Imperial College London

Centre for Reservoir Geophysics

Seismic waveform tomography

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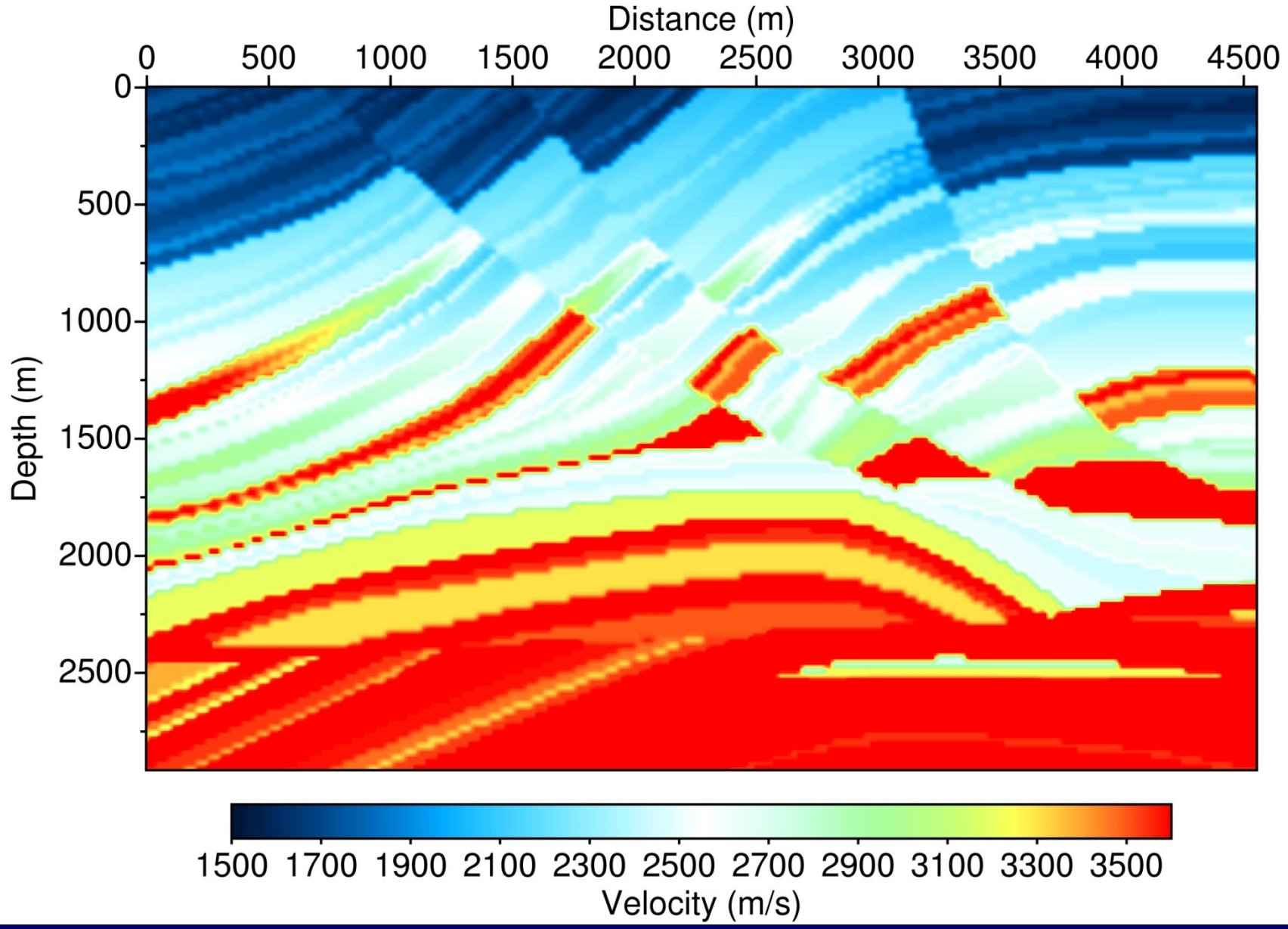
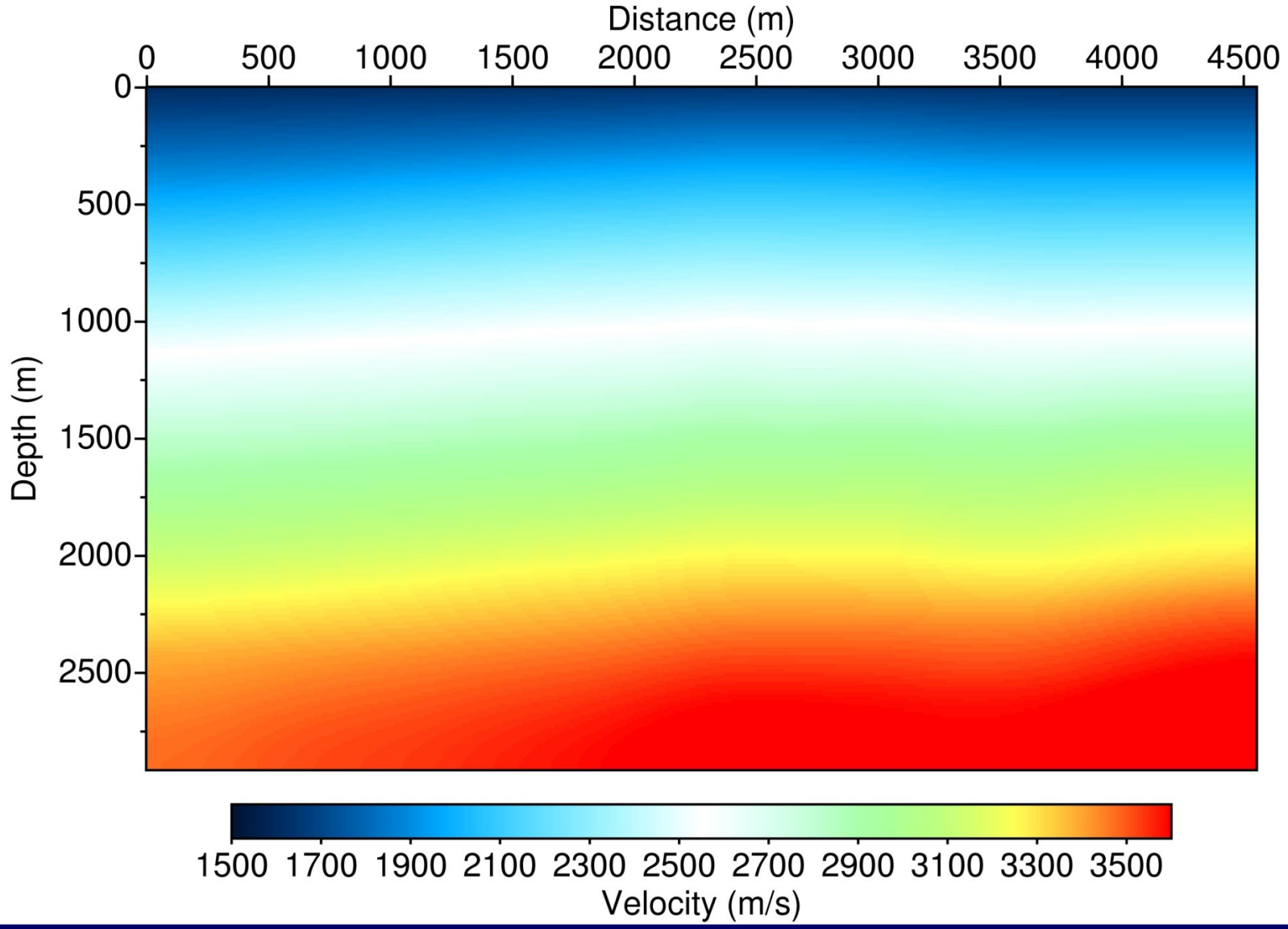
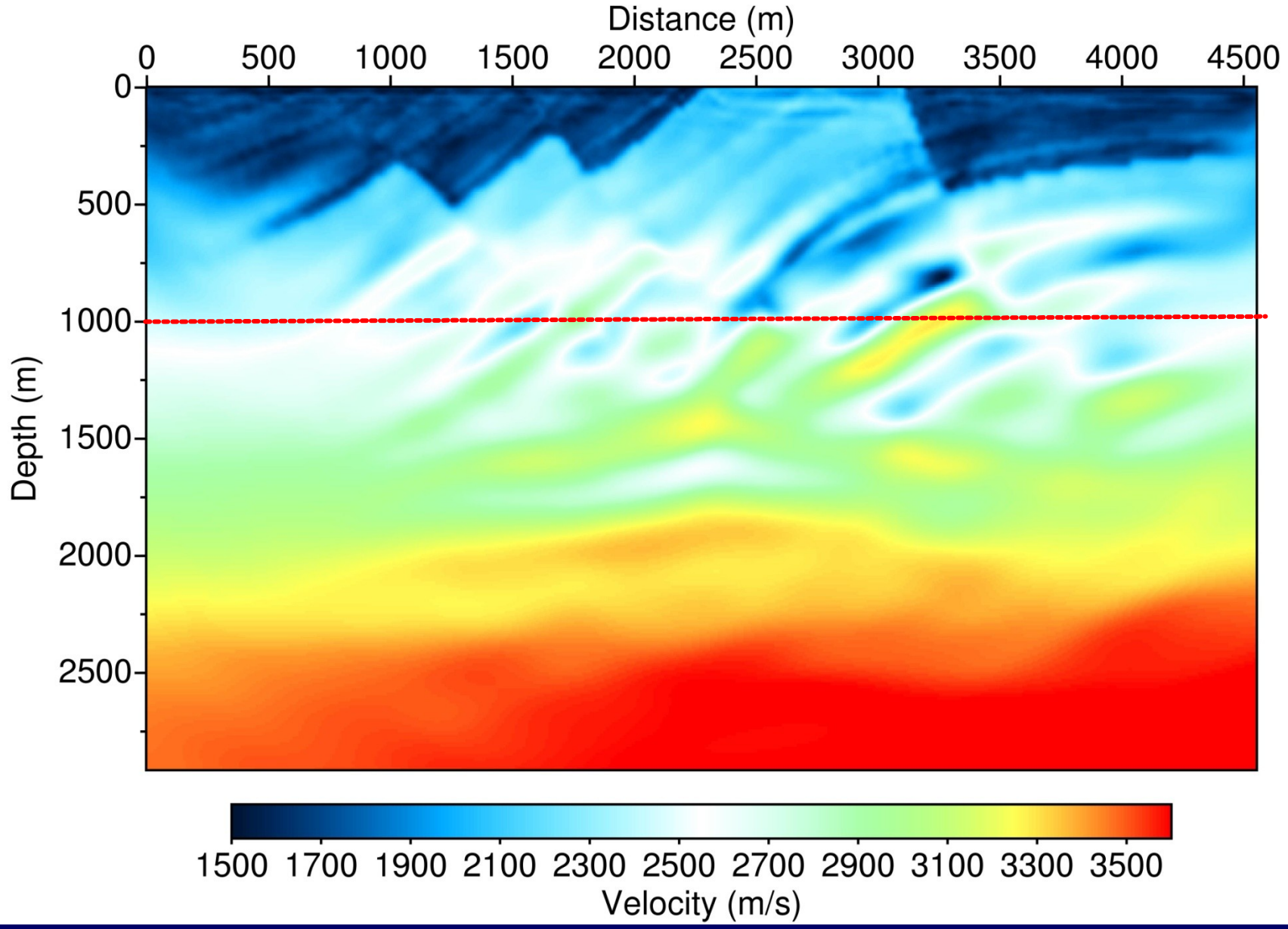
- Chair Professor in Reservoir Geophysics
- Director, Centre for Reservoir Geophysics

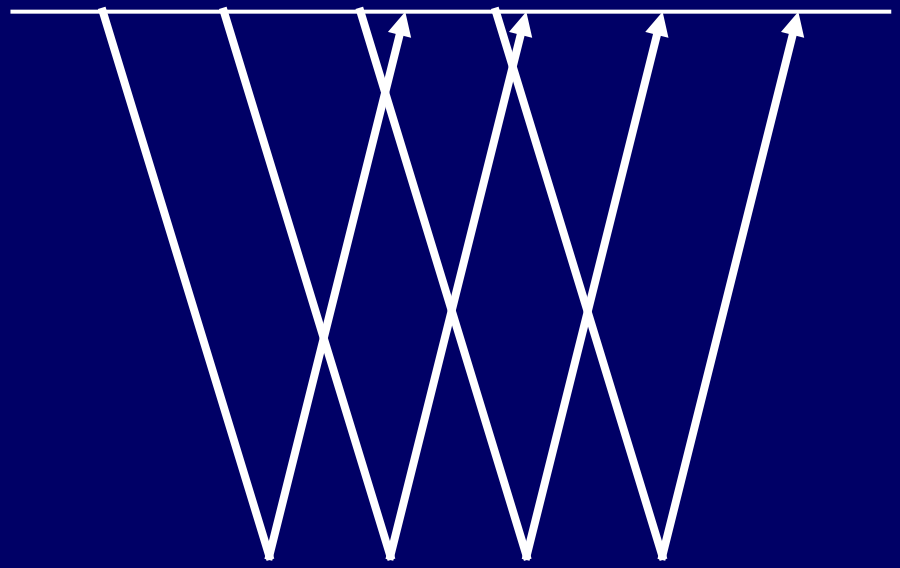

Distance (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Depth (m)
0
500
1000
1500
2000
2500
1500 1700 1900 2100 2300 2500 2700 2900 3100 3300 3500
Velocity (m/s)


Distance (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Depth (m)
0
500
1000
1500
2000
2500
1500 1700 1900 2100 2300 2500 2700 2900 3100 3300 3500
Velocity (m/s)


Distance (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Depth (m)
0
500
1000
1500
2000
2500
1500 1700 1900 2100 2300 2500 2700 2900 3100 3300 3500
Velocity (m/s)

Reflection waveform tomography

In seismic waveform tomography, if using reflection data with limited source-receiver offsets, it is difficult to reconstruct the deep part of the subsurface velocity model.



Weighted Updating Scheme

By definition, tomography is an integral along the ray path; that is, data residuals are spread evenly along the ray path.

The residual projected to a cell is then linearly related to the model update of the cell, and thus the model update depends upon the total length of ray segments within the cell, i.e. the ray density.

Weighted Updating Scheme

Since the ray density in the shallow depth is much higher than that in deeper parts of the model, the model update in the shallow depth is much higher than that in the deep portion of the model.

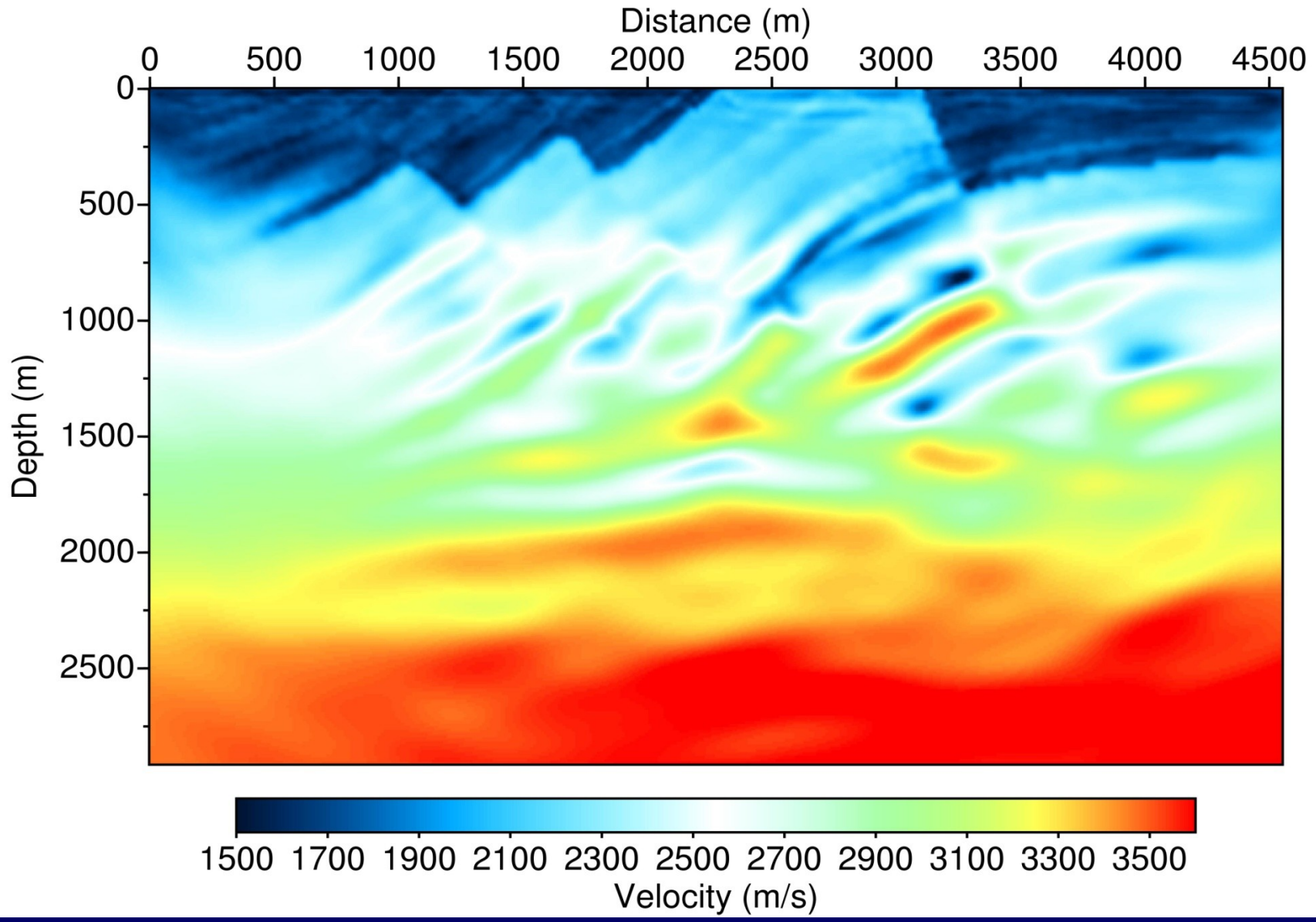
This is a underlying rationale for using depth-dependent weights in model updating.

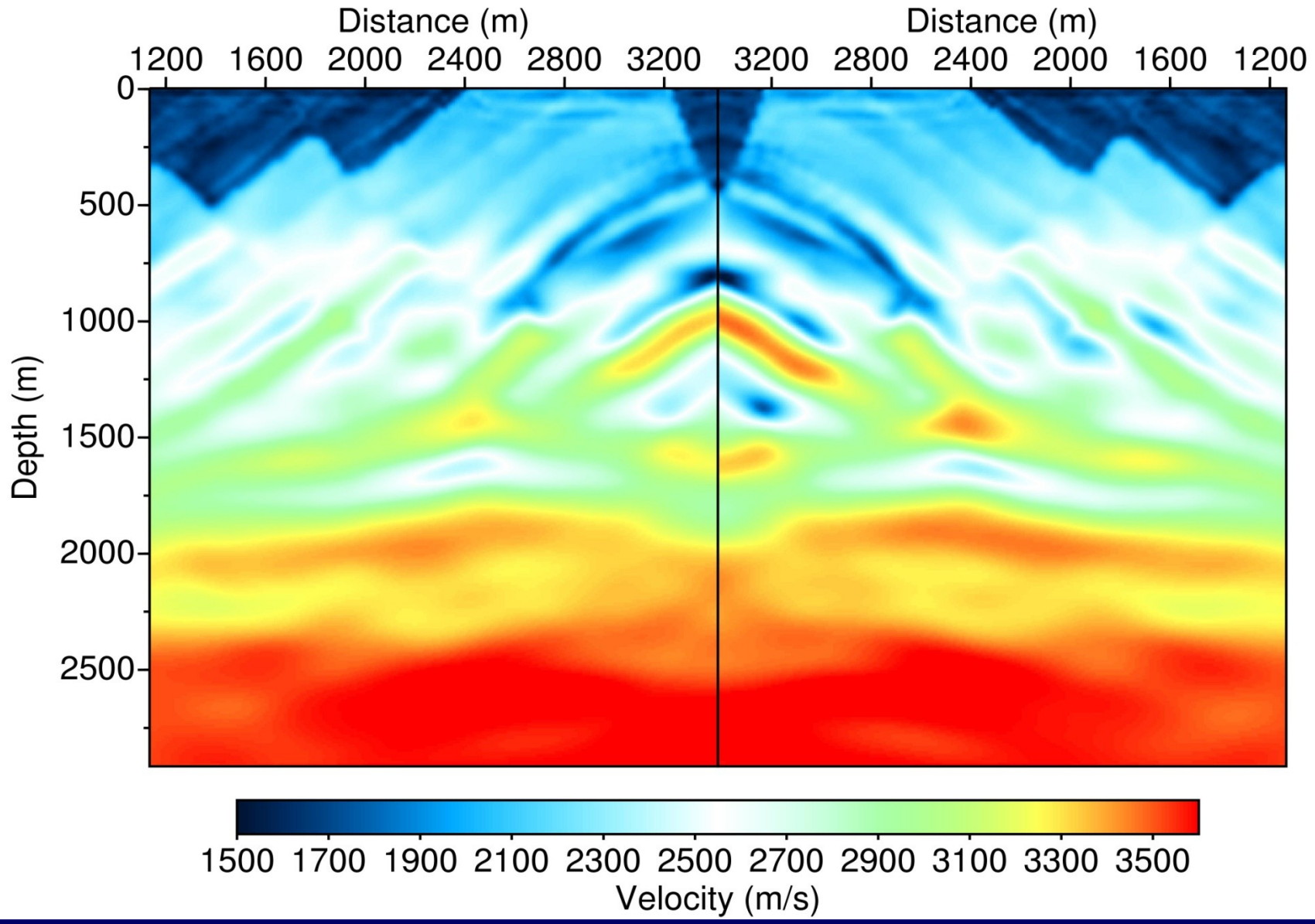
Weighted Updating Scheme

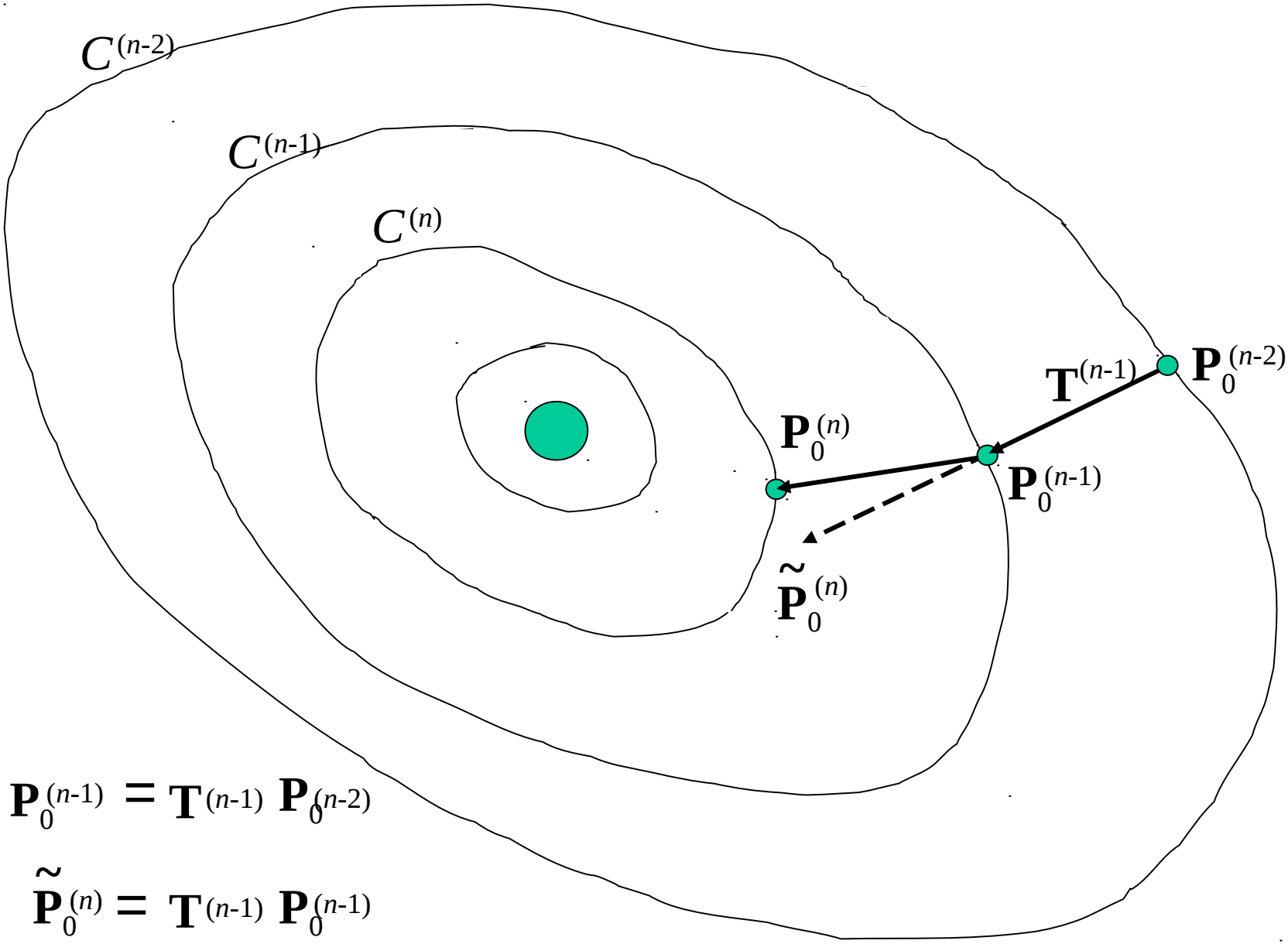
$$\mathbf{m}^{(\ell+1)} = \mathbf{m}^{(\ell)} - \alpha\boldsymbol{\gamma}$$

$$\mathbf{m}^{(\ell+1)} = \mathbf{m}^{(\ell)} - \alpha\mathbf{H}^{-1}\boldsymbol{\gamma}$$

$$\mathbf{m}^{(\ell+1)} = \mathbf{m}^{(\ell)} - \alpha\beta(z)\boldsymbol{\gamma}$$

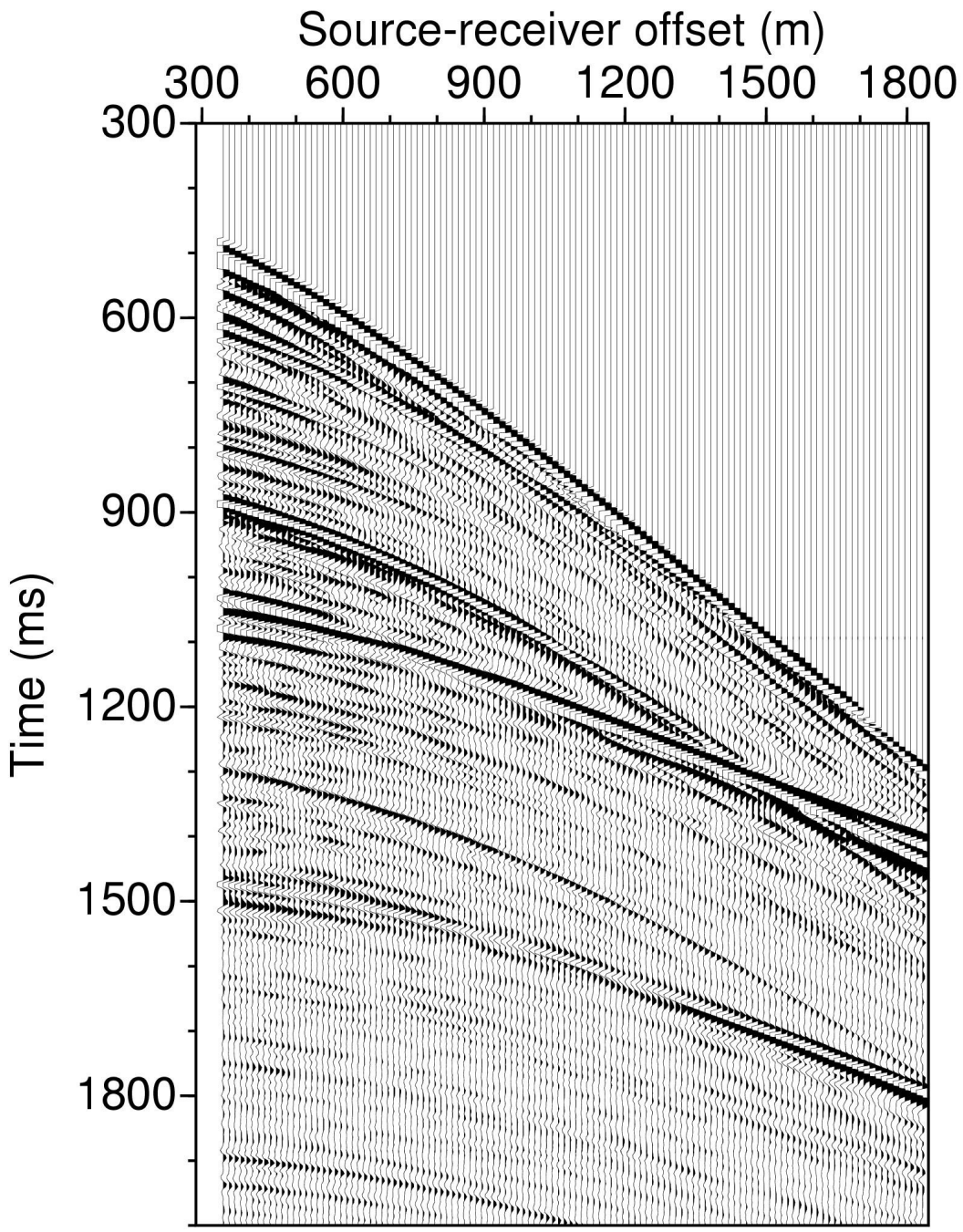

Distance (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Depth (m)
0
500
1000
1500
2000
2500
1500 1700 1900 2100 2300 2500 2700 2900 3100 3300 3500
Velocity (m/s)

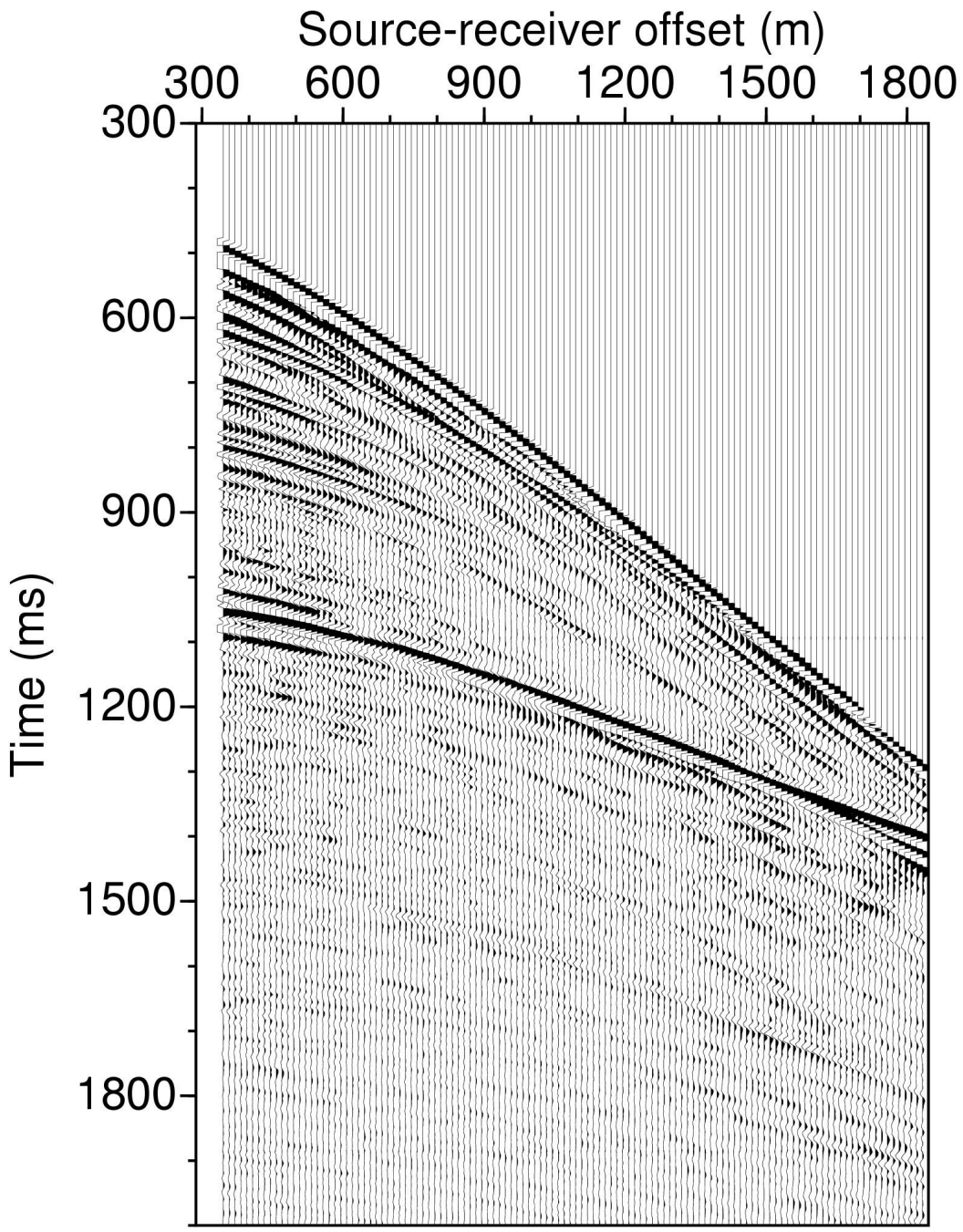

Distance (m)
1200 1600 2000 2400 2800 3200
Distance (m)
3200 2800 2400 2000 1600 1200
0
500
1000
1500
2000
2500
Depth (m)
1500 1700 1900 2100 2300 2500 2700 2900 3100 3300 3500
Velocity (m/s)

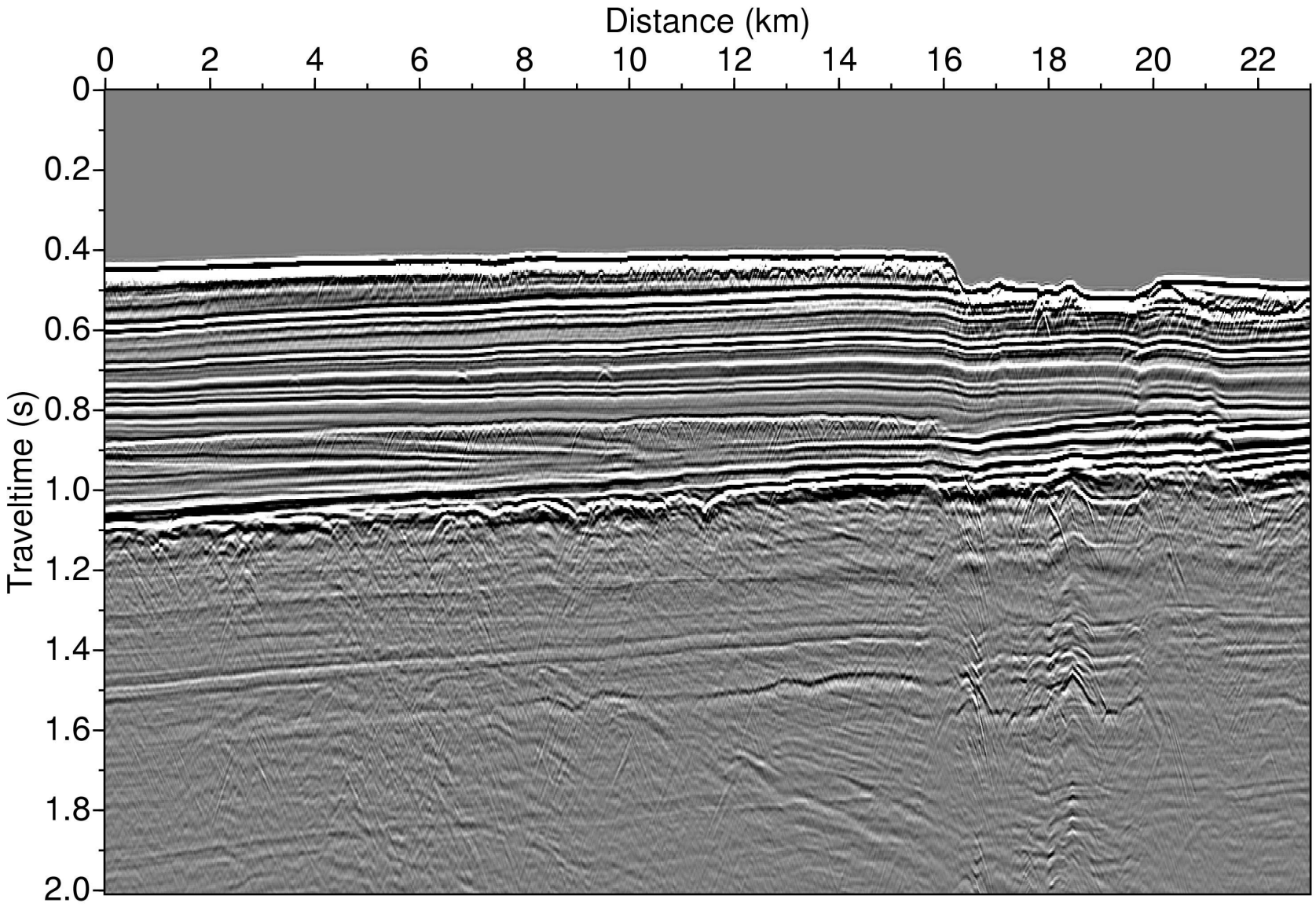


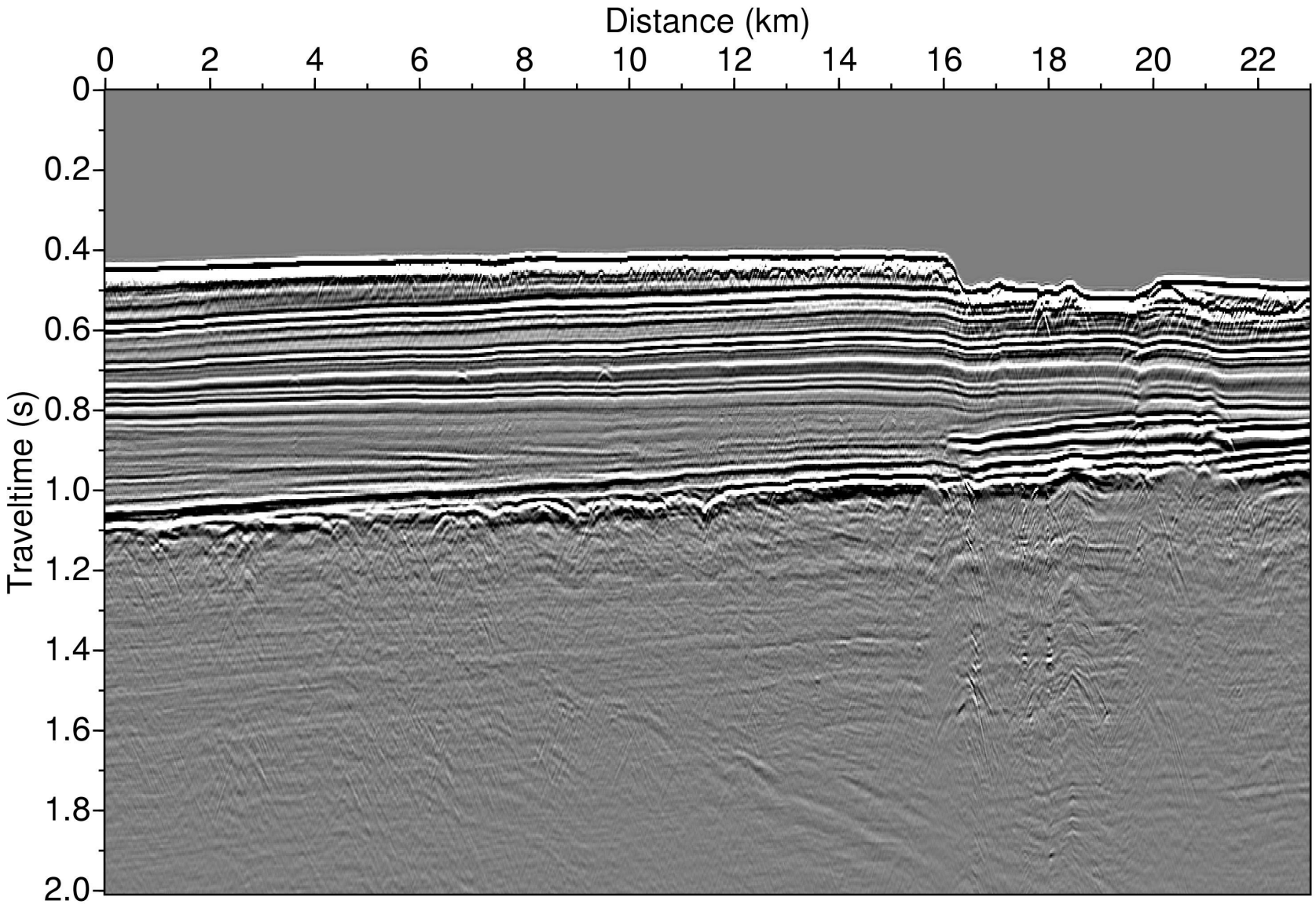
$$\mathbf{P}_0^{(n-1)} = \mathbf{T}^{(n-1)}\,\mathbf{P}_0^{(n-2)}$$

$$\tilde{\mathbf{P}}_0^{(n)} = \mathbf{T}^{(n-1)}\,\mathbf{P}_0^{(n-1)}$$

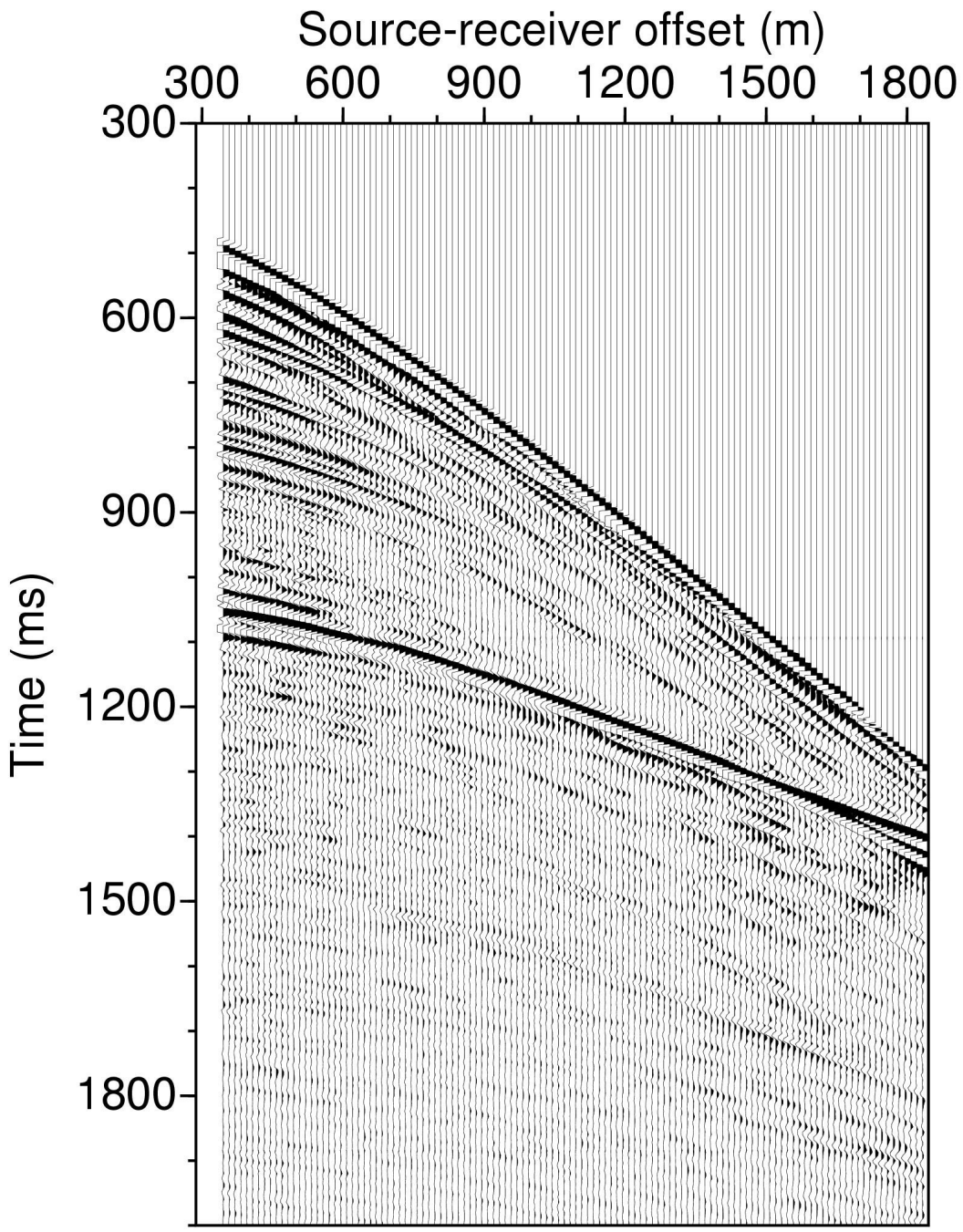

Source-receiver offset (m)
300
600
900
1200
1500
1800
Time (ms)
300
600
900
1200
1500
1800

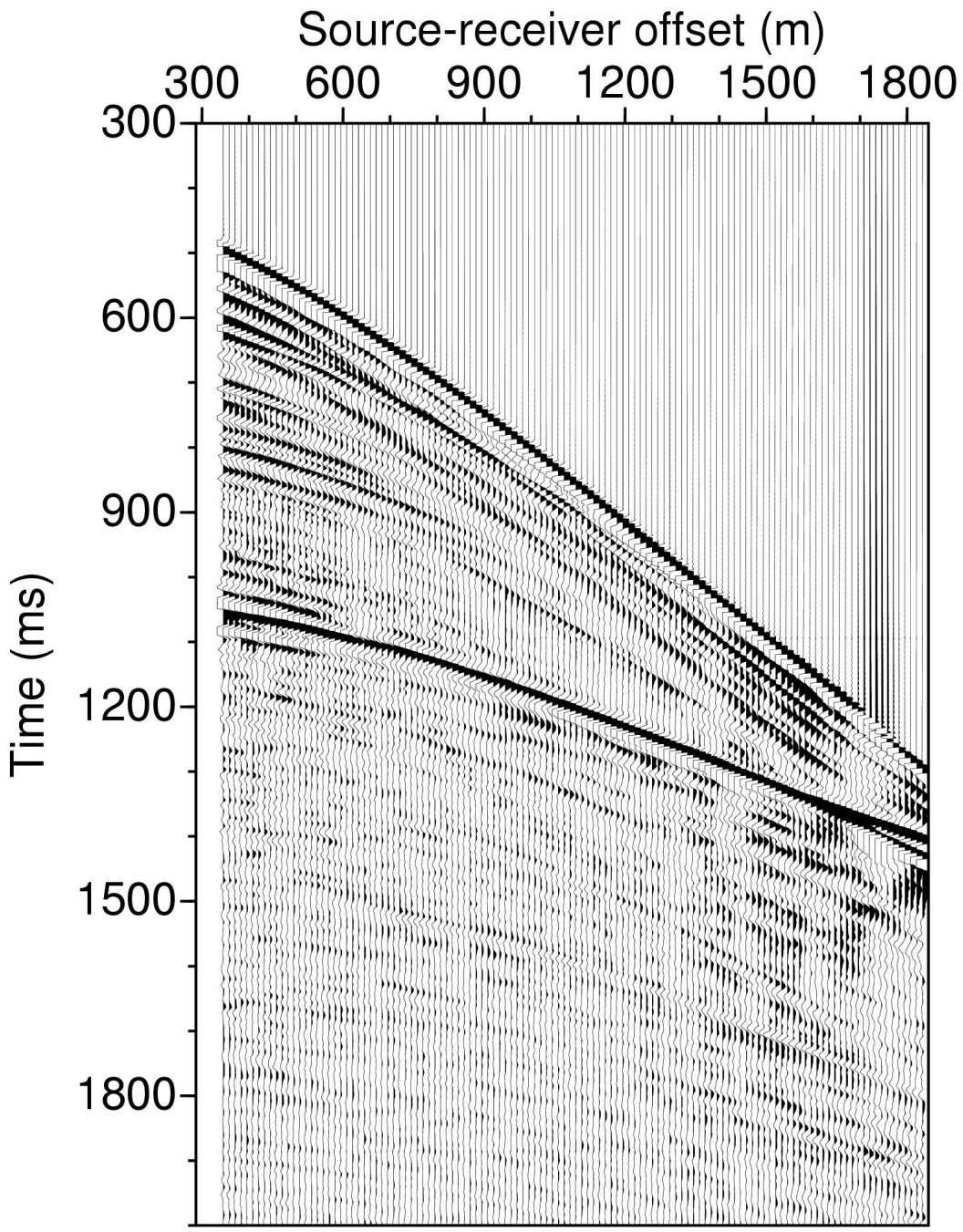

Source-receiver offset (m)
300
600
900
1200
1500
1800
Time (ms)
300
600
900
1200
1500
1800


Distance (km)
0
2
4
6
8
10
12
14
16
18
20
22
Traveltime (s)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0



Multiple attenuation


Source-receiver offset (m)
300
600
900
1200
1500
1800
Time (ms)
300
600
900
1200
1500
1800


Source-receiver offset (m)
300
600
900
1200
1500
1800
Time (ms)
300
600
900
1200
1500
1800

2D

$$G_{2D}(\mathbf{r},\mathbf{r}_s,\omega)=\left(\frac{-\mathrm{i}c}{8\pi\omega R}\right)^{1/2}\exp\left(-\mathrm{i}\omega\frac{R}{c}\right)$$

3D

$$G_{3D}(\mathbf{r},\mathbf{r}_s,\omega)=\frac{1}{4\pi R}\exp\left(-\mathrm{i}\omega\frac{R}{c}\right)$$

Partial compensation

$$W(\omega)=\sqrt{\frac{2\pi Rc}{\mathrm{i}\omega}}$$

(frequency domain)

$$W(t)=D_{-1/2}(t)\sqrt{2\pi Rc}$$

(time domain)

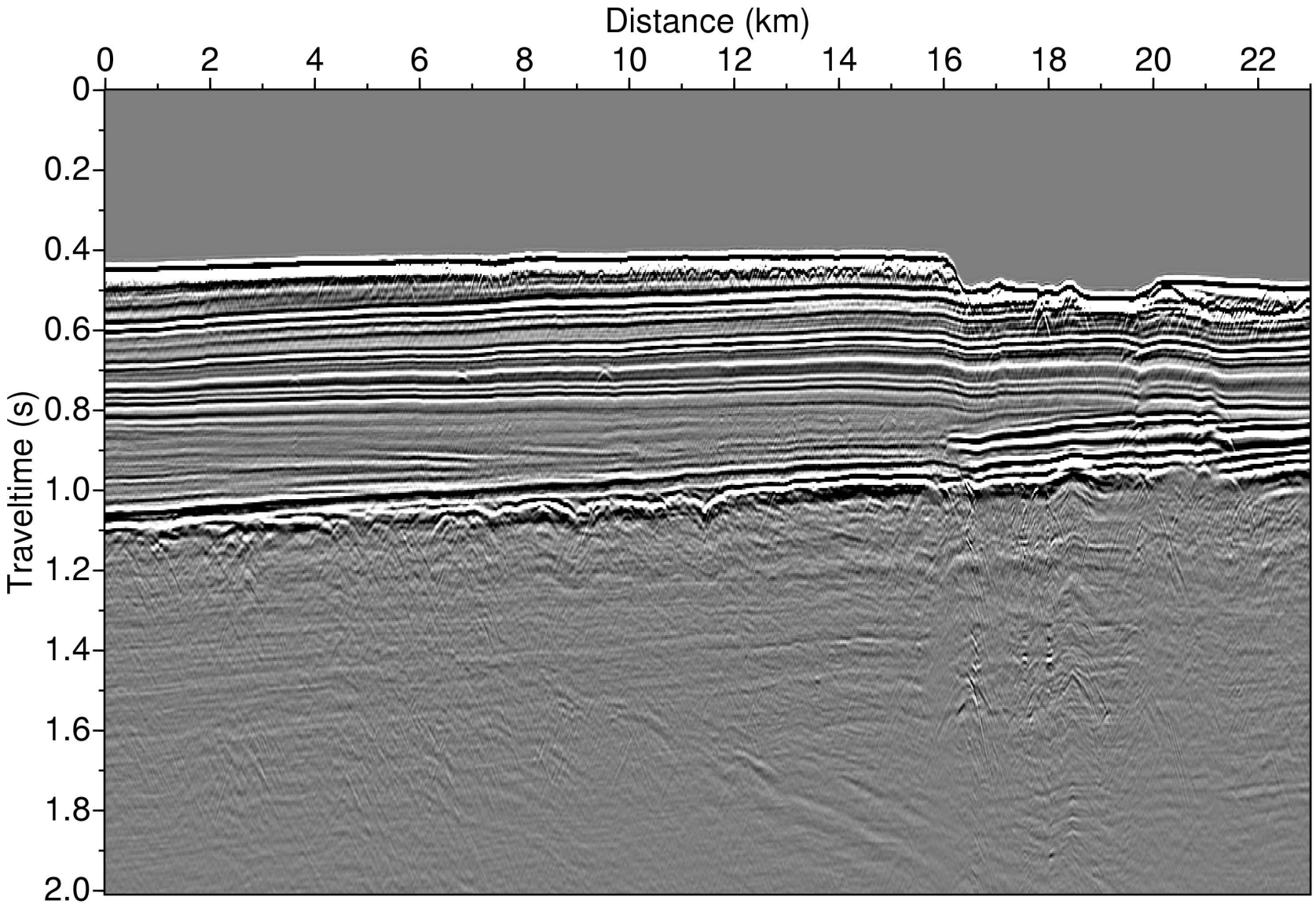
Partial compensation

$$W(t) \propto D_{-1/2}(t)\, c(t) \sqrt{t}$$

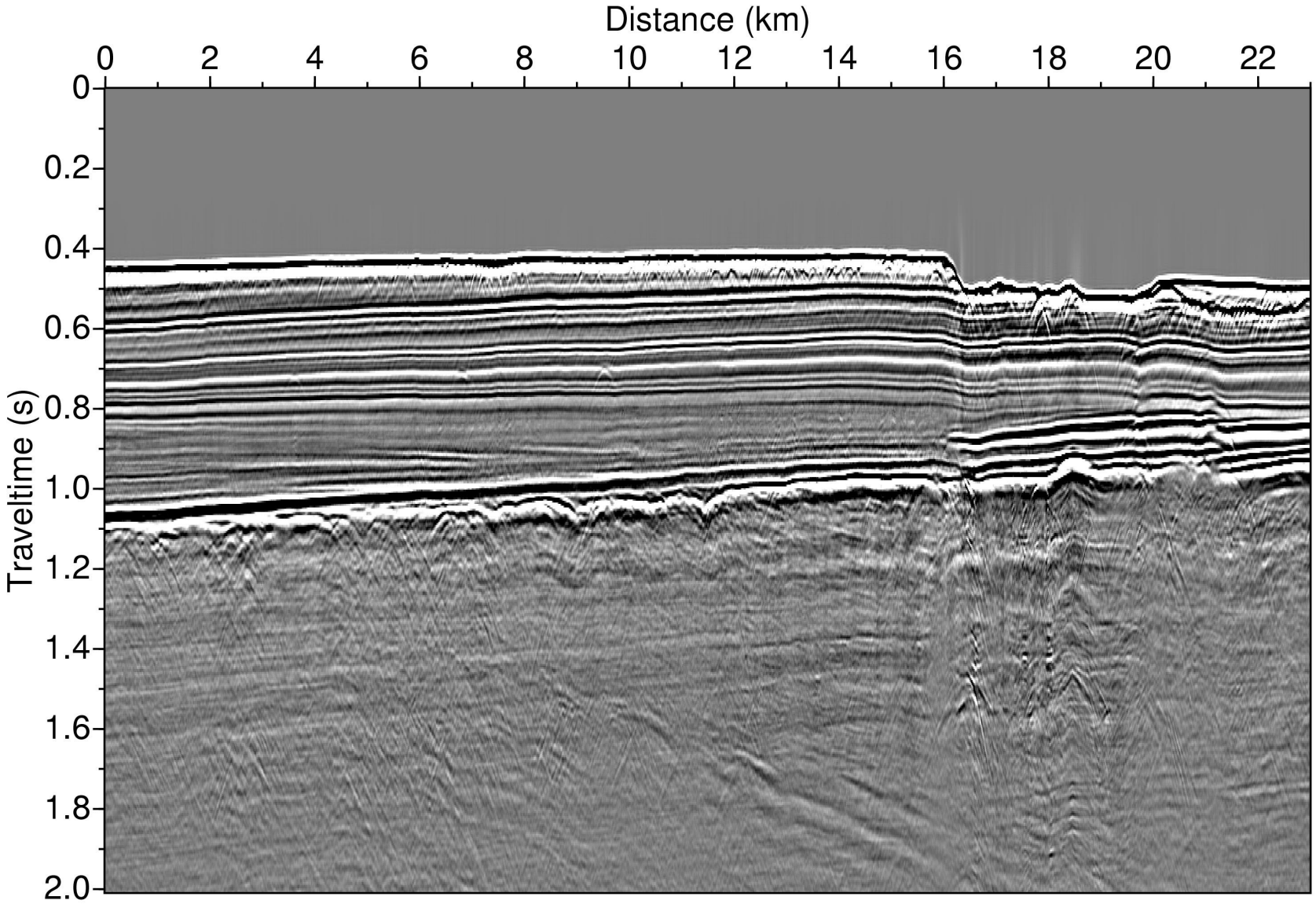
Implementation

Amplitude compensation in the time domain

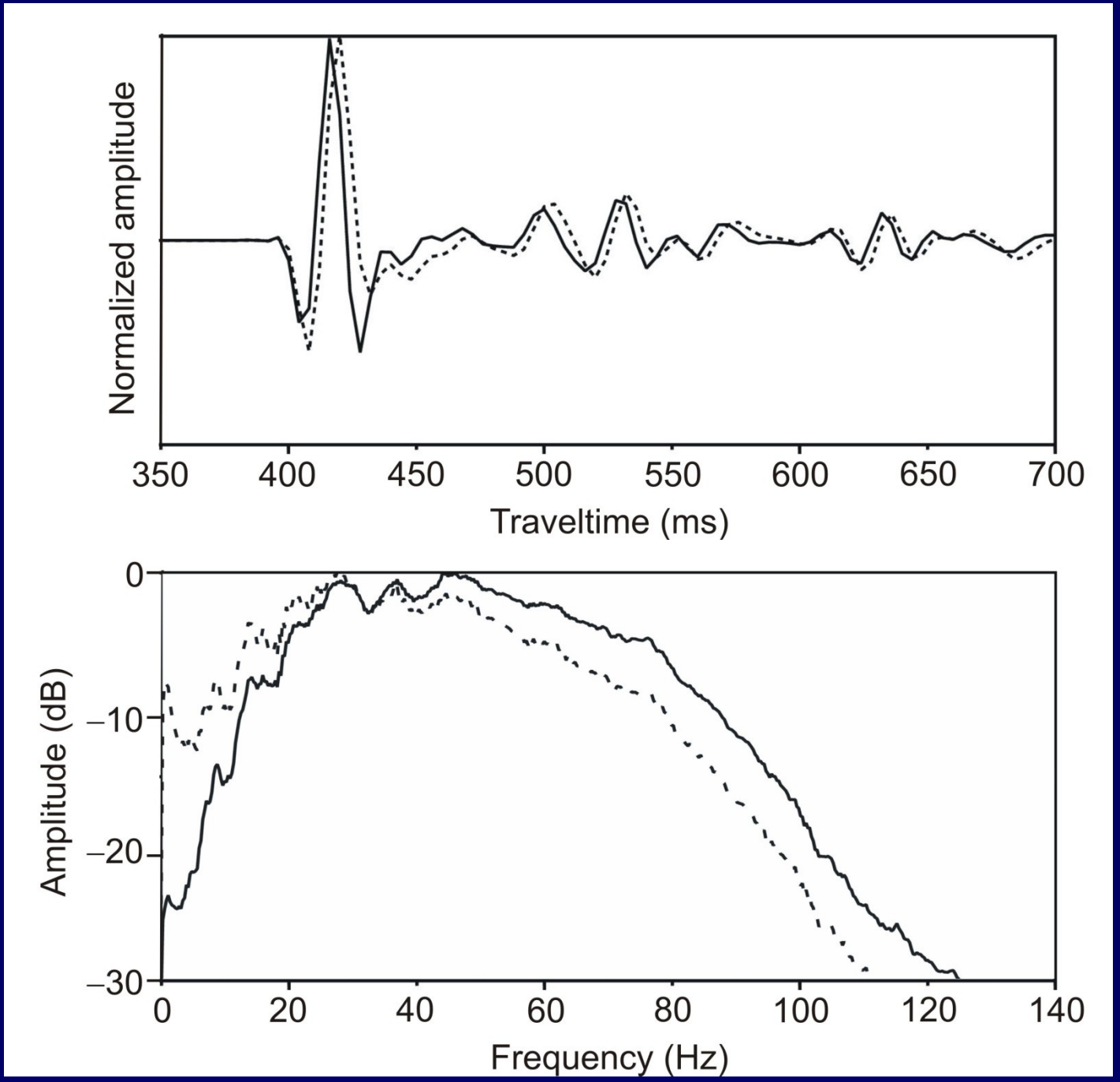
Phase correction in the frequency domain

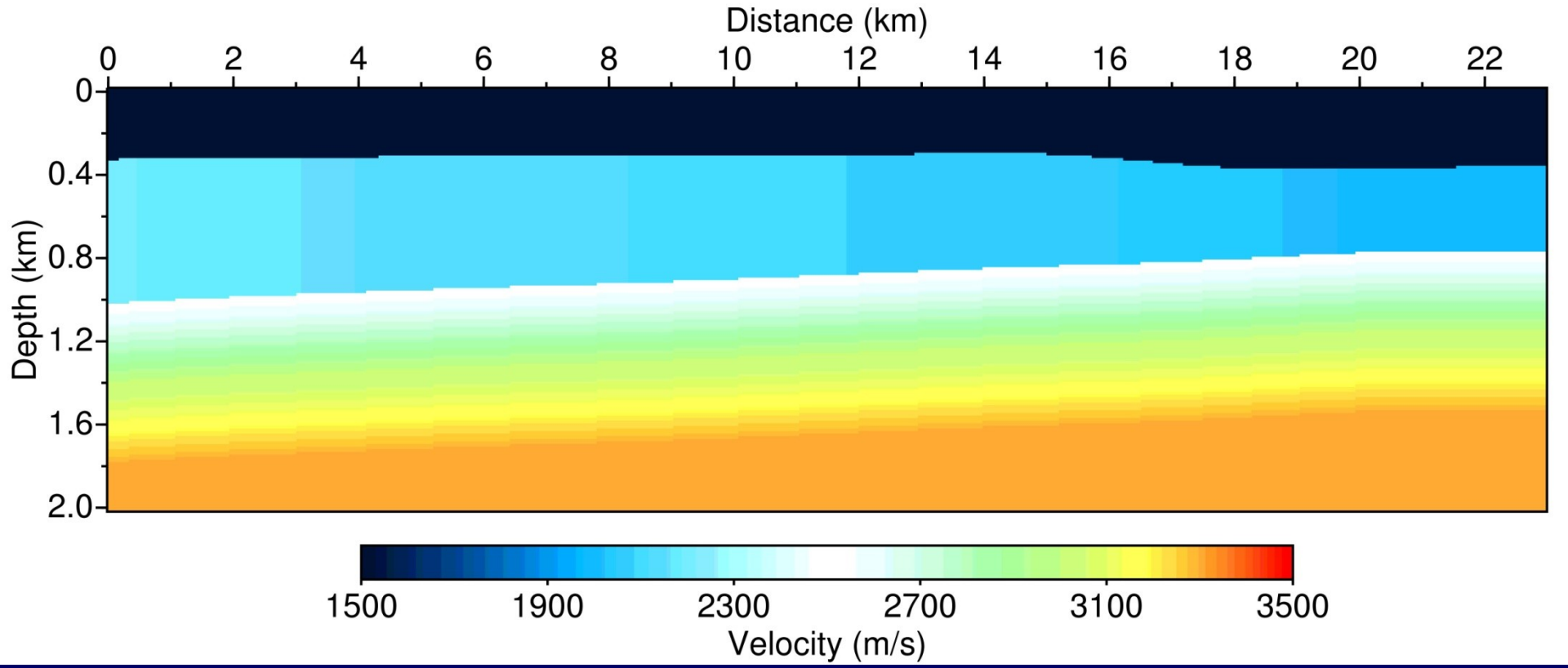


Multiple attenuation

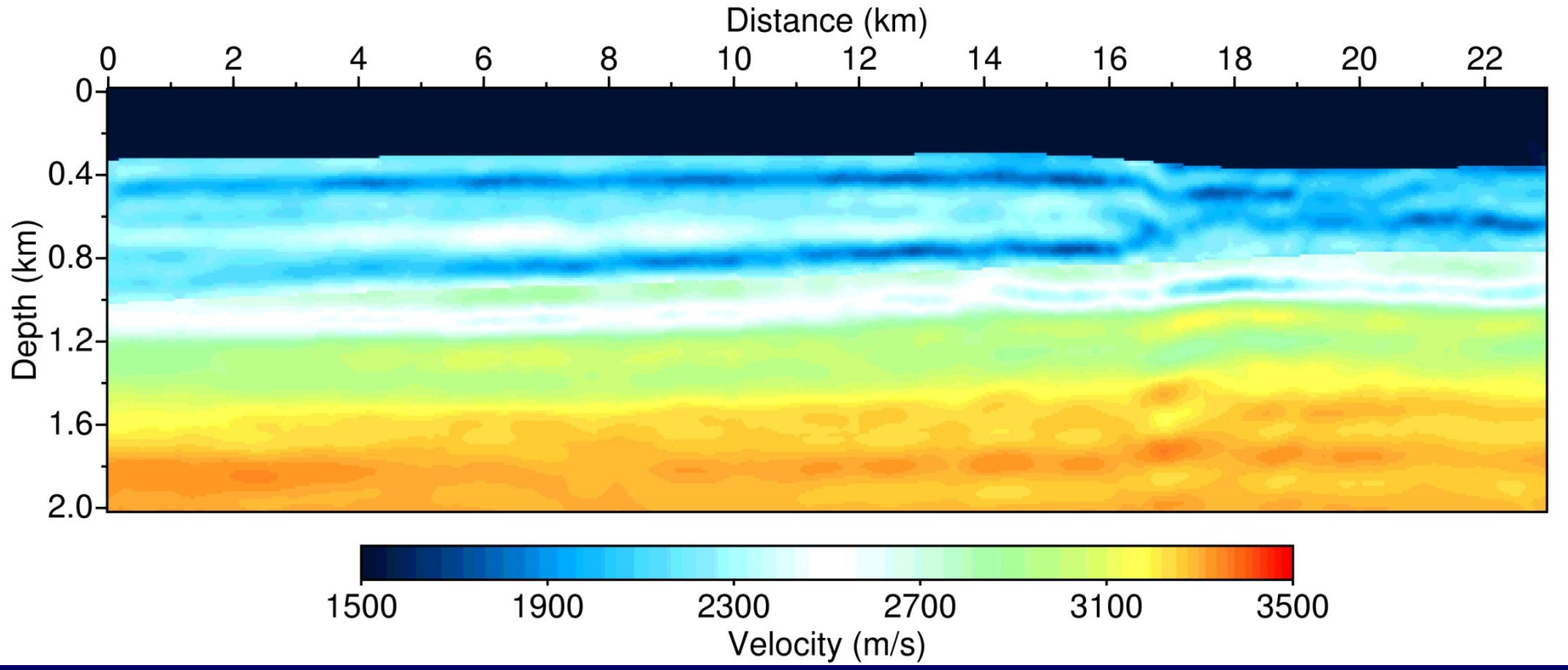


Amplitude and phase compensation

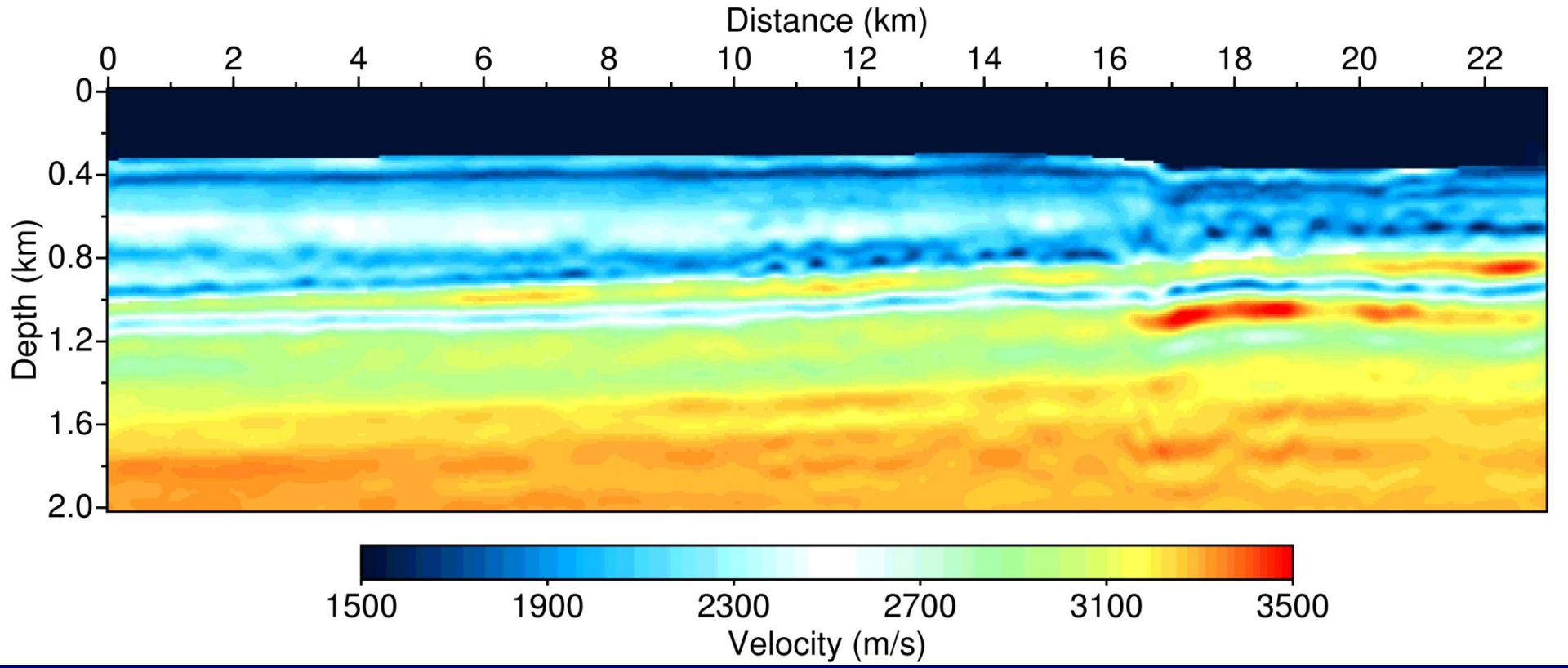

Normalized amplitude
350
400
450
500
550
600
650
700
Traveltime (ms)
0
−10
−20
−30
Amplitude (dB)
0
20
40
60
80
100
120
140
Frequency (Hz)



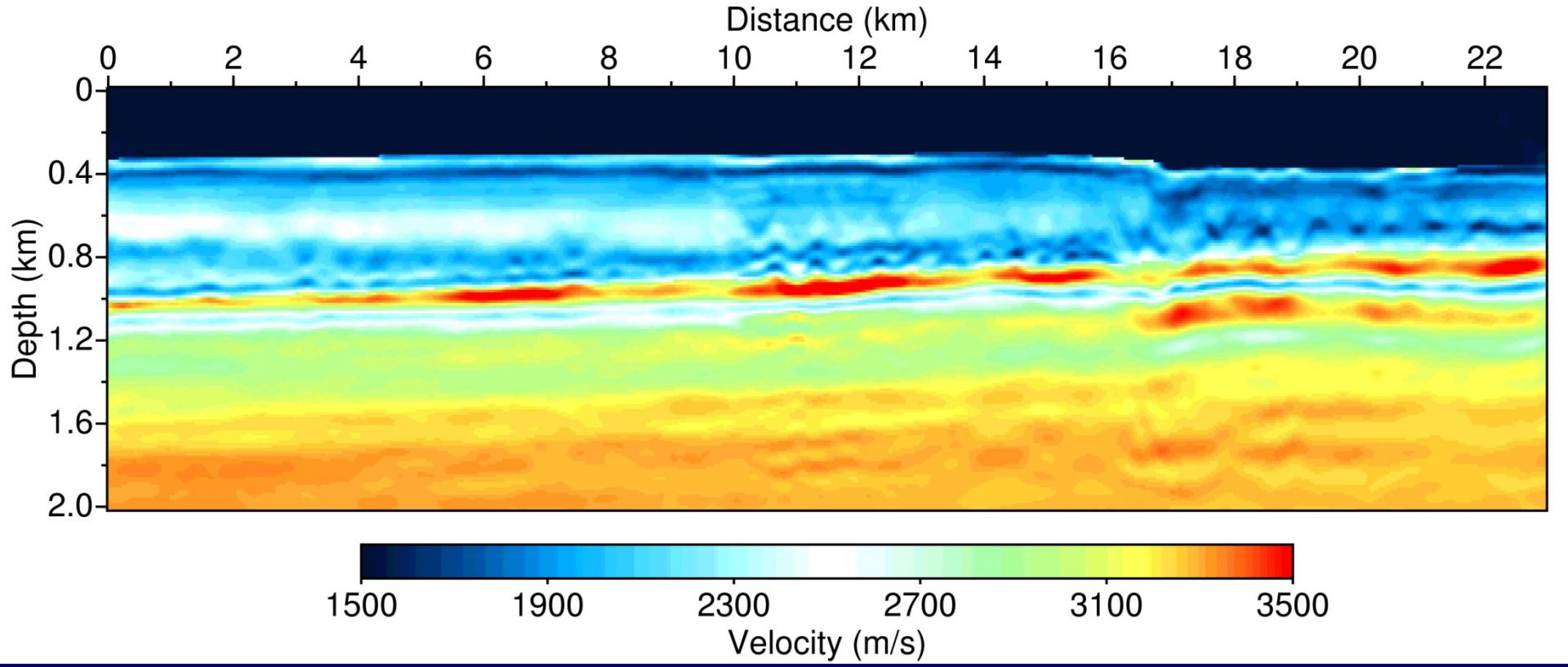
Traveltime tomography



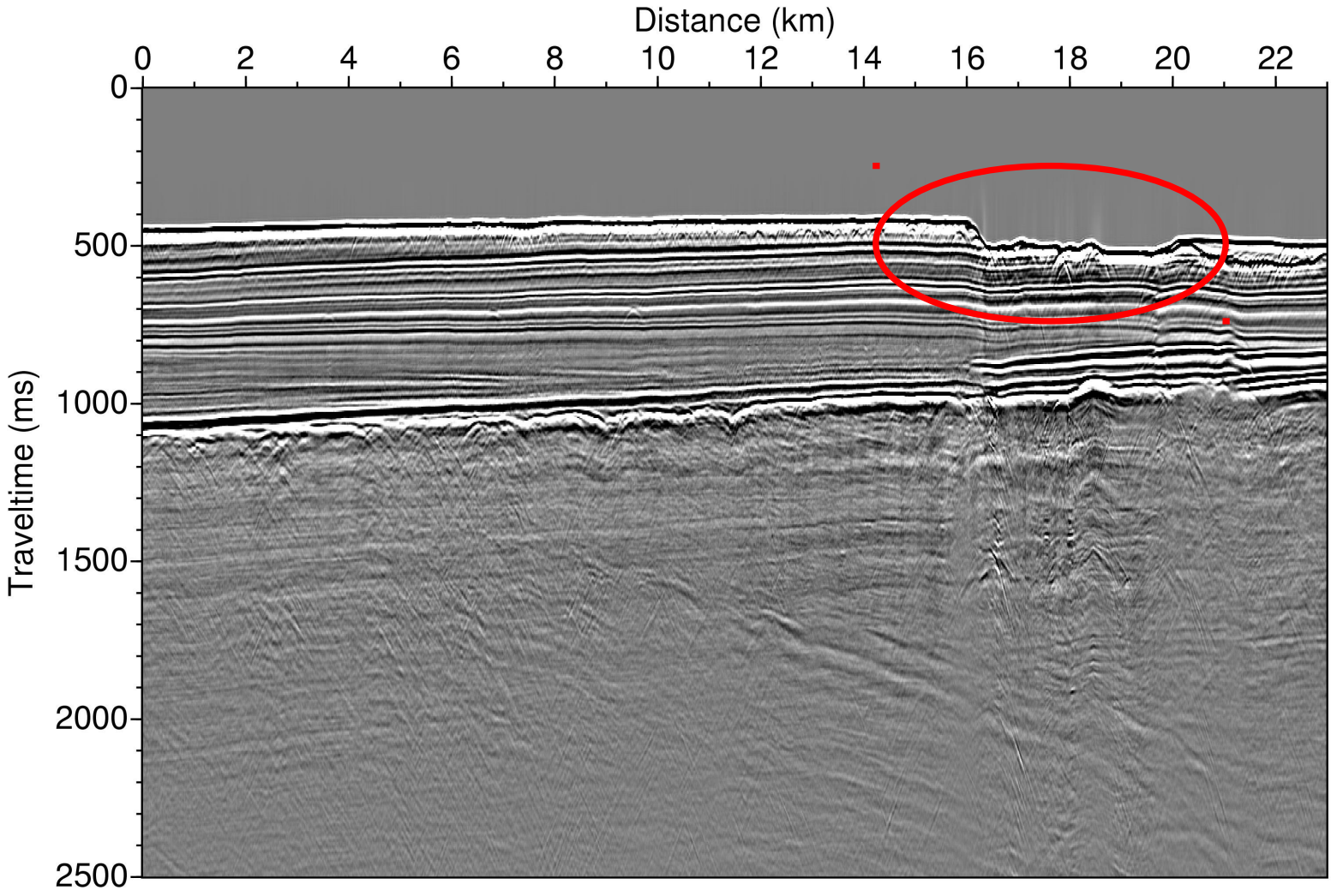
Tomography using frequencies of 6.9-7.5 Hz



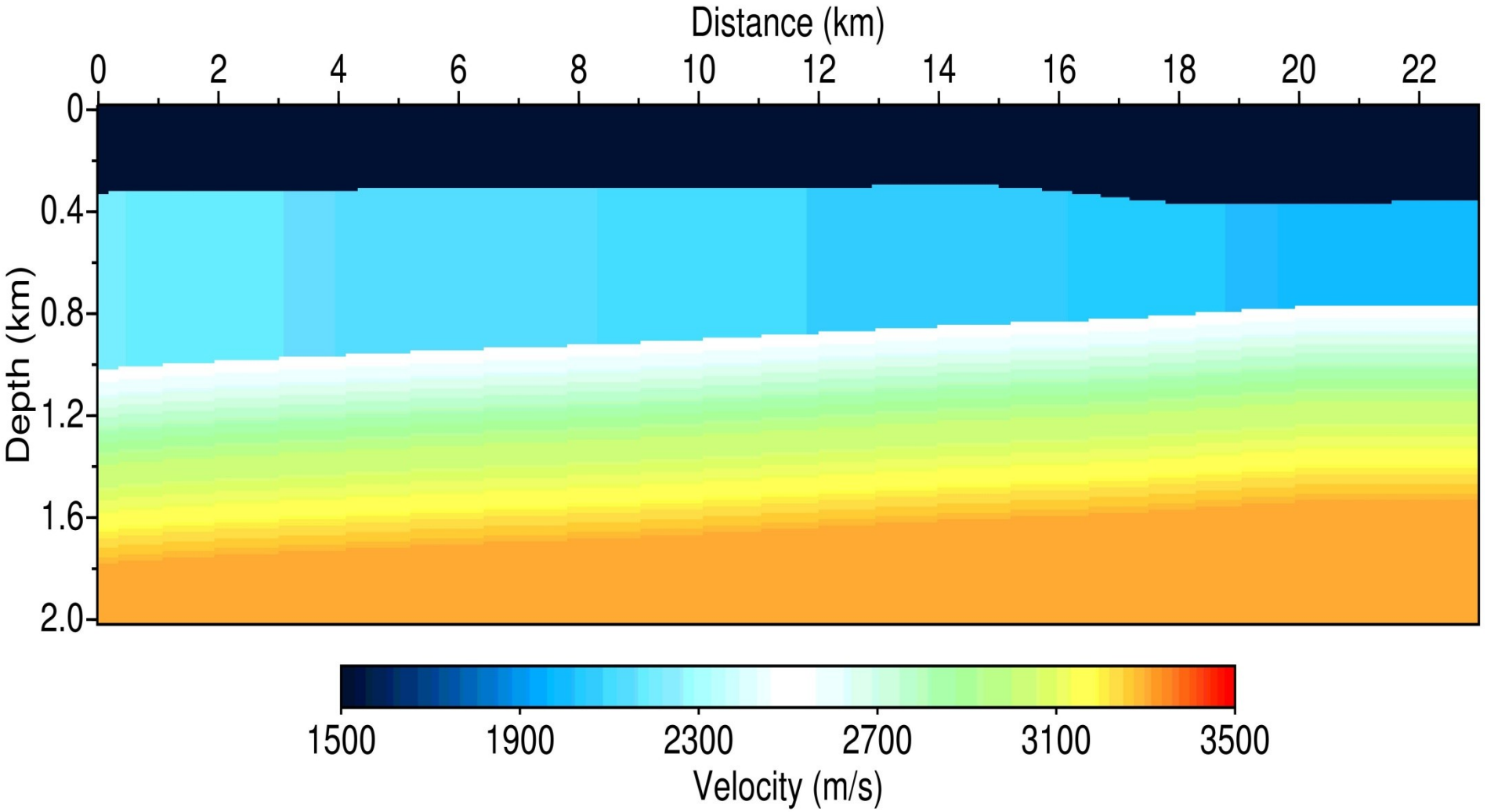
Tomography using frequencies of 6.9-13.8 Hz



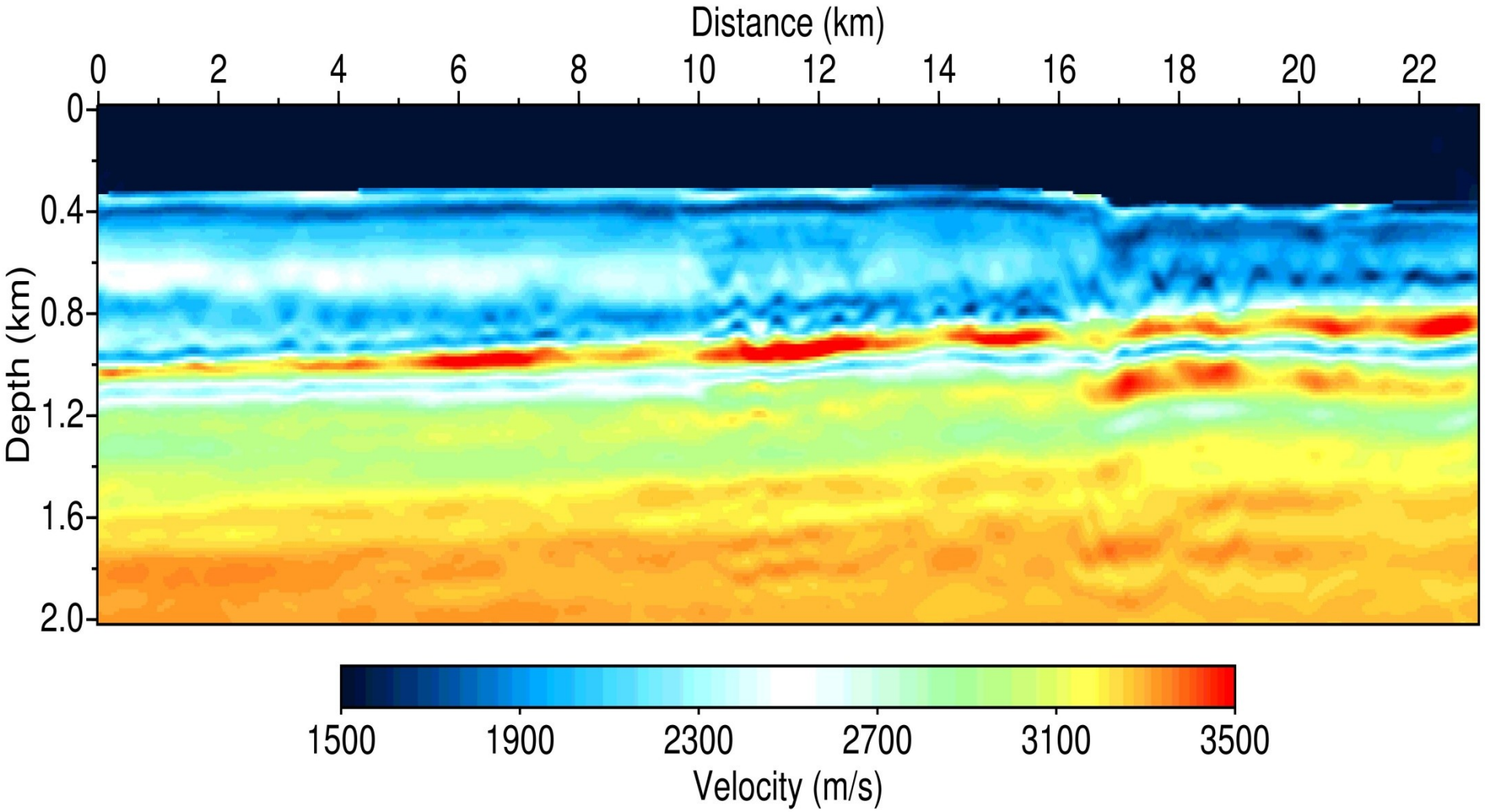
Tomography using frequencies of 6.9-30.0 Hz



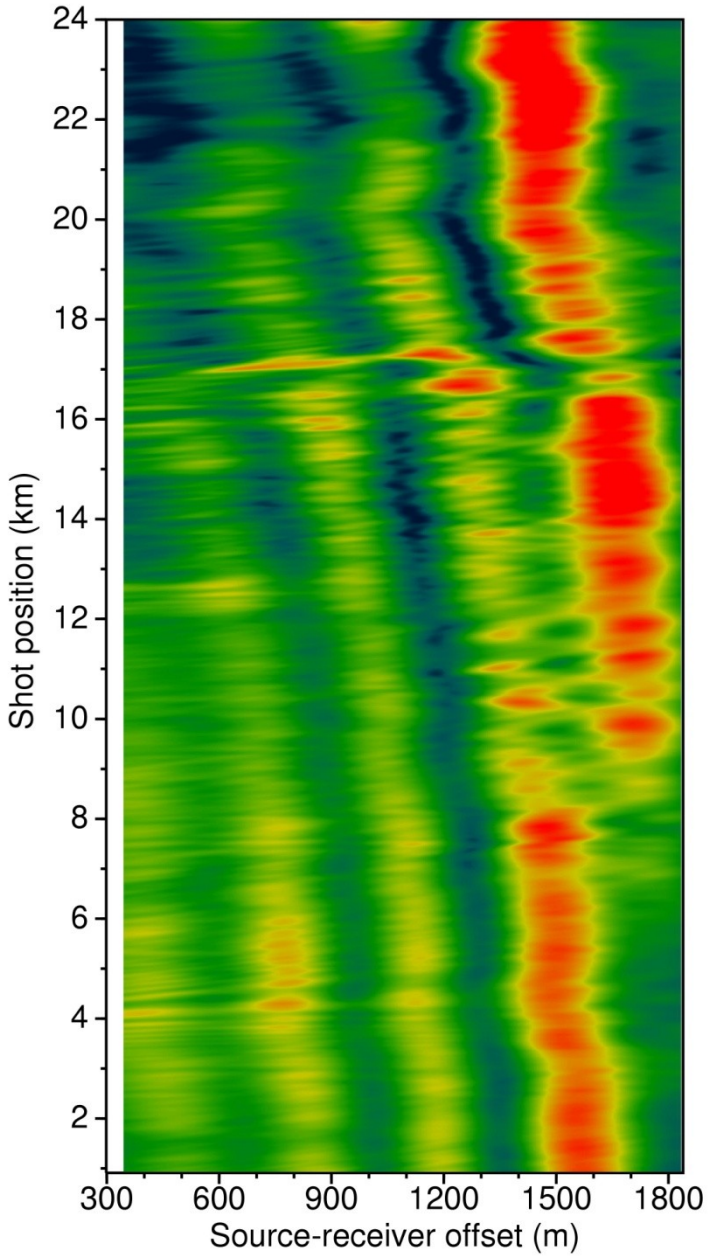
Stack section with amplitude and Phase compansation

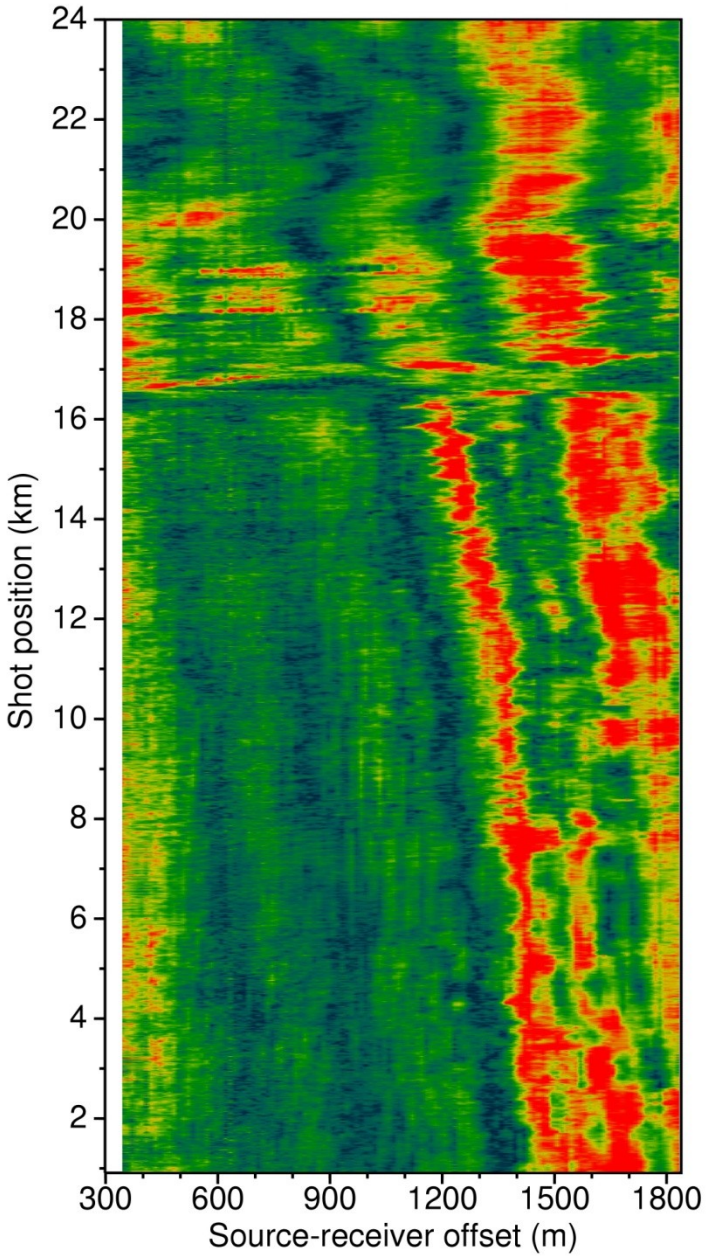


Traveltime tomography



Waveform tomography


Shot position (km)
24
22
20
18
16
14
12
10
8
6
4
2
300
600
900
1200
1500
1800
Source-receiver offset (m)


Shot position (km)
24
22
20
18
16
14
12
10
8
6
4
2
300
600
900
1200
1500
1800
Source-receiver offset (m)

Key points

Weighted updating scheme for inversion

Pre-stack multiple attenuation

Partial compensation of 3D to 2D

Applicable to the exploration seismic data