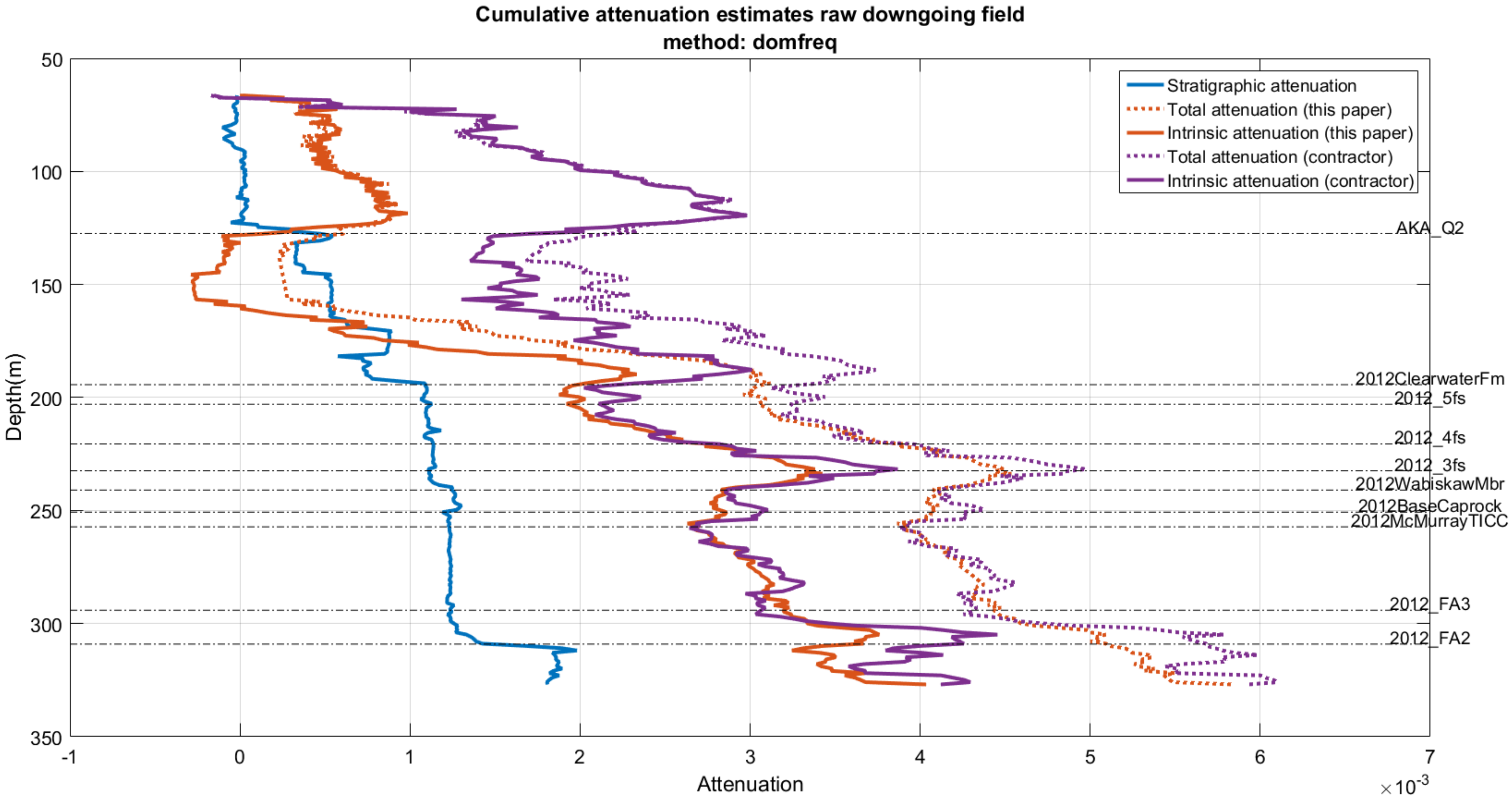




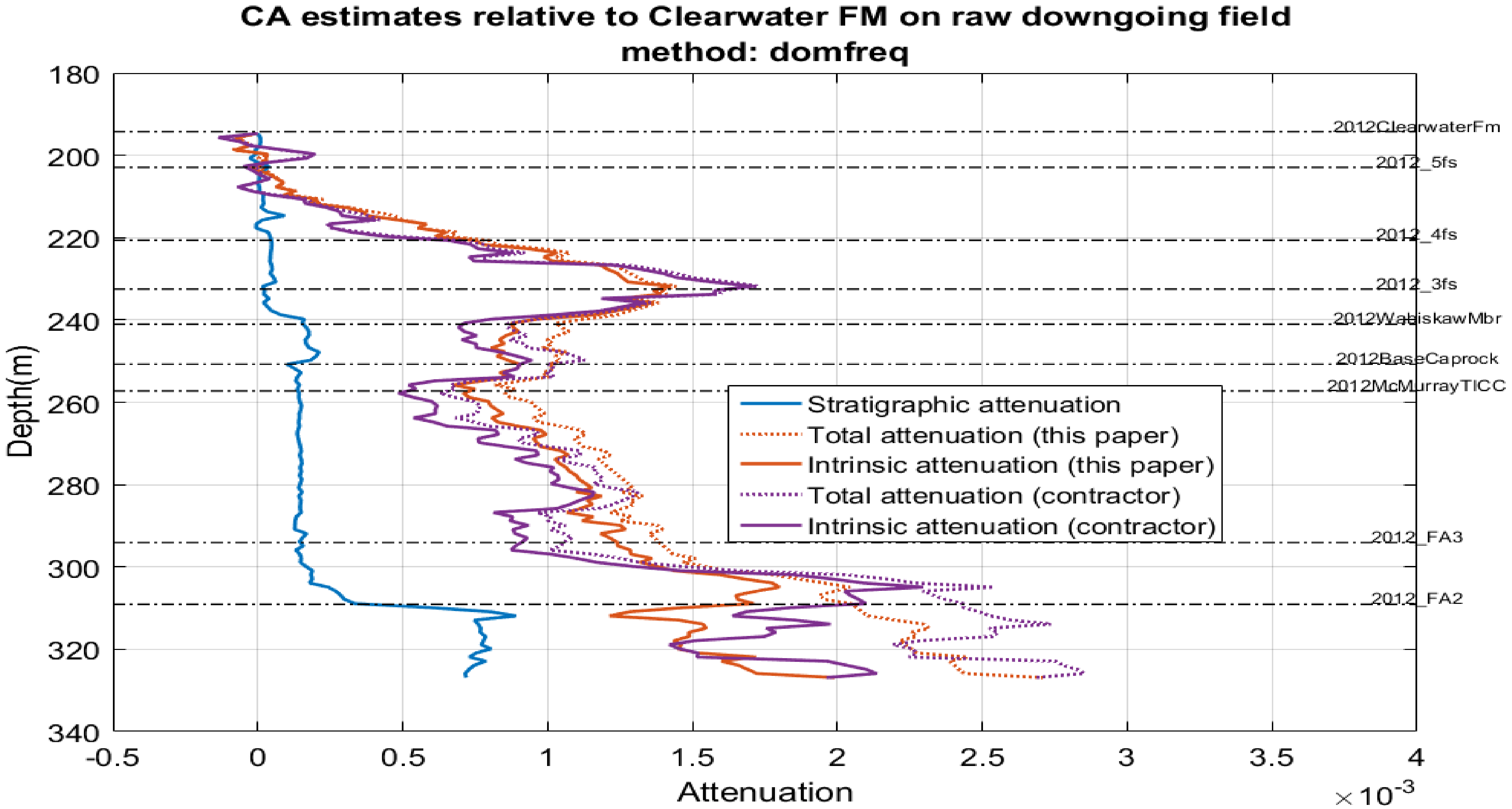
Estimating intrinsic attenuation: Synthetic versus real downgoing fields



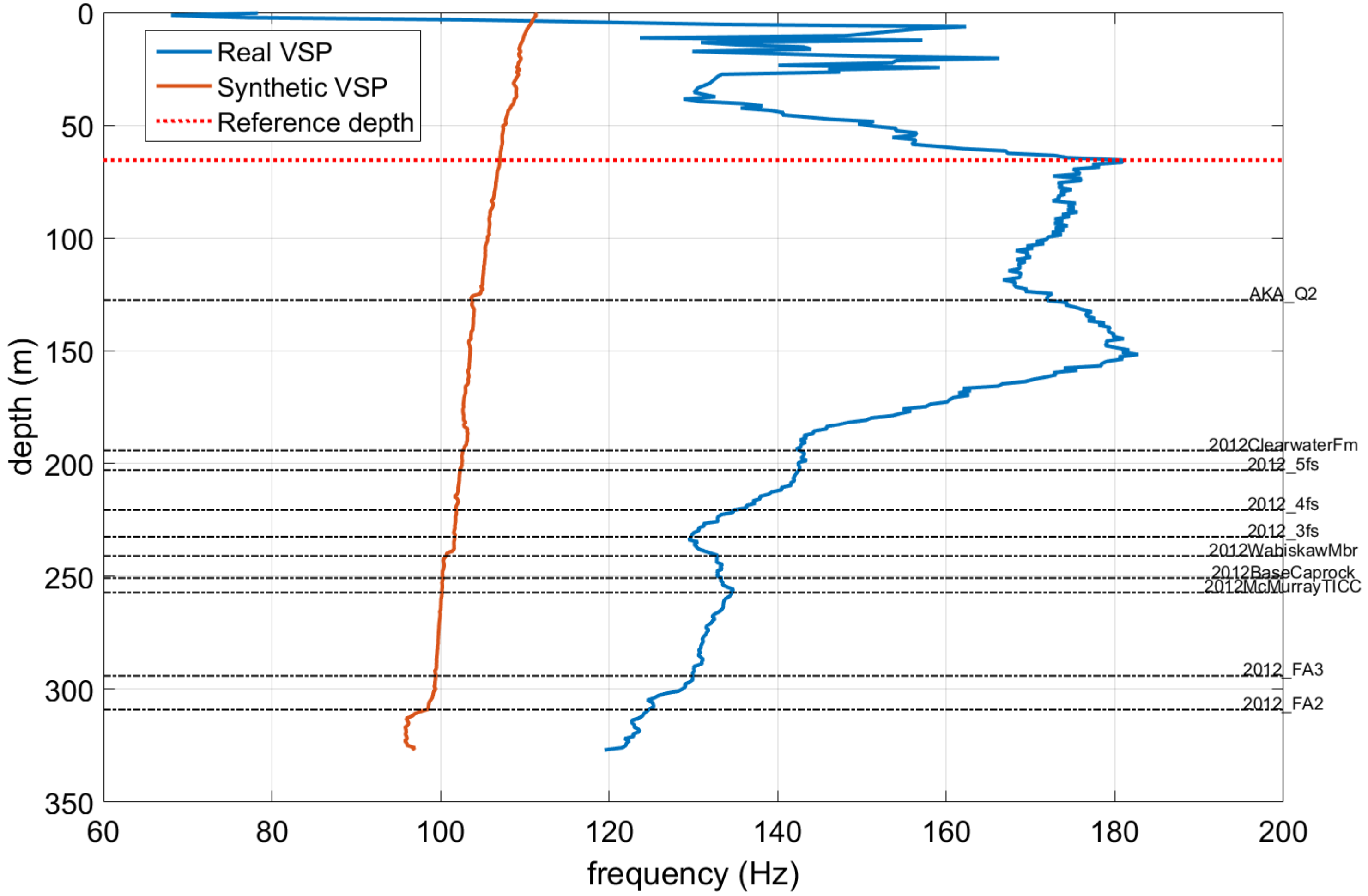
Estimating intrinsic attenuation: Intrinsic Q estimates



Estimating intrinsic attenuation: Intrinsic *Q* estimates



Estimating intrinsic attenuation: Dominant frequency real VSP



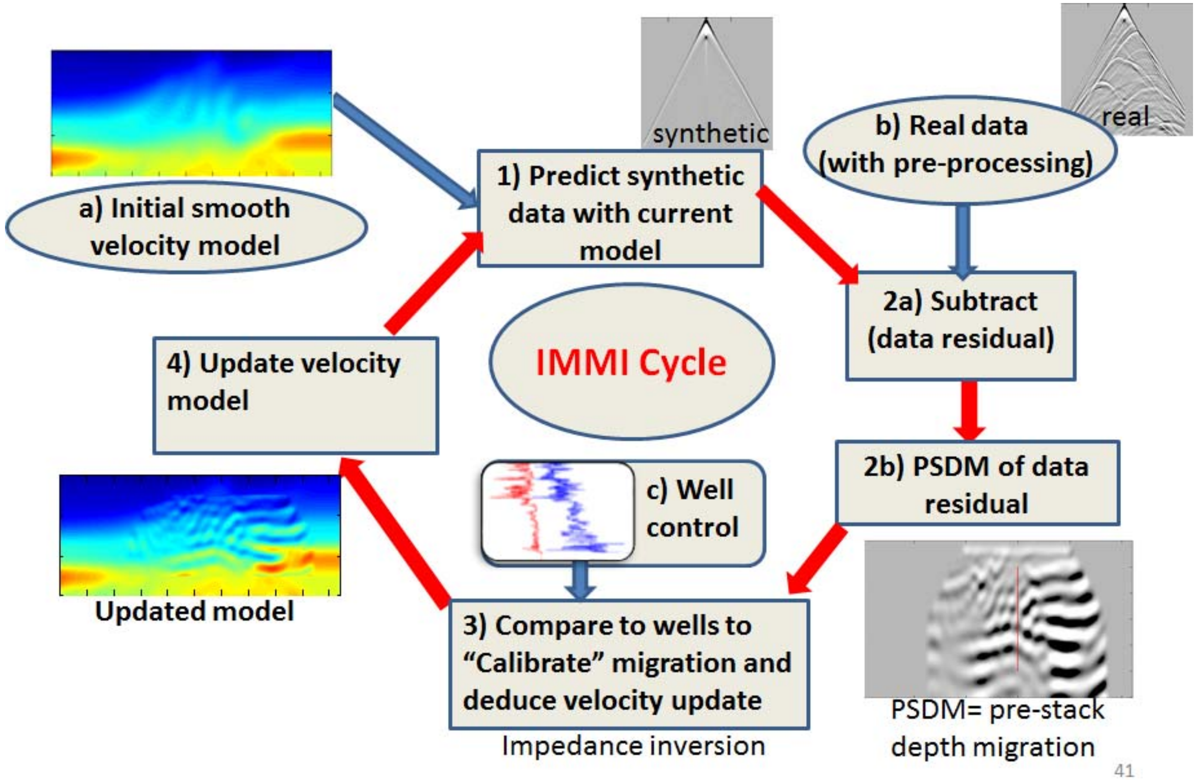
Estimating intrinsic attenuation: Conclusions

- Estimation of intrinsic attenuation requires correcting measurements for stratigraphic attenuation.
- Stratigraphic attenuation can be estimated from well logs.
- The stratigraphic attenuation estimates made here seem too small.
- The intrinsic attenuation estimates fail to be monotonic
- Possible causes:
    1. Imperfect wavefield separation
    2. Inadequate well logs (do we need finer sampling?)
    3. Visco-acoustic approximation may be insufficient

Post-stack IMMI: Introduction

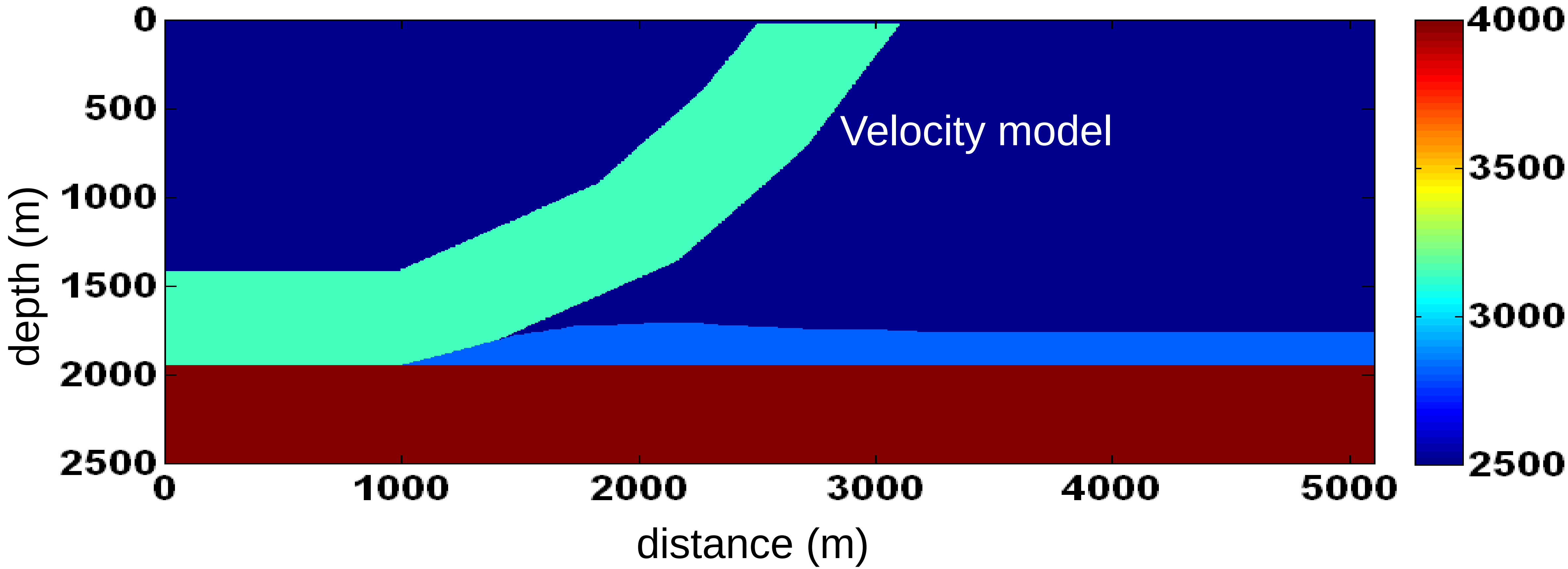
The idea:

- **IMMI, iterated modelling, migration, and inversion, has been proposed as a generalization of FWI.**
- **Post-stack processes require far less computation than prestack.**
- **We know how to do post-stack depth migration and inversion.**
- **Can the exploding reflector concept be used to model the CMP stack and make a viable post-stack IMMI?**



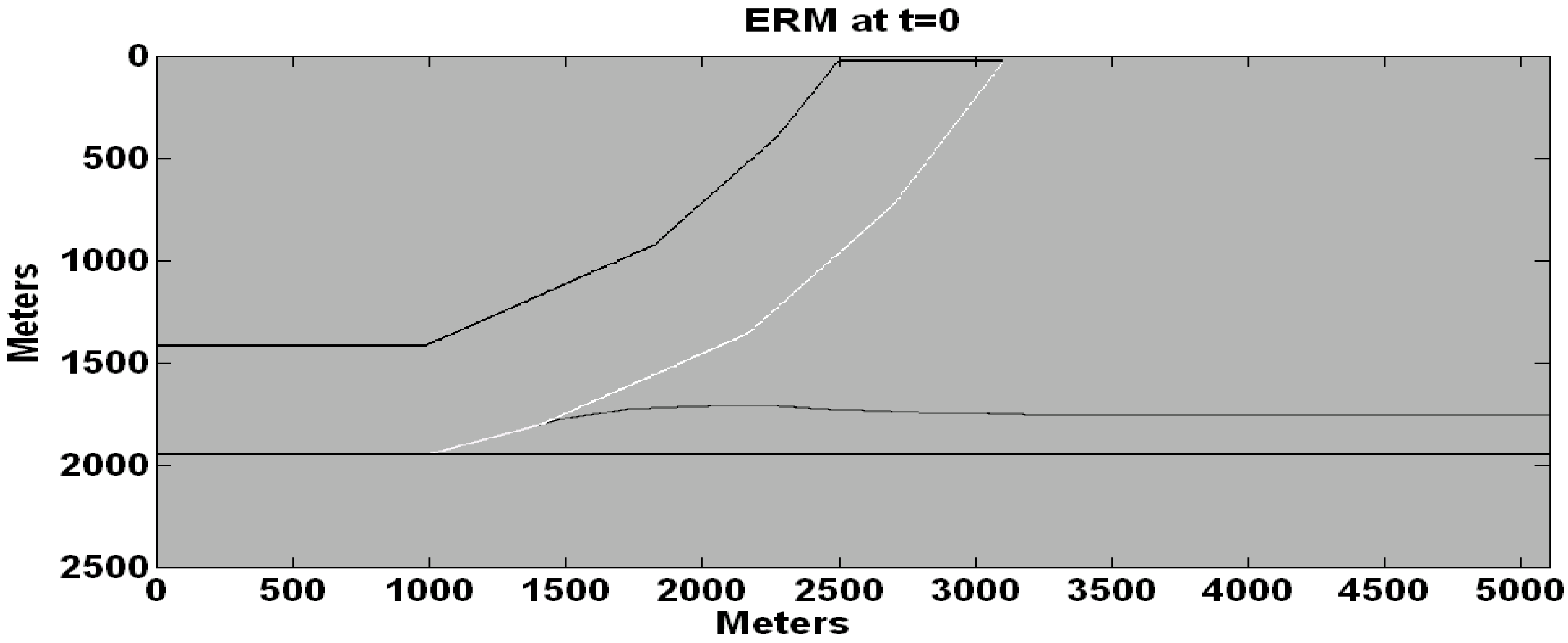
The IMMI/FWI cycle (Margrave et al., 2012)

Post-stack IMMI: Exploding Reflector model

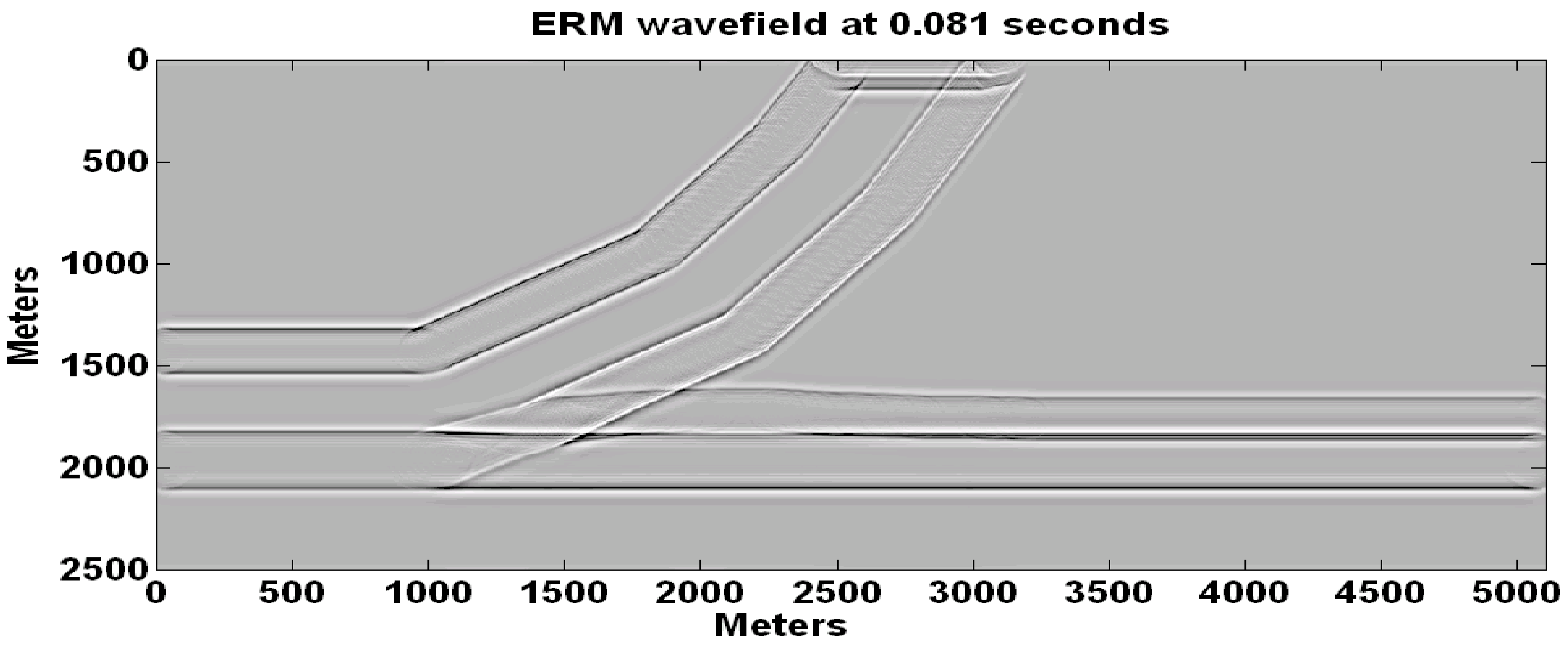



```
>> thrust_explode
>> save thrust vel seisf x z t dx dt
```

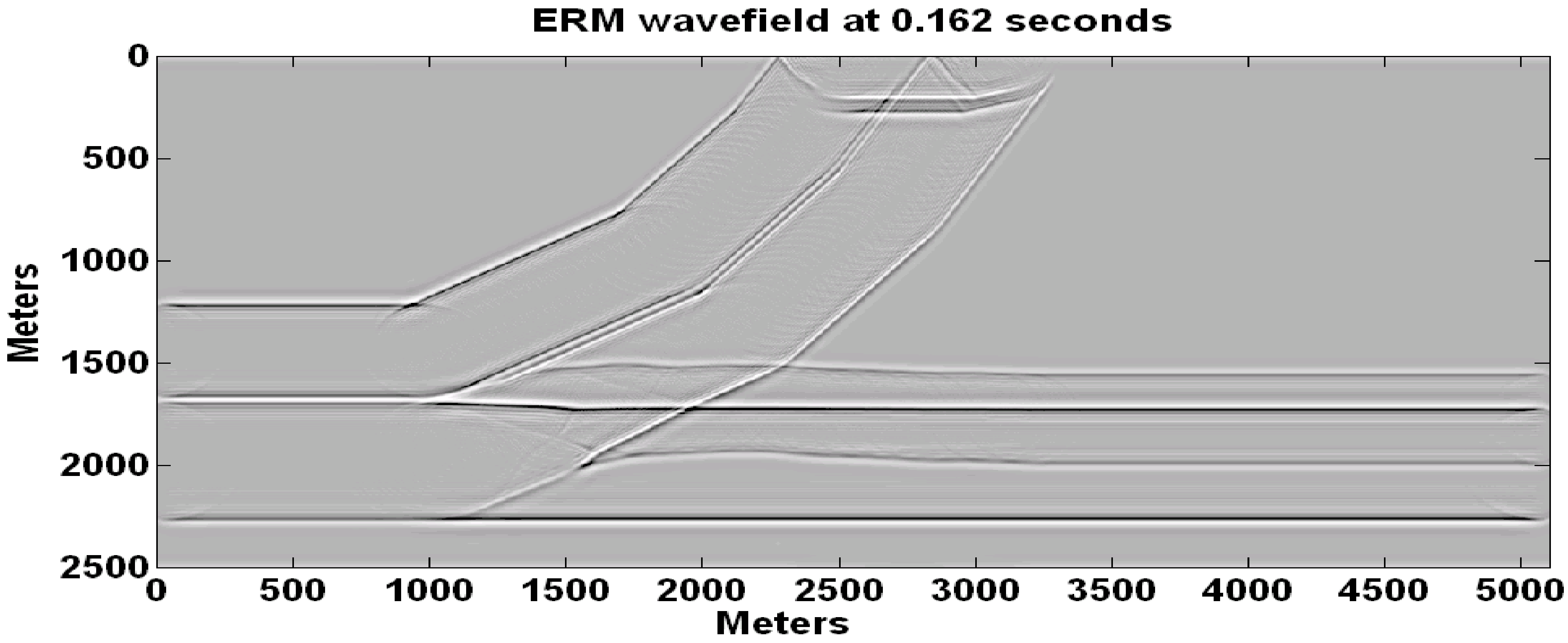
Post-stack IMMI: Exploding Reflector Model



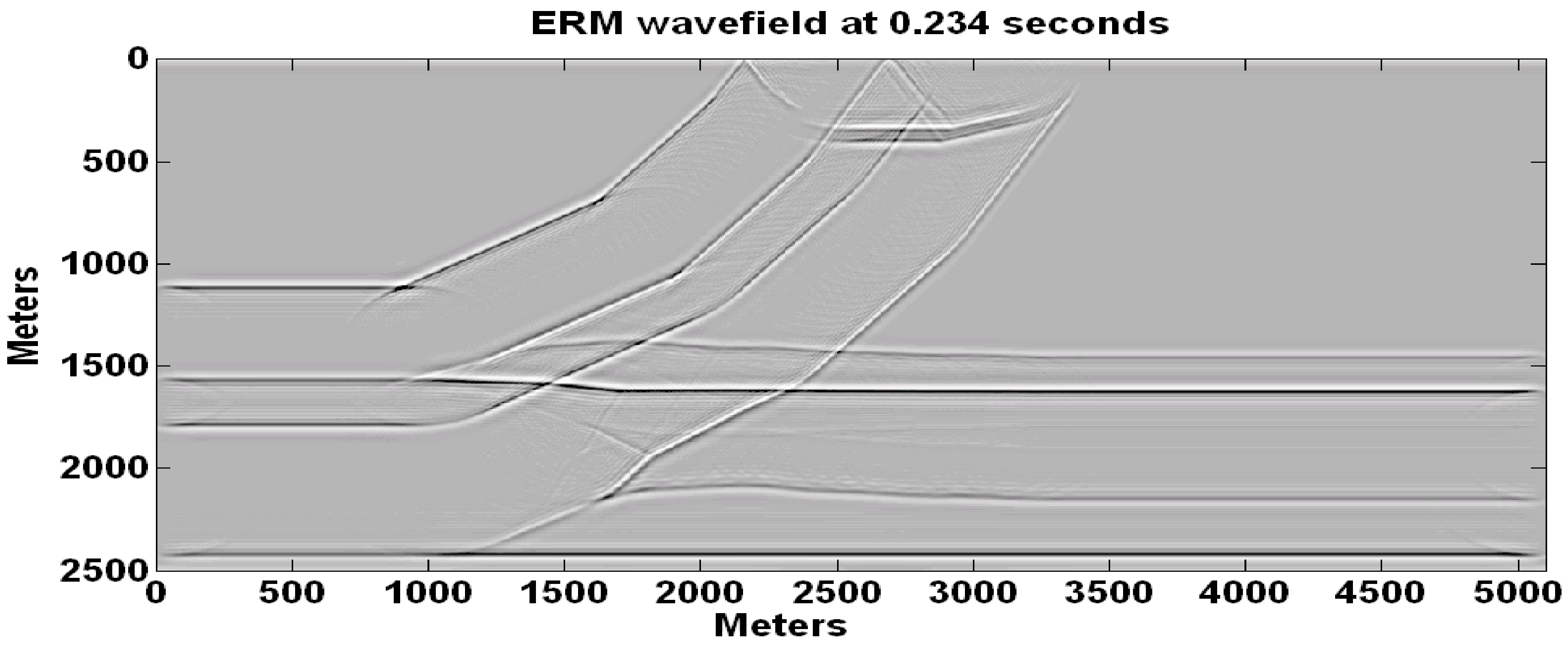
Post-stack IMMI: Exploding Reflector Model



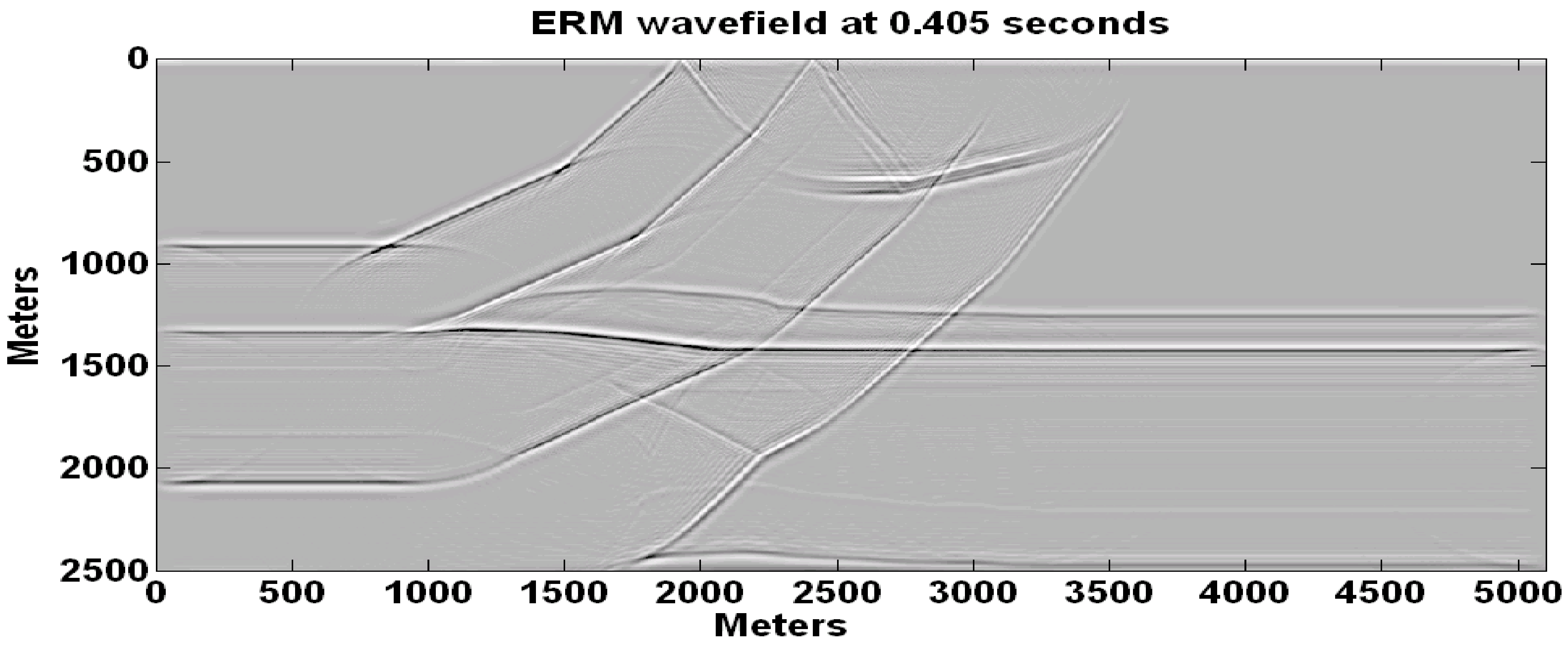
Post-stack IMMI: Exploding Reflector Model



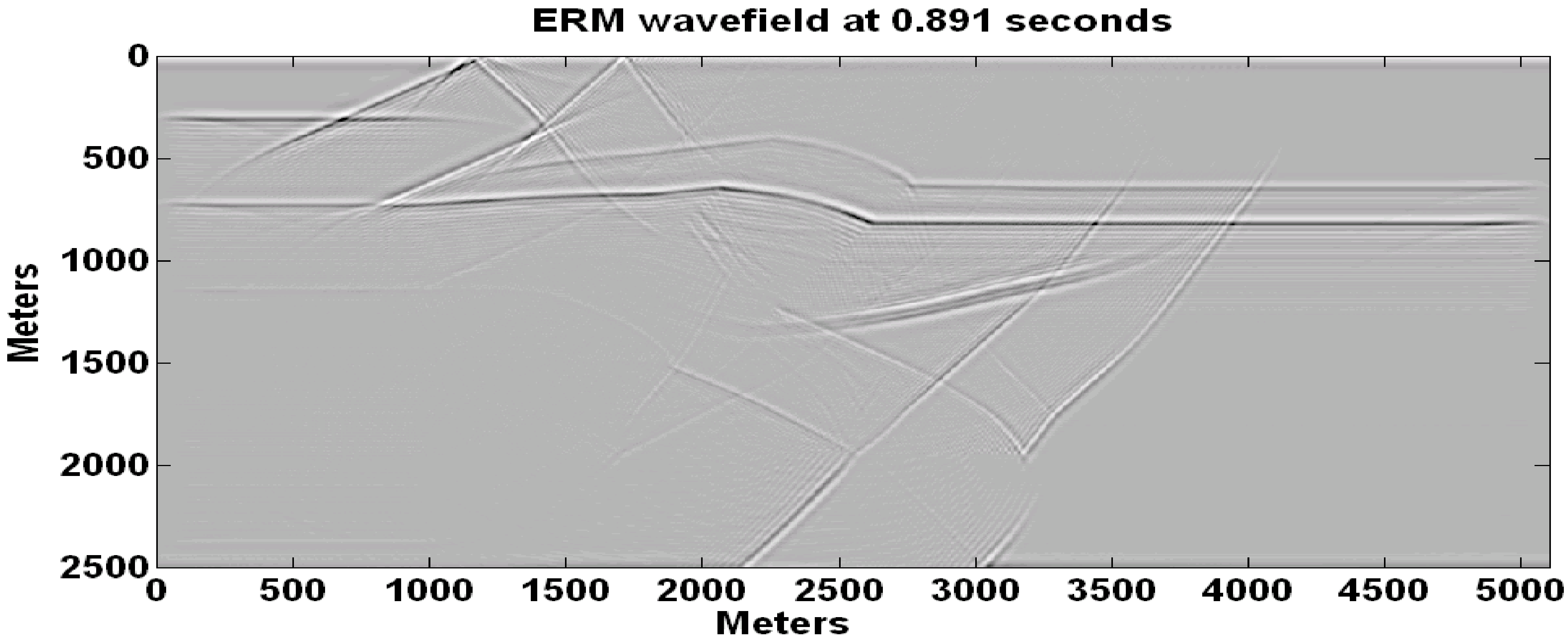
Post-stack IMMI: Exploding Reflector Model



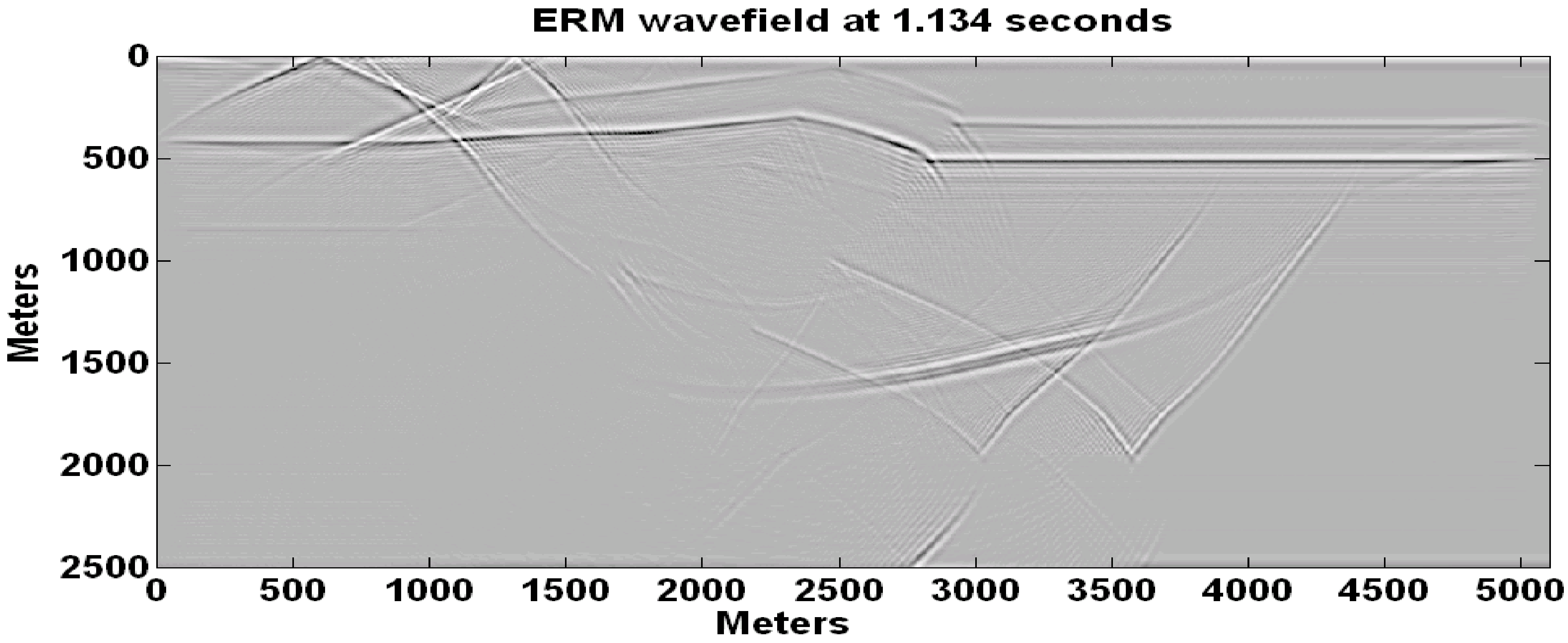
Post-stack IMMI: Exploding Reflector Model



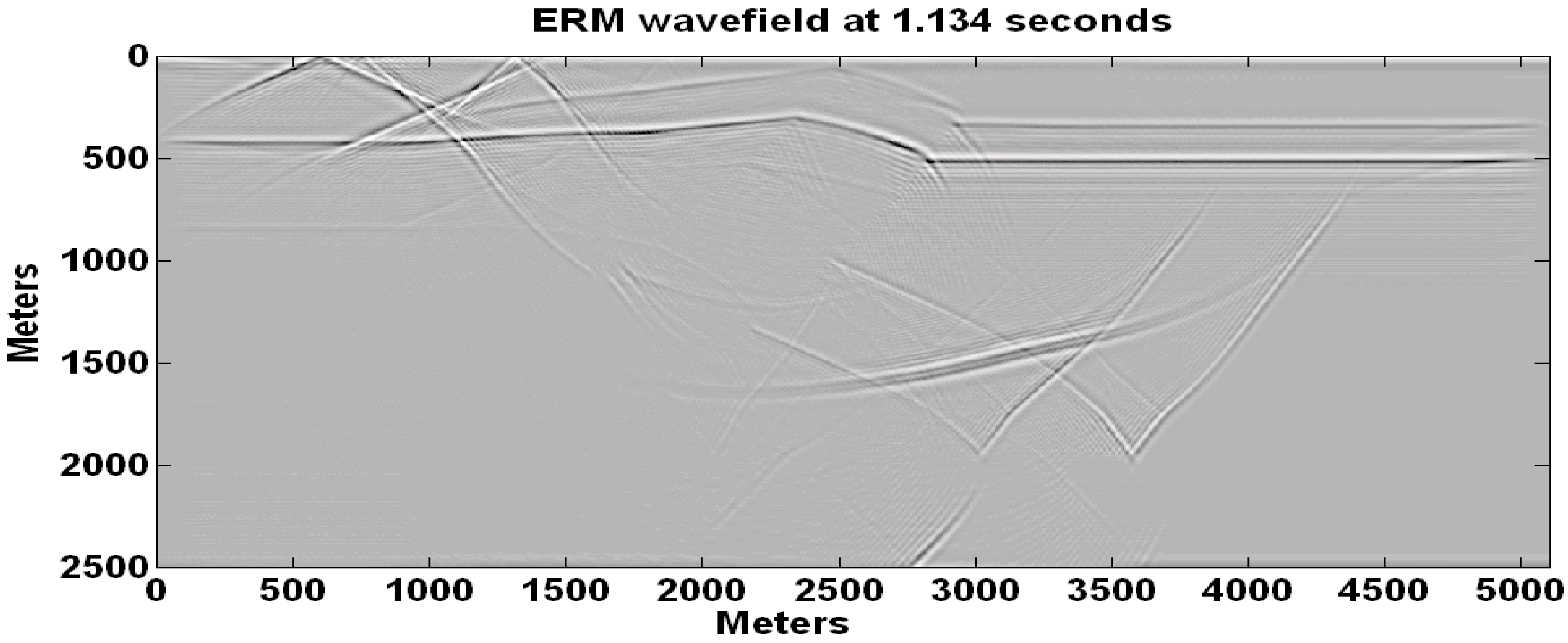
Post-stack IMMI: Exploding Reflector Model



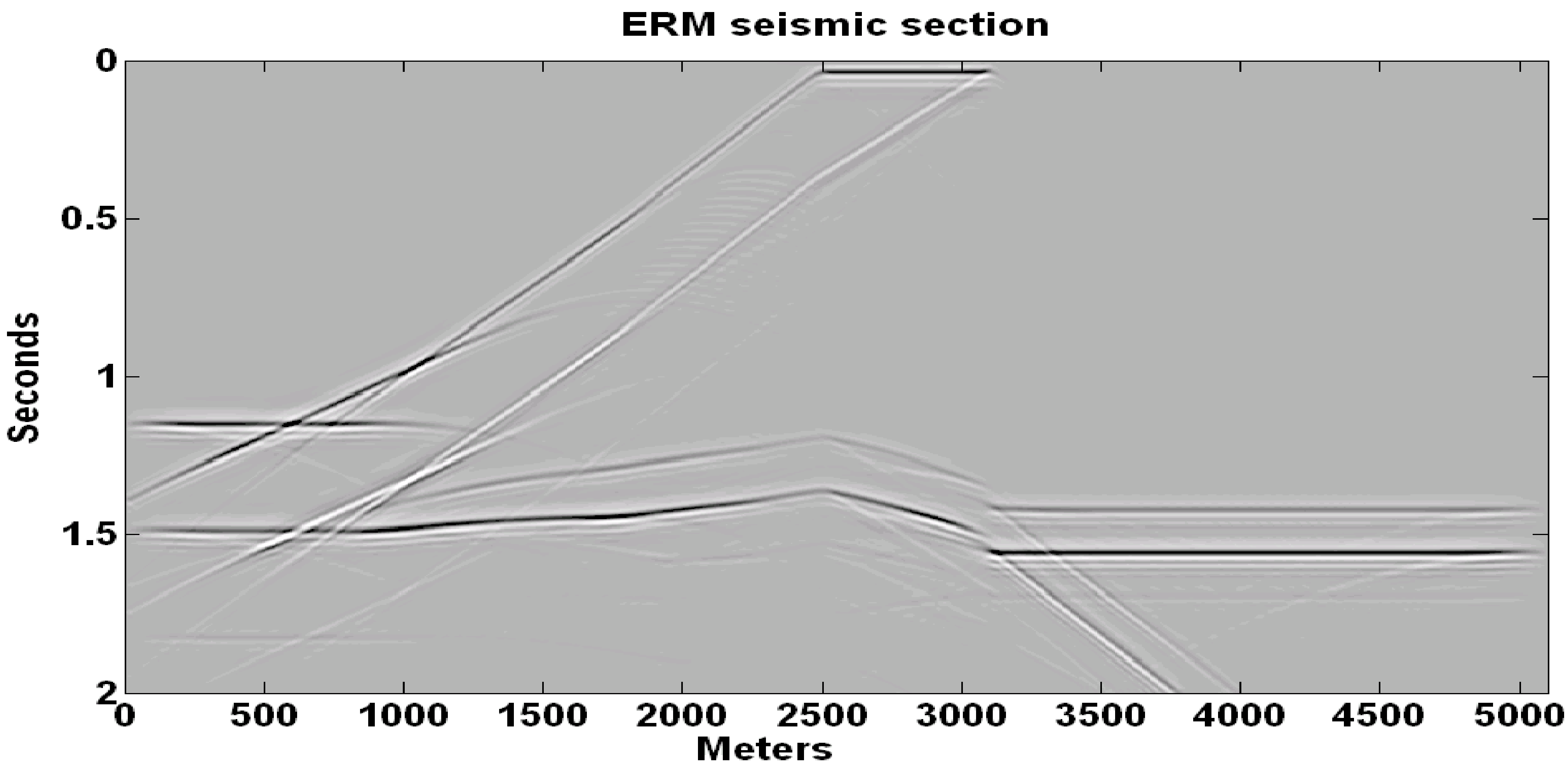
Post-stack IMMI: Exploding Reflector Model



Post-stack IMMI: Exploding Reflector Model

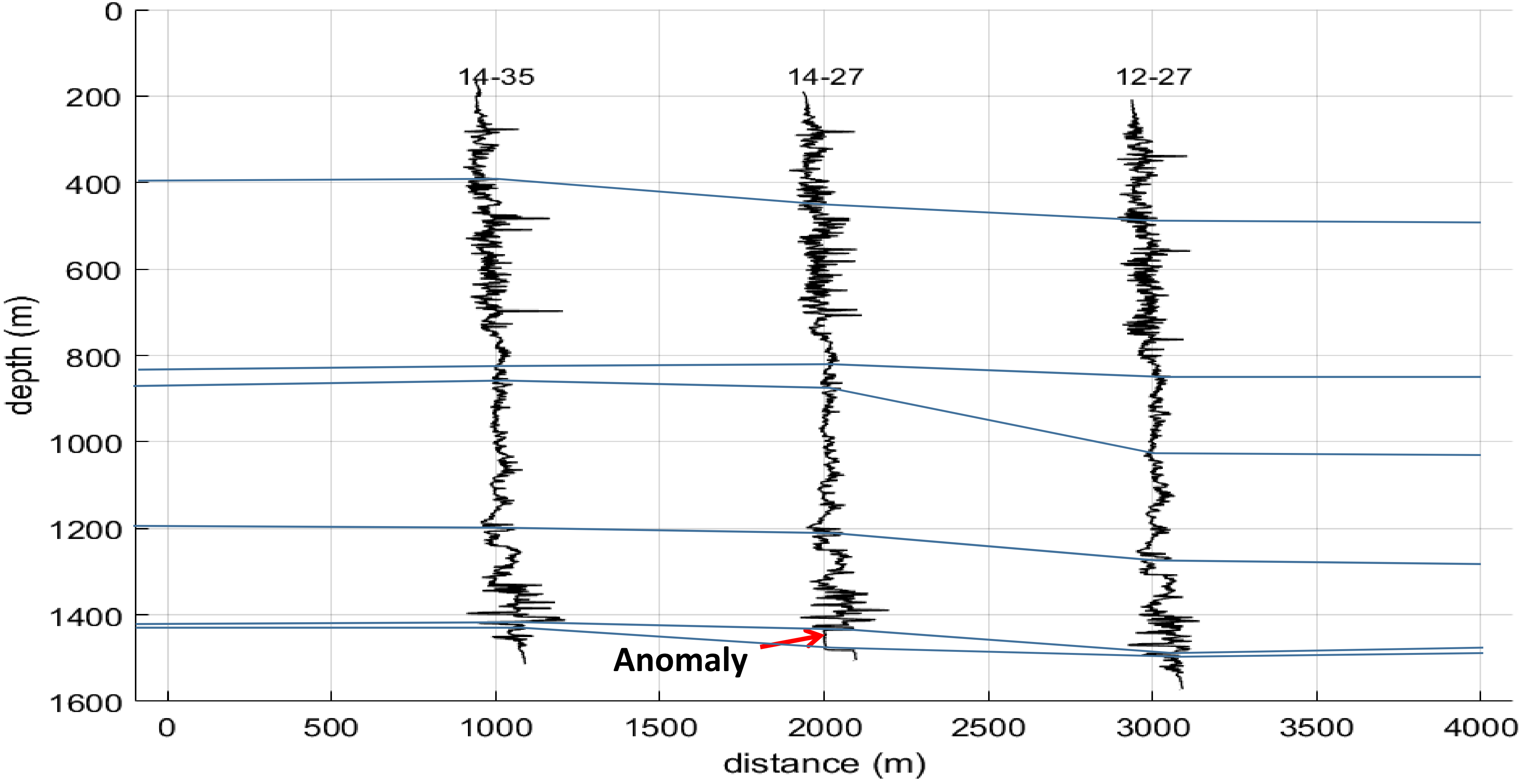


Post-stack IMMI: Exploding Reflector Model



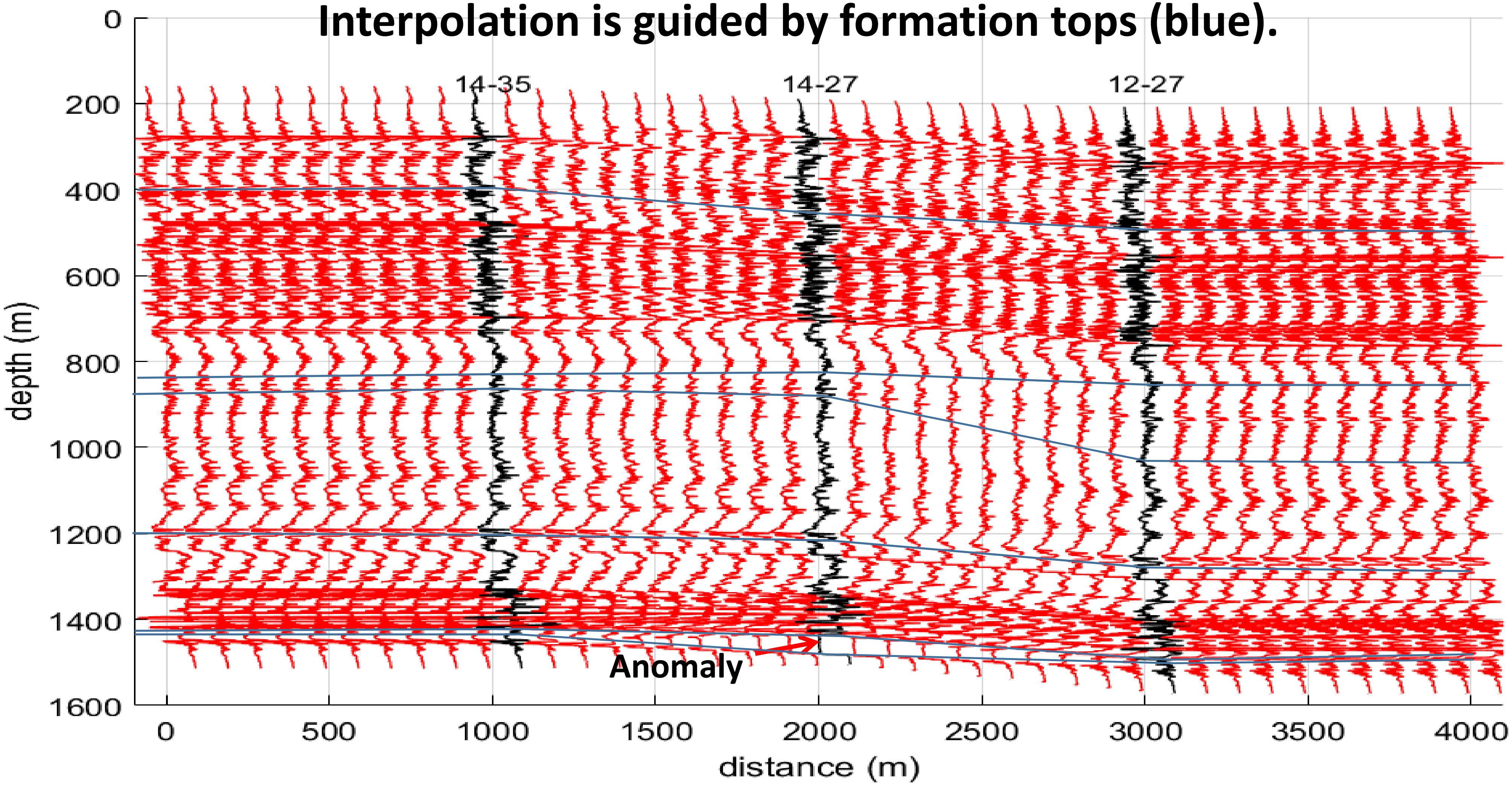
Post-stack IMMI: Hussar sonic log section

Three Hussar sonic logs plus a subset of the formation tops linked as horizons.

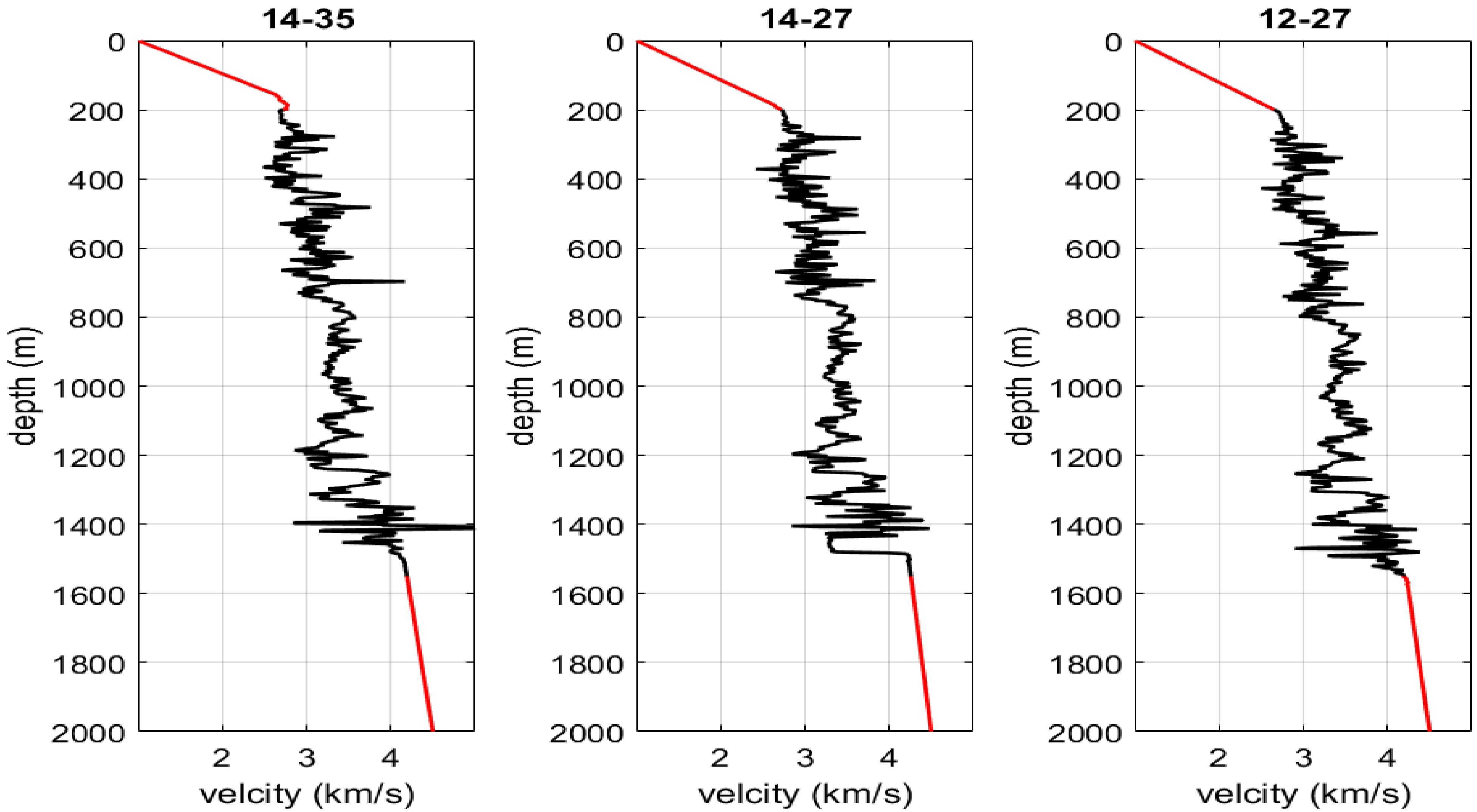


Post-stack IMMI: Hussar sonic log section

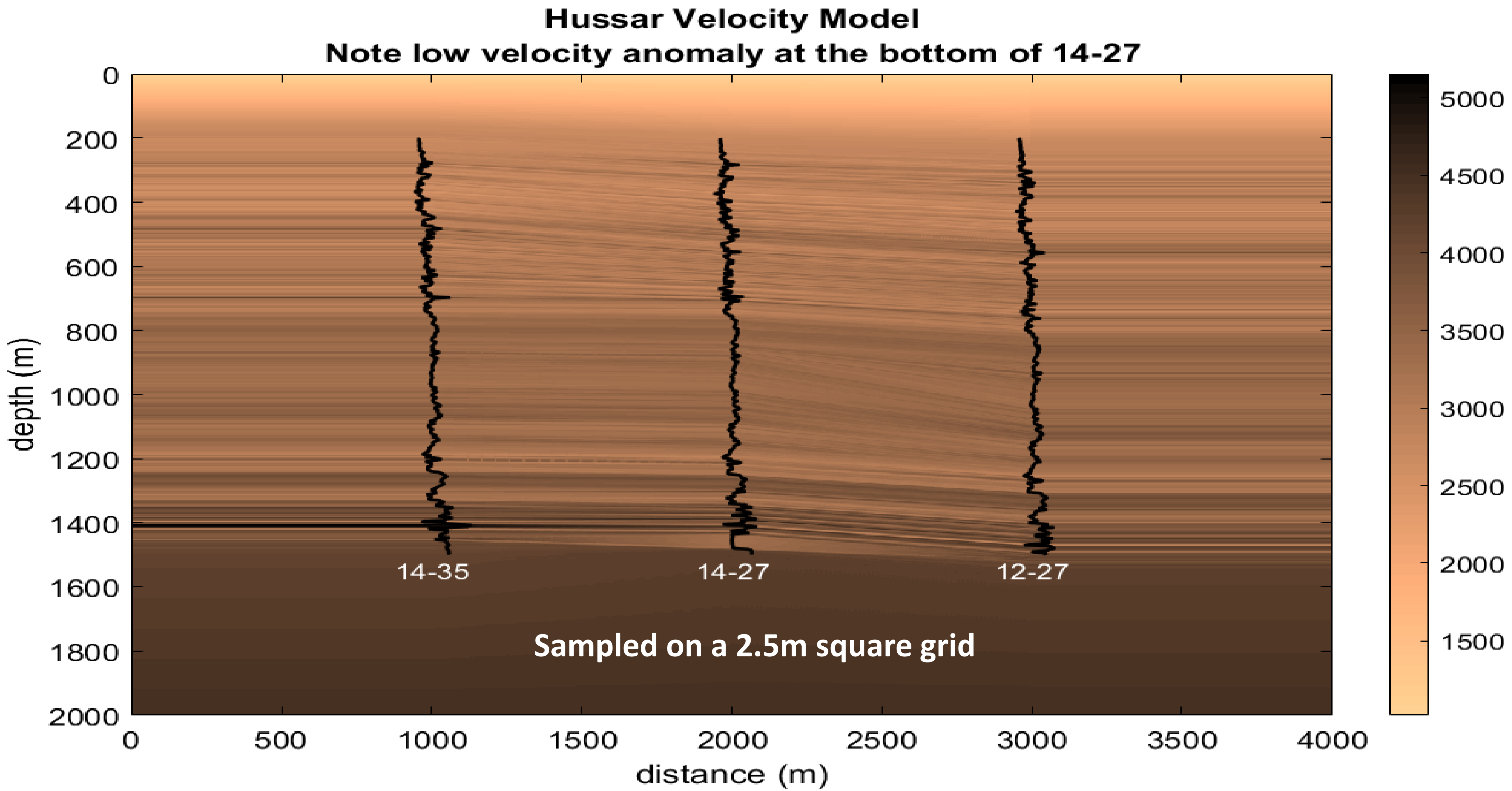
An interpolated log is shown every 100m.
Interpolation is guided by formation tops (blue).



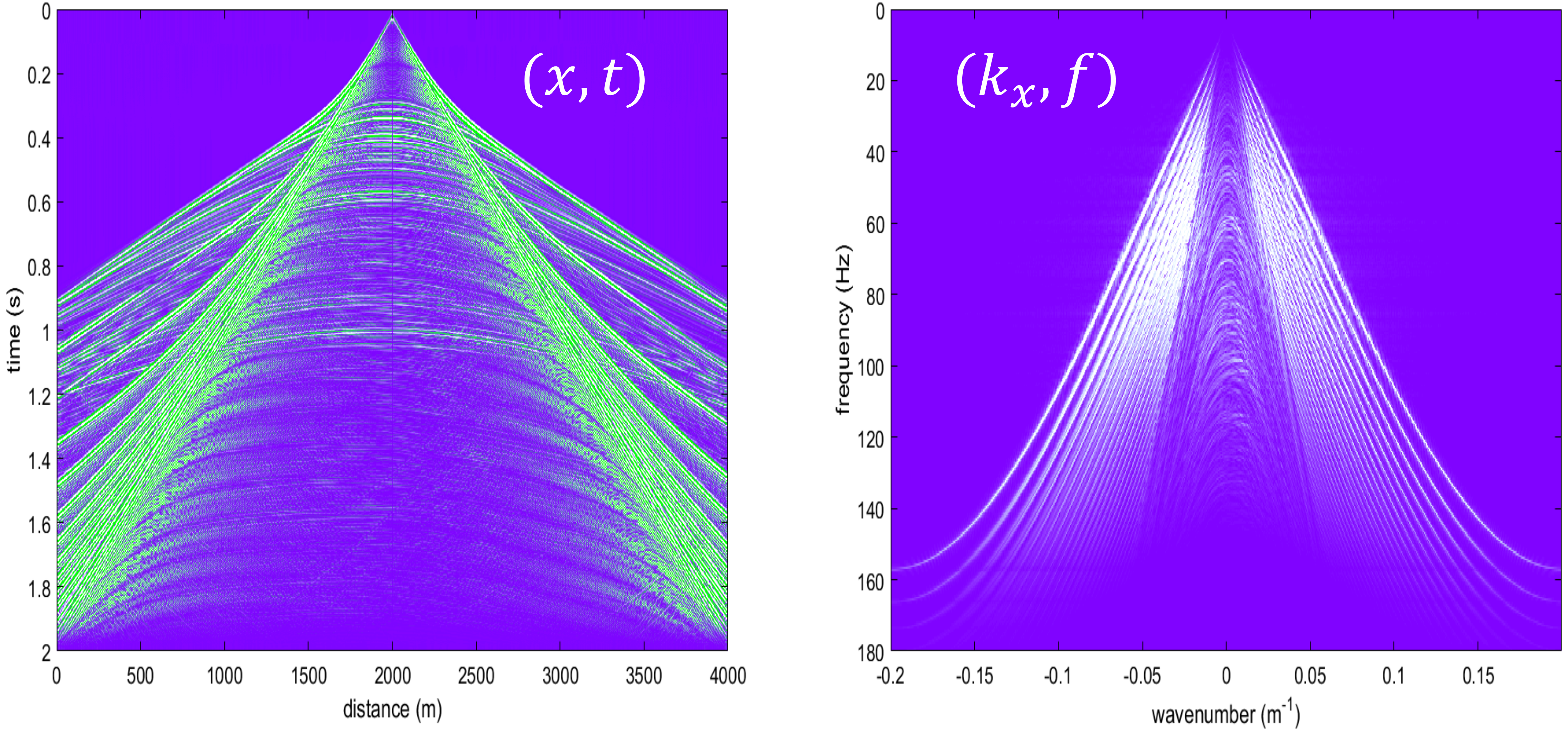
Post-stack IMMI: Overburden and underburden



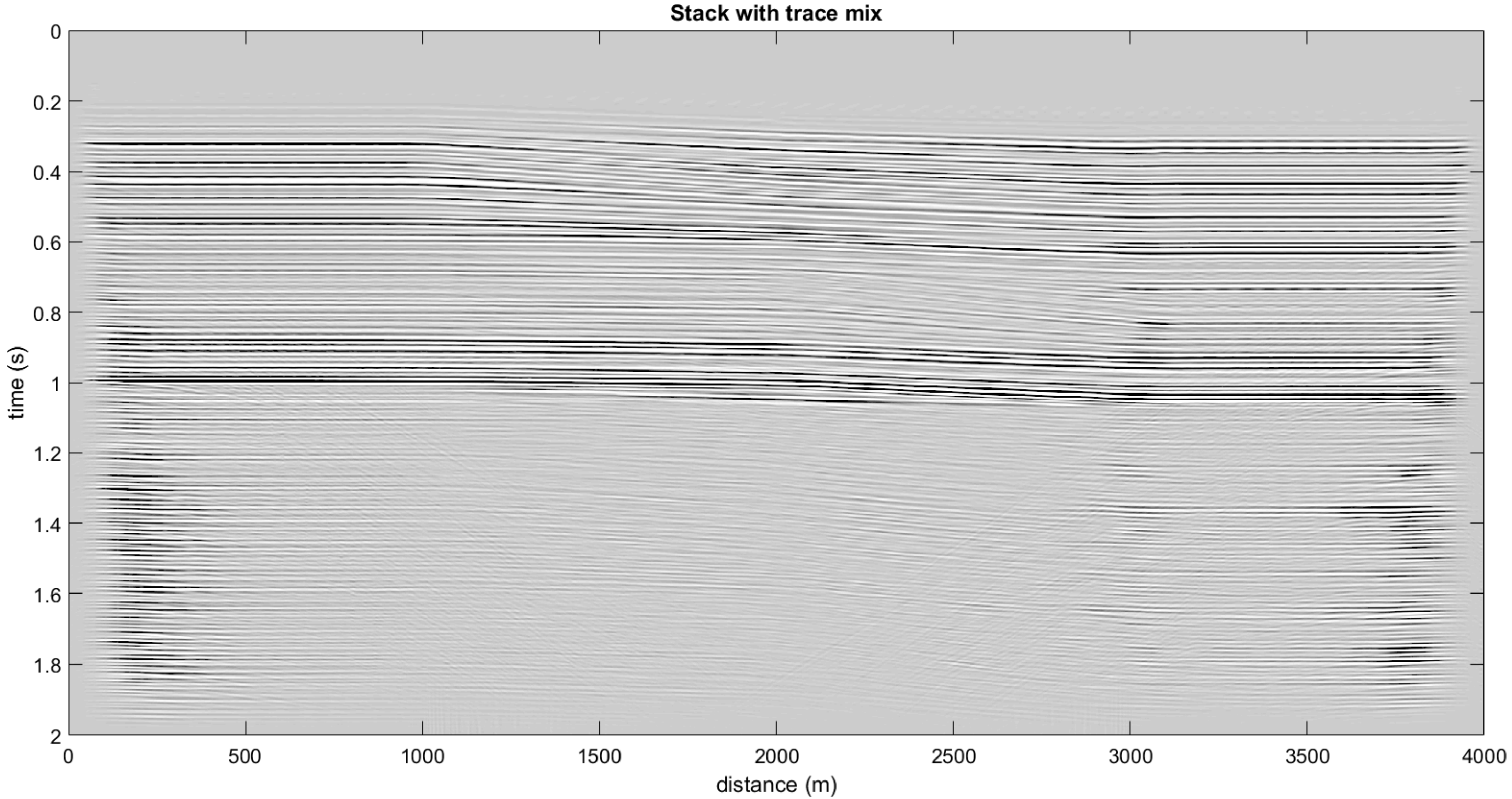
Post-stack IMMI: Final velocity model



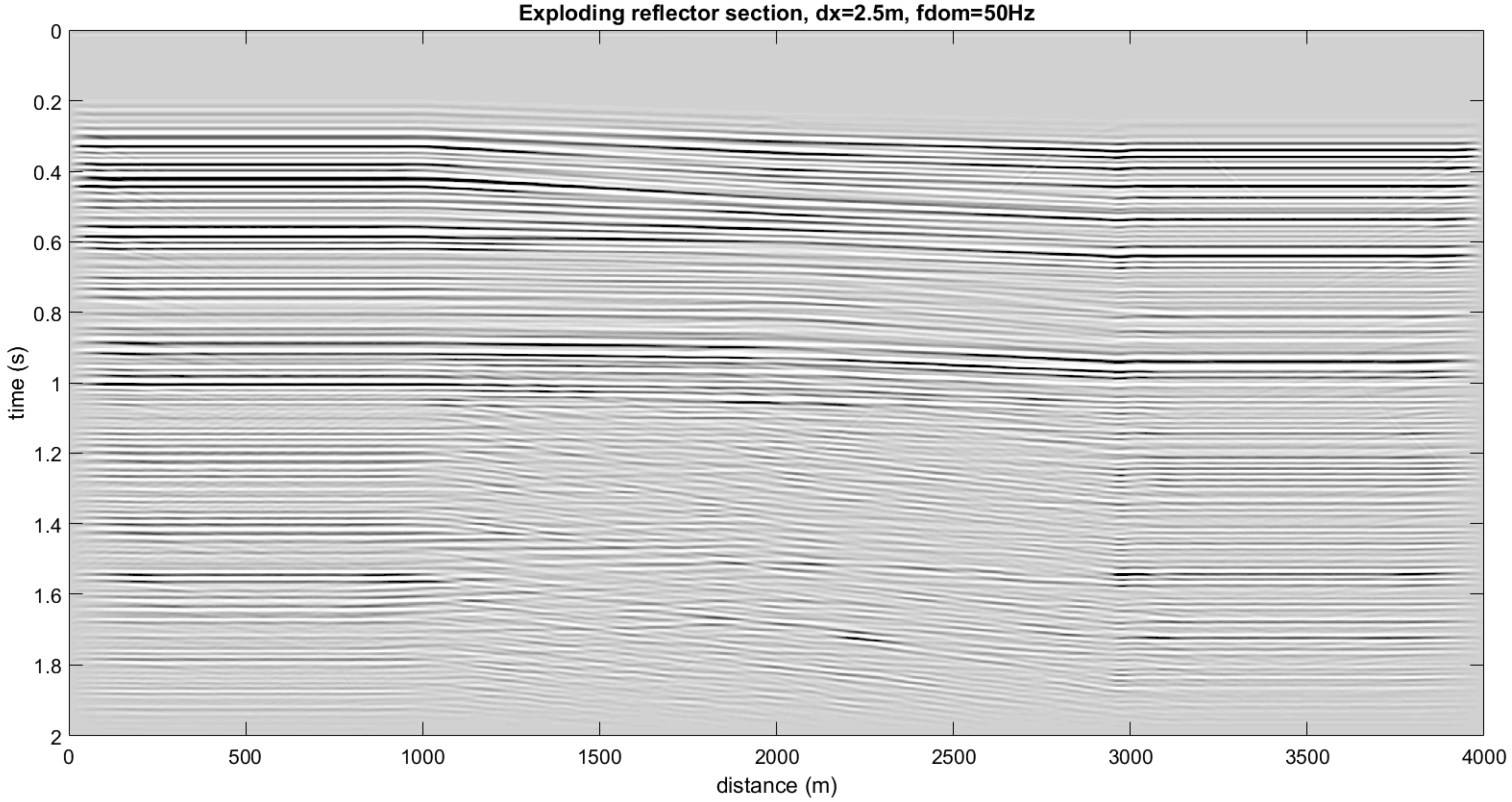
Post-stack IMMI: Example shot record



Post-stack IMMI: CMP stack

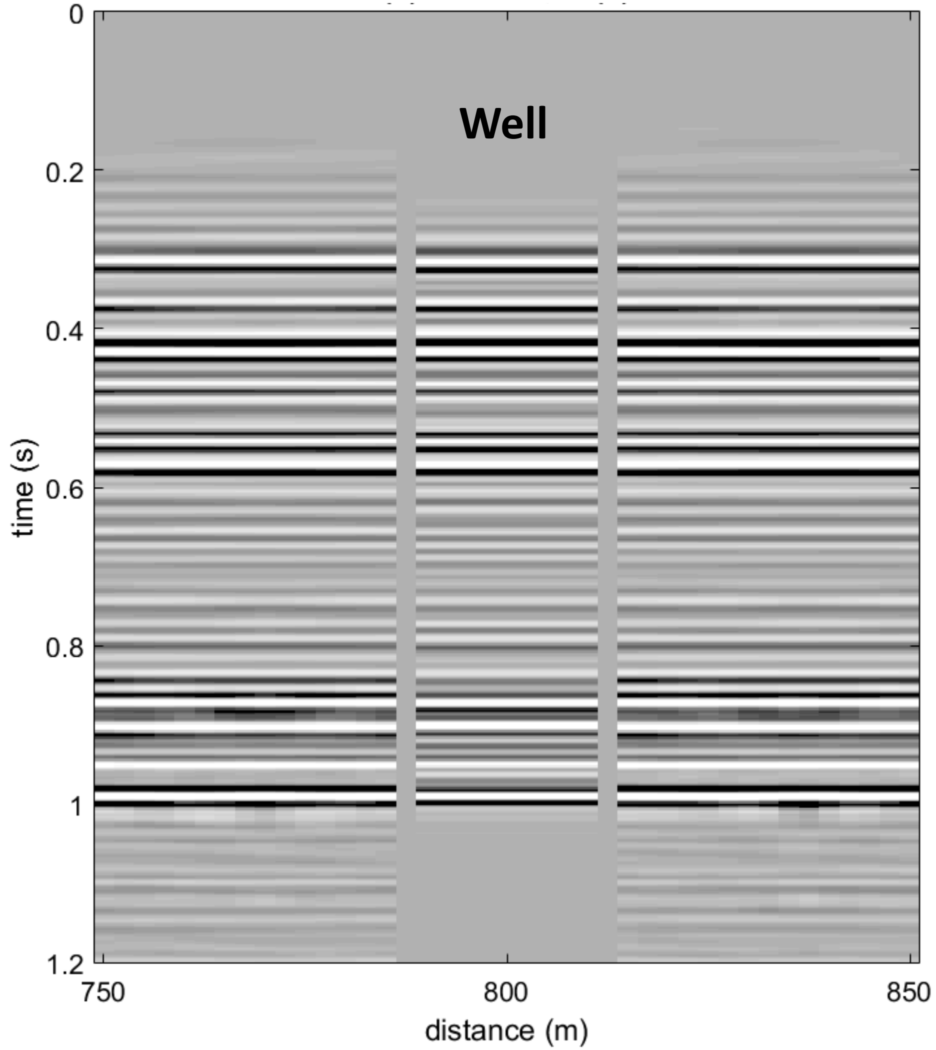


Post-stack IMMI: Exploding reflector section

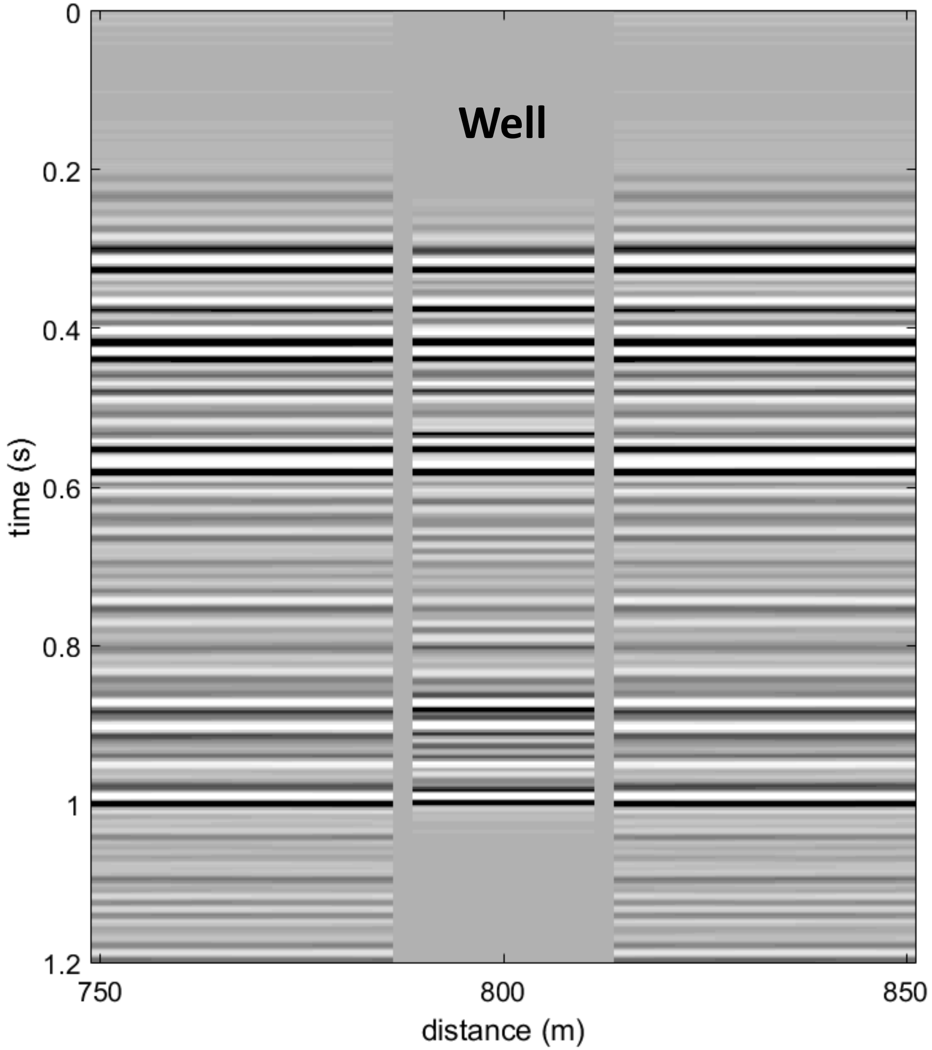


Post-stack IMMI: Matching to well

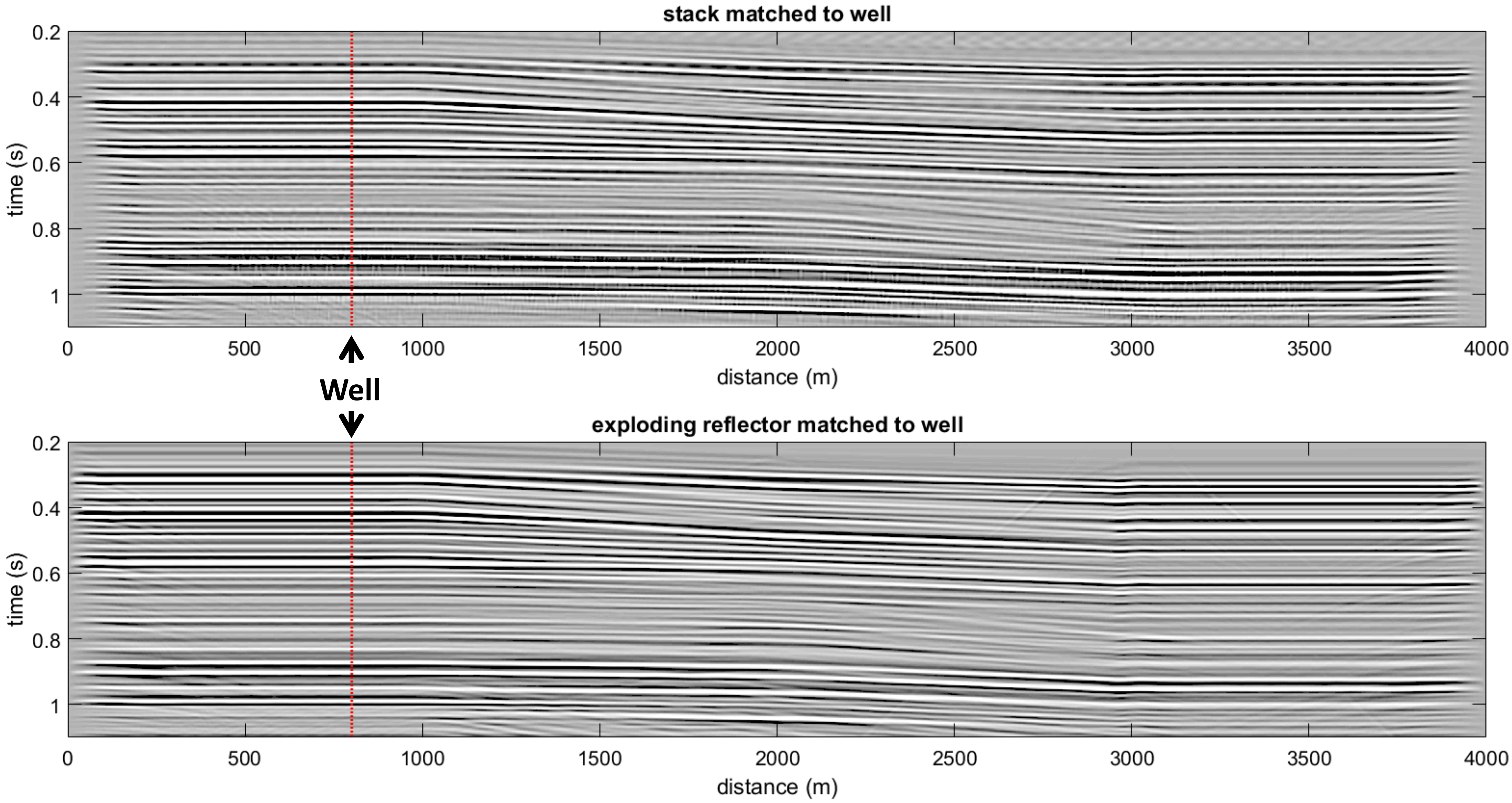
Stack, phs=0^o
cc(1)=0.93016, cc(2)=0



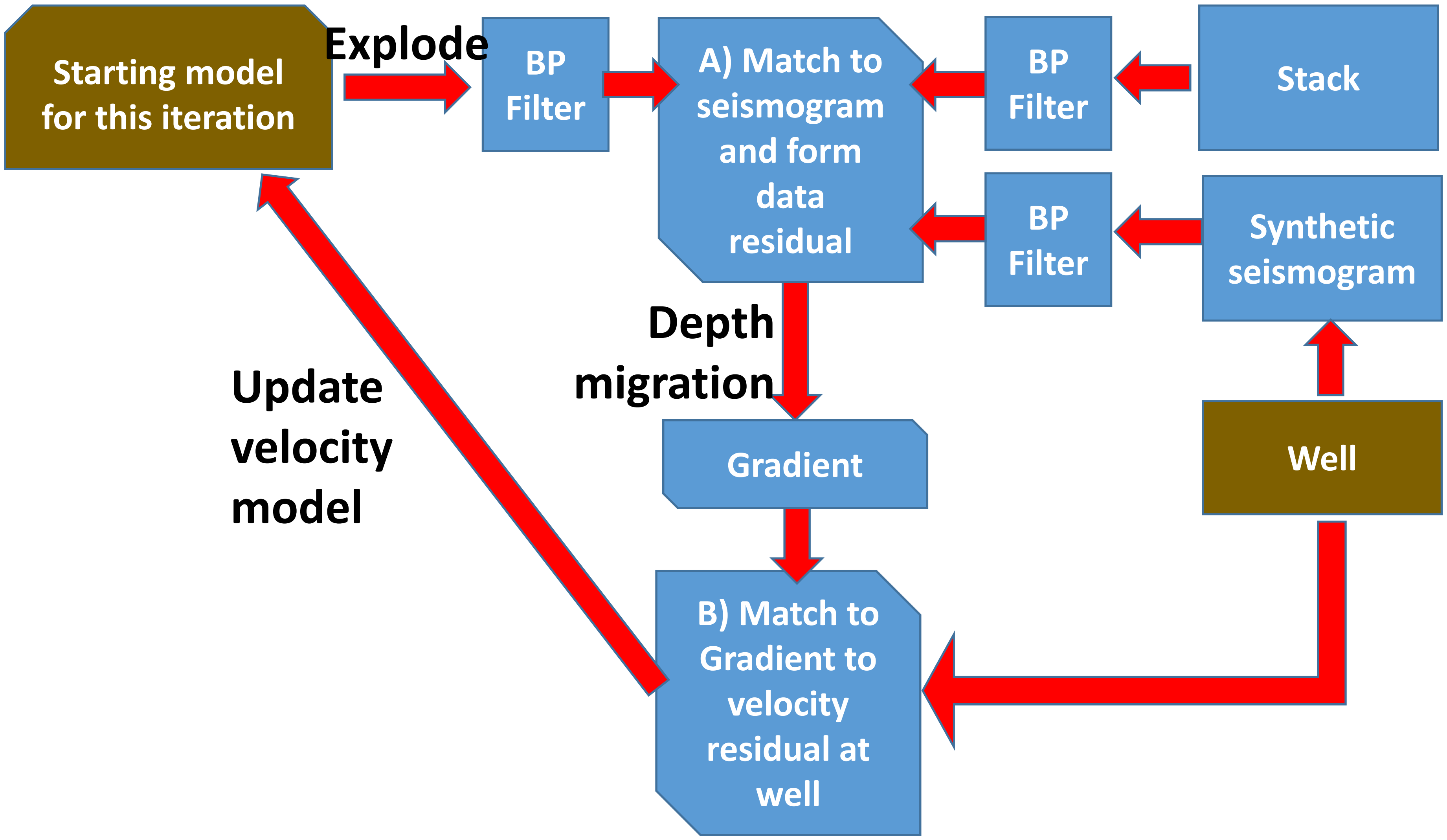
Explode, phs=2^o
cc(1)=0.89984, cc(2)=-0.1



Post-stack IMMI: Stack and Explode after matching



Post-stack IMMI: Post-stack IMMI process



Post-stack IMMI: Converting reflectivity to velocity (impedance)

Conventional FWI (steepest descent) uses

$$v_{k+1} = v_k + aG_k \text{ (icond=2)}$$

where v_k is the velocity model for iteration k, G_k is the “gradient” or migrated data residual, and a is a scalar called the “step length”. This is appropriate if the migration process estimates a velocity or impedance perturbation.

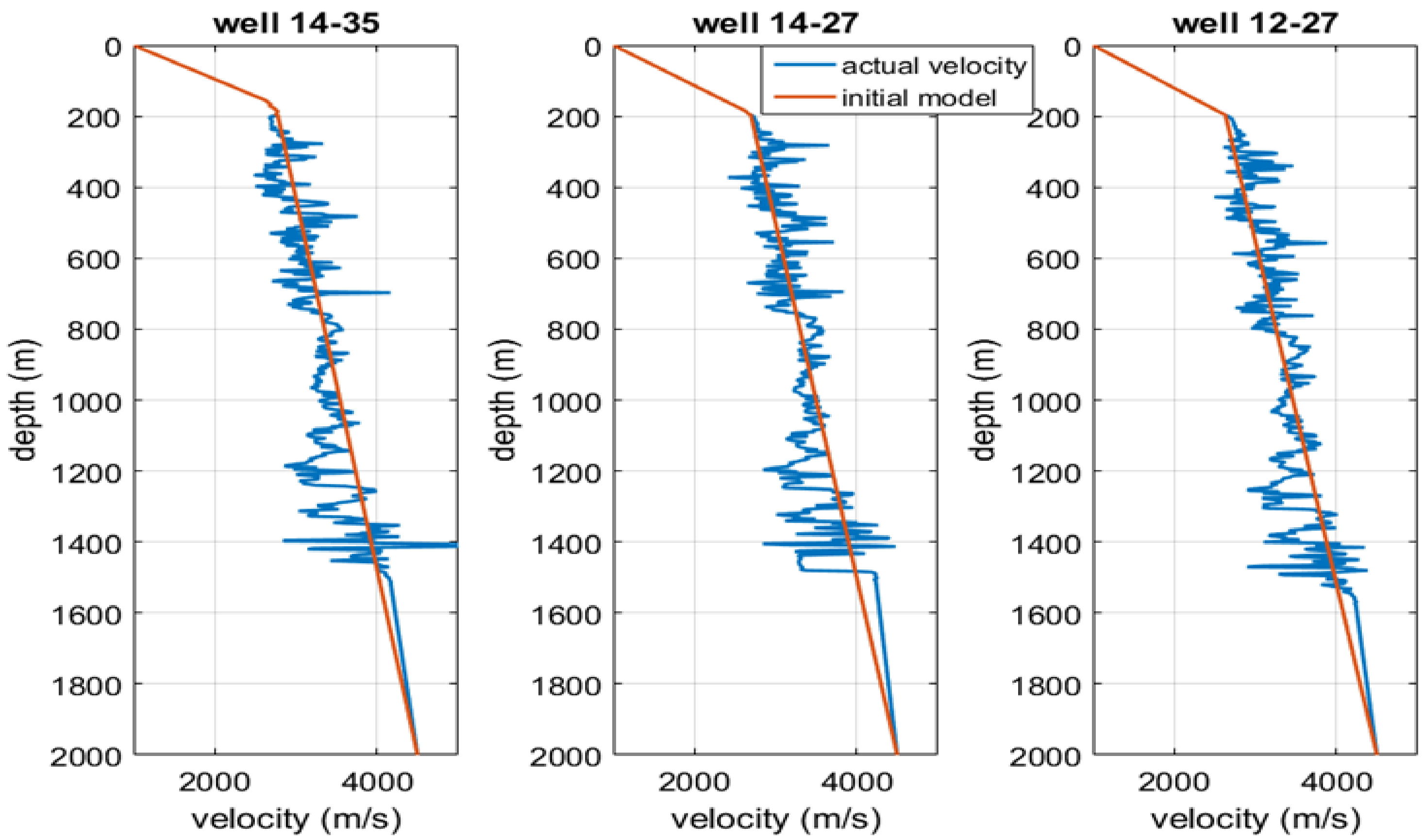
Conventional migrations estimate reflectivity. Using $R_k = \frac{v_{k+1} - v_k}{v_{k+1} - v_k} \approx \frac{\Delta v_k}{2v_k}$, it follows that $v_{k+1} = v_k + \Delta v_k = v_k + 2R_k v_k$. Assuming the migrated data are proportional to reflectivity we then have

$$v_{k+1} = v_k + 2aG_k v_k = v_k(1 + 2aG_k) \text{ (icond=1)}$$

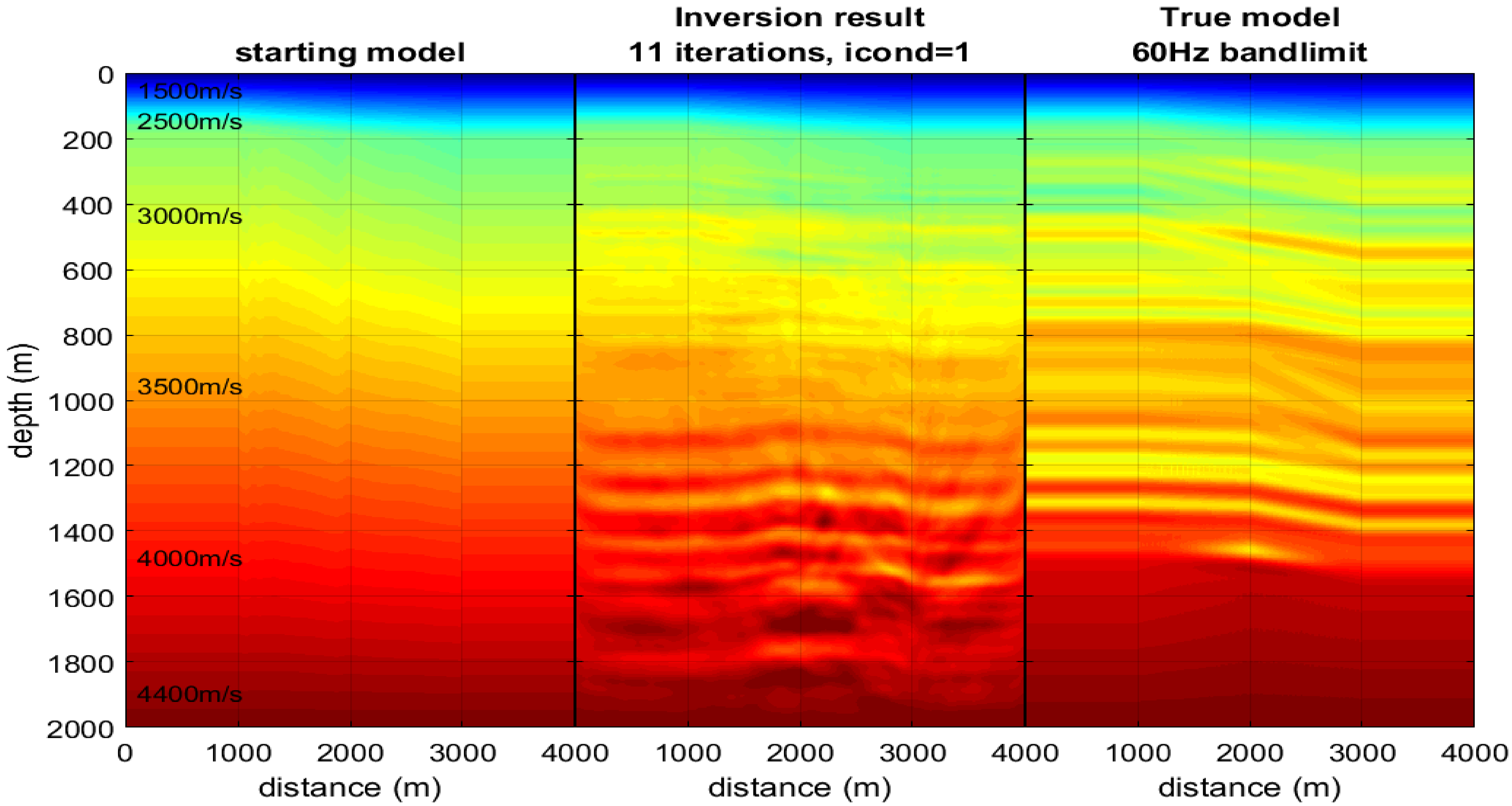
Using either formulation, the scalar a can be determined at a well. Formulae in report.

Post-stack IMMI: Starting Model

The overburden (0-200m) is assumed known through tomography. The initial model then uses a simple linear gradient from the base of the overburden to a value of 4500m/s at 2000m

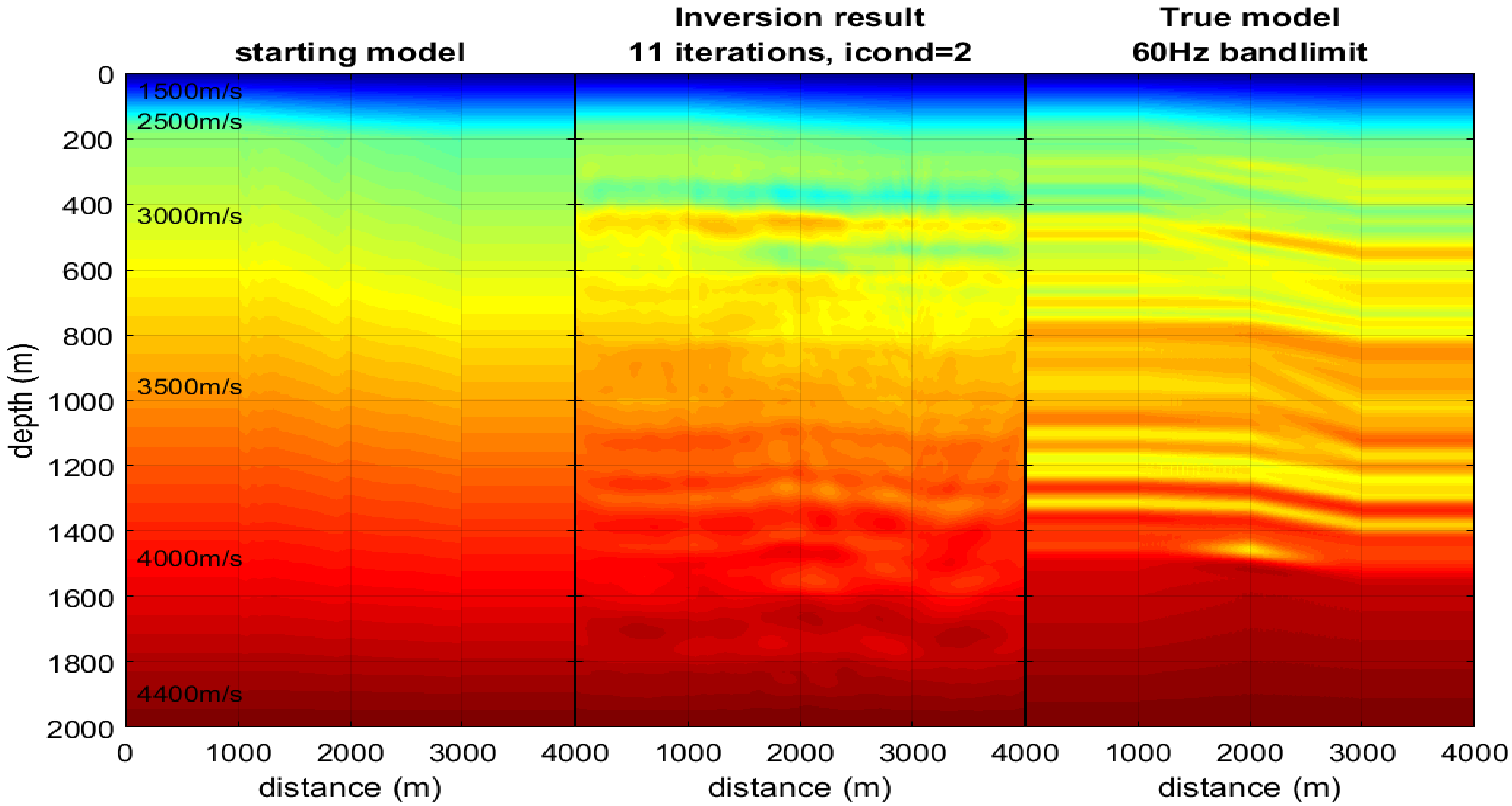


Post-stack IMMI: Best result (icond=1), expanding frequency band



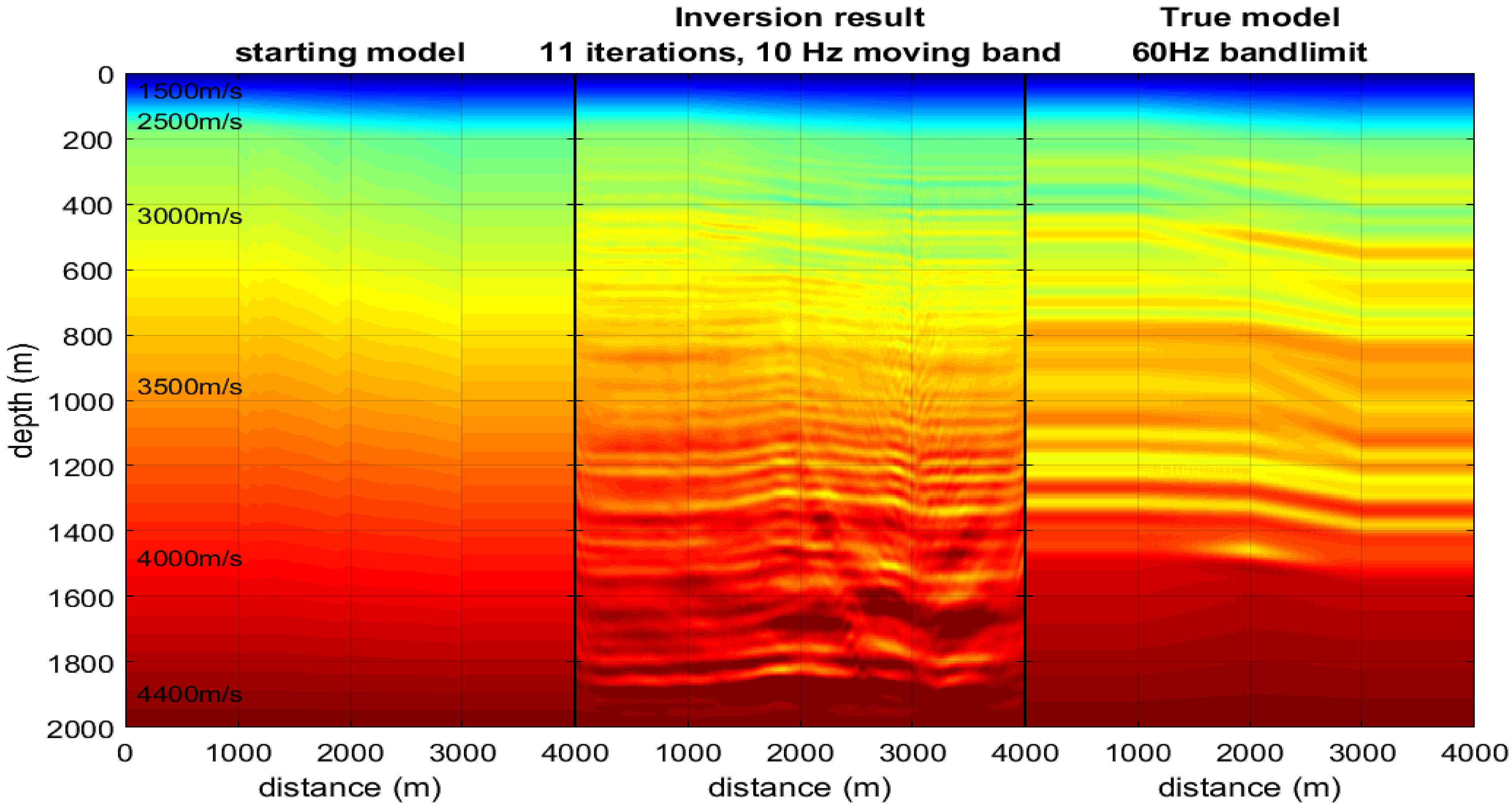
f_{min}	f_{max}
0	10
0	15
0	20
0	25
0	30
0	35
0	40
0	45
0	50
0	55
0	60

Post-stack IMMI: Result (icond=2), expanding frequency band



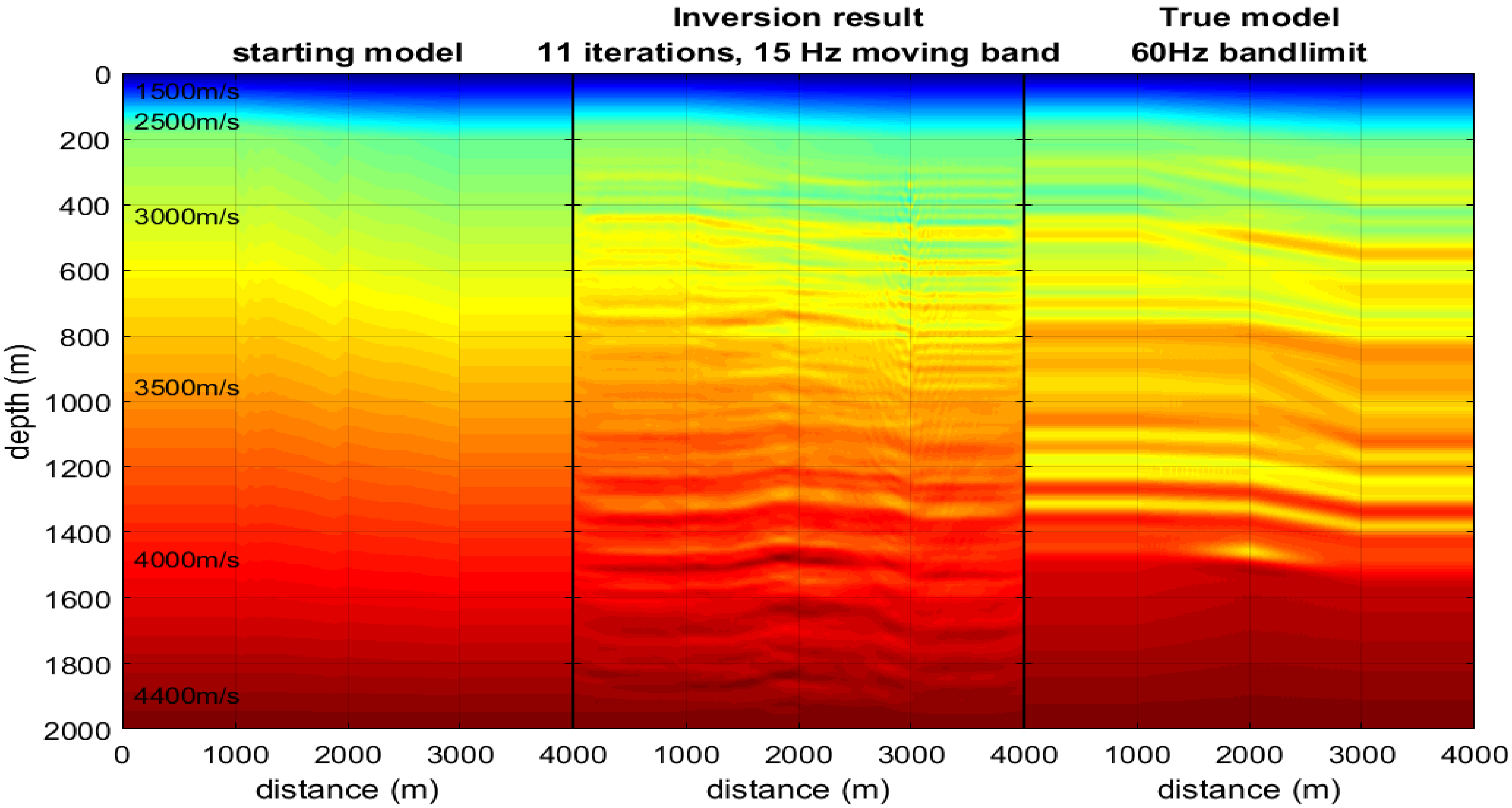
f_{min}	f_{max}
0	10
0	15
0	20
0	25
0	30
0	35
0	40
0	45
0	50
0	55
0	60

Post-stack IMMI: Result (icond=1), 10 Hz moving frequency band



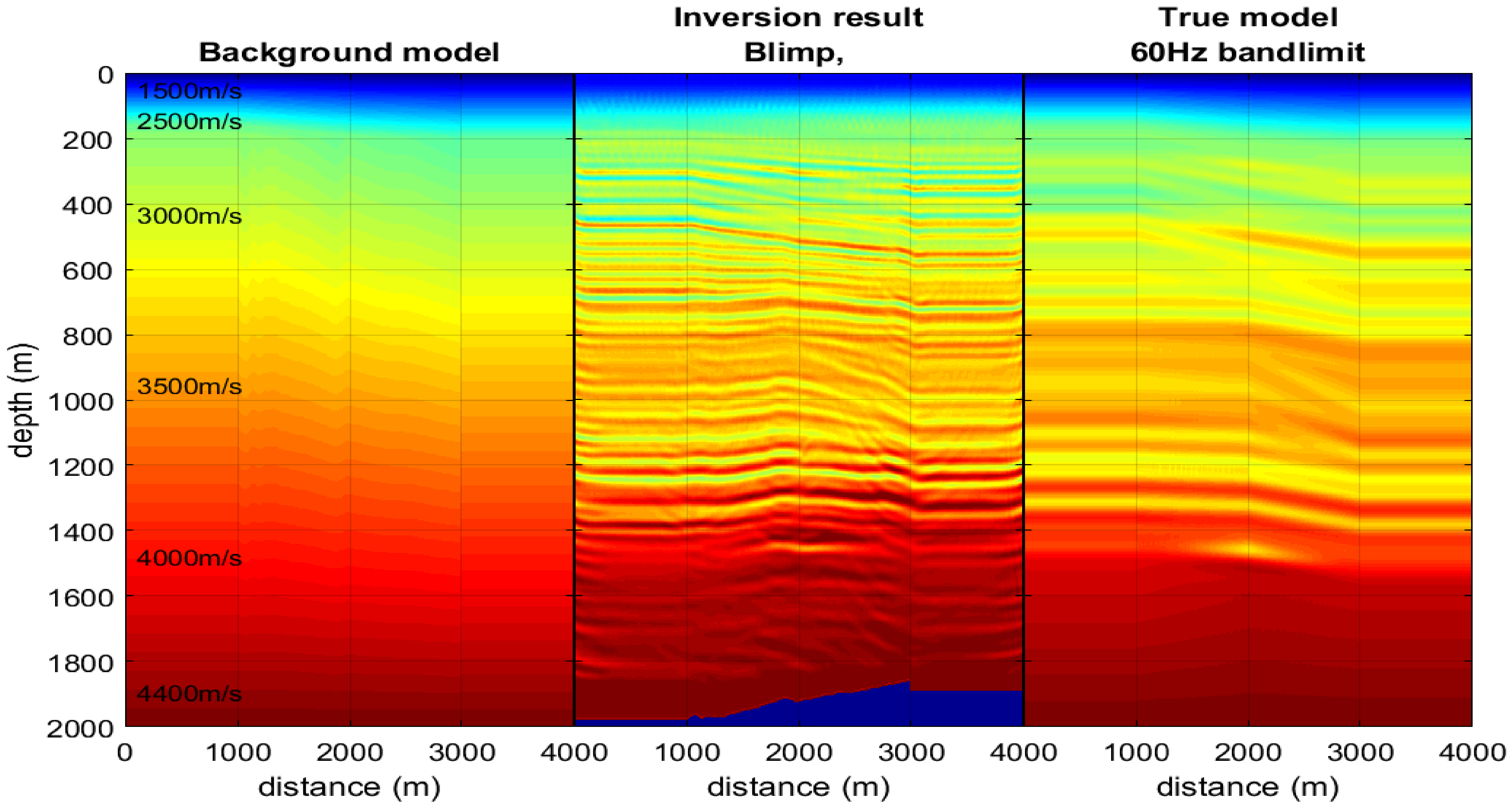
f_{min}	f_{max}
0	10
5	15
10	20
15	25
20	30
25	35
30	40
35	45
40	50
45	55
50	60

Post-stack IMMI: Result (icond=1), 15 Hz moving frequency band



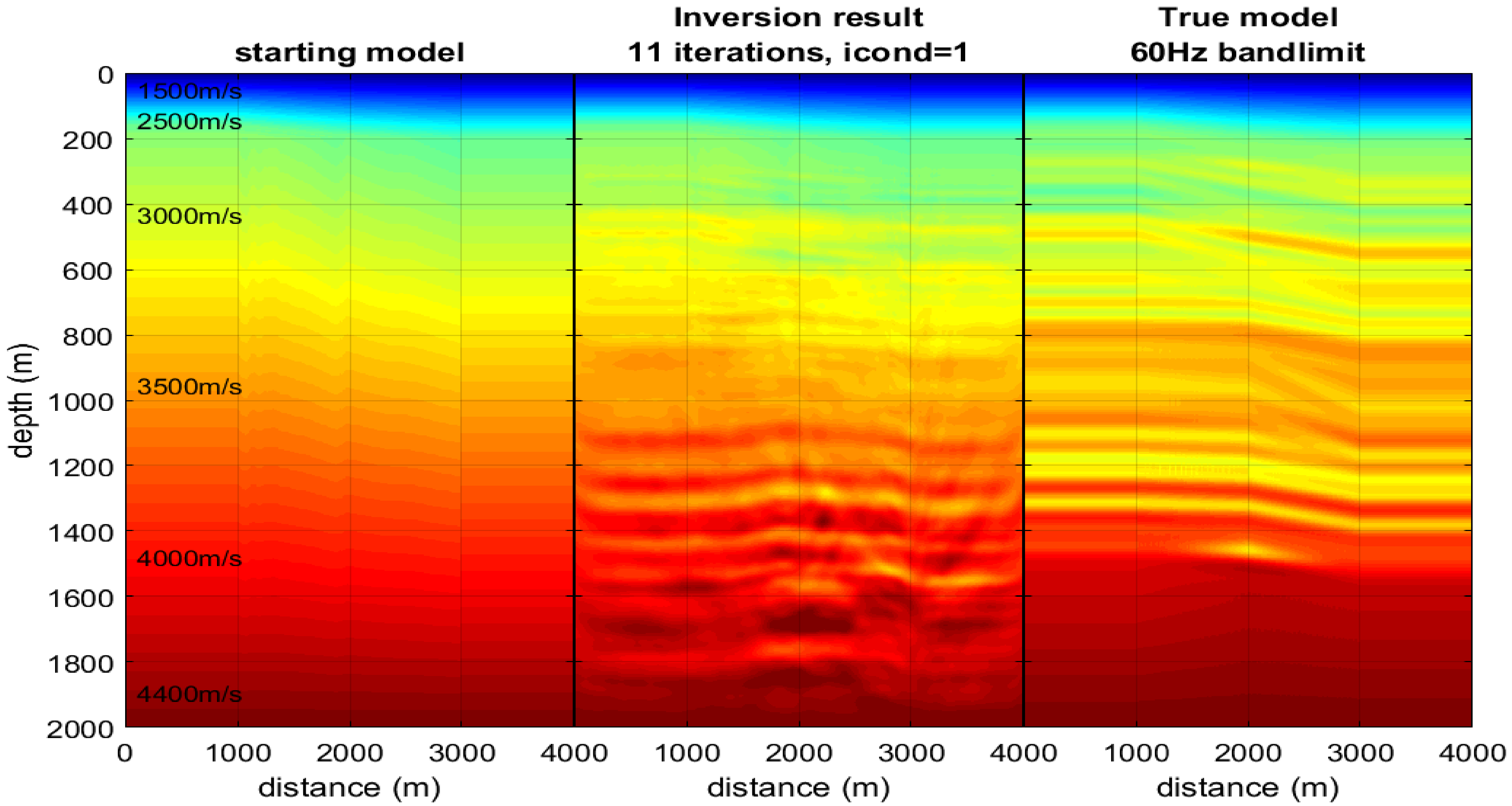
f_{min}	f_{max}
0	15
5	20
10	25
15	30
20	35
25	40
30	45
35	50
40	55
45	60
50	65

Post-stack IMMI: Blimp (Band-limited impedance inversion)



3 Hz cutoff frequency

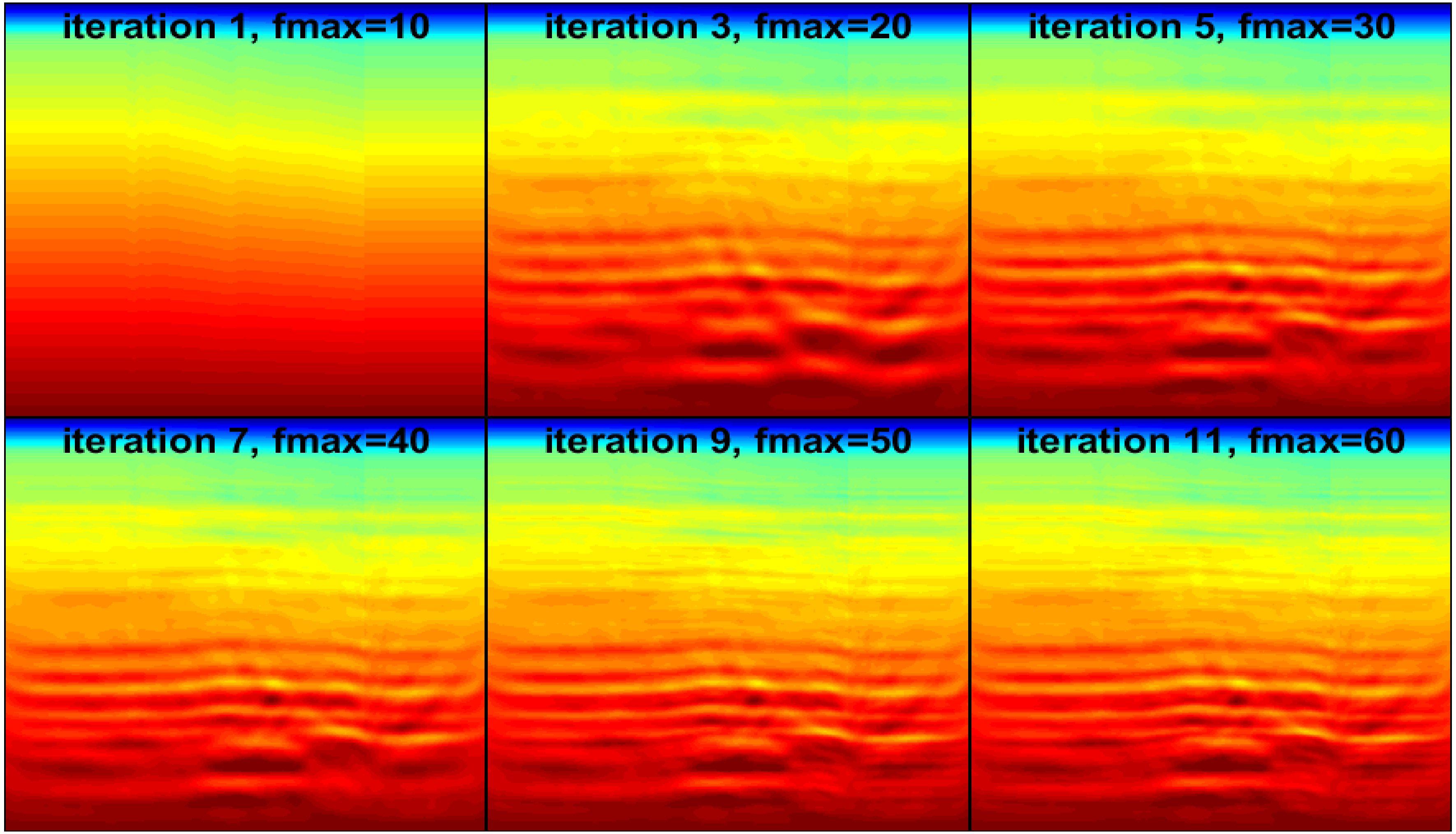
Post-stack IMMI: Best result (icond=1), expanding frequency band



f_{min}	f_{max}
0	10
0	15
0	20
0	25
0	30
0	35
0	40
0	45
0	50
0	55
0	60

Post-stack IMMI: Best result (icond=1), expanding frequency band

Evolution of the velocity model with iteration



f_{min}	f_{max}
0	10
0	15
0	20
0	25
0	30
0	35
0	40
0	45
0	50
0	55
0	60

Post-stack IMMI: Conclusions

- **Post-stack IMMI appears to be possible at least for P-P reflectivity.**
- **The present method appears to stop improving after only a few iterations.**
- **Resolution should be better.**
- **Simplicity of the approach suggests this may be a good way to study IMMI (or FWI).**
- **This also reveals the underlying simplicity of IMMI/FWI.**
- **If successful, the result would be an initial prestack depth migration model.**

Acknowledgements

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Thank you for your attention.