Full Waveform Inversion – A Synthetic Test Using the PSPI Migration

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Robert Ferguson

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CREWES

Outline

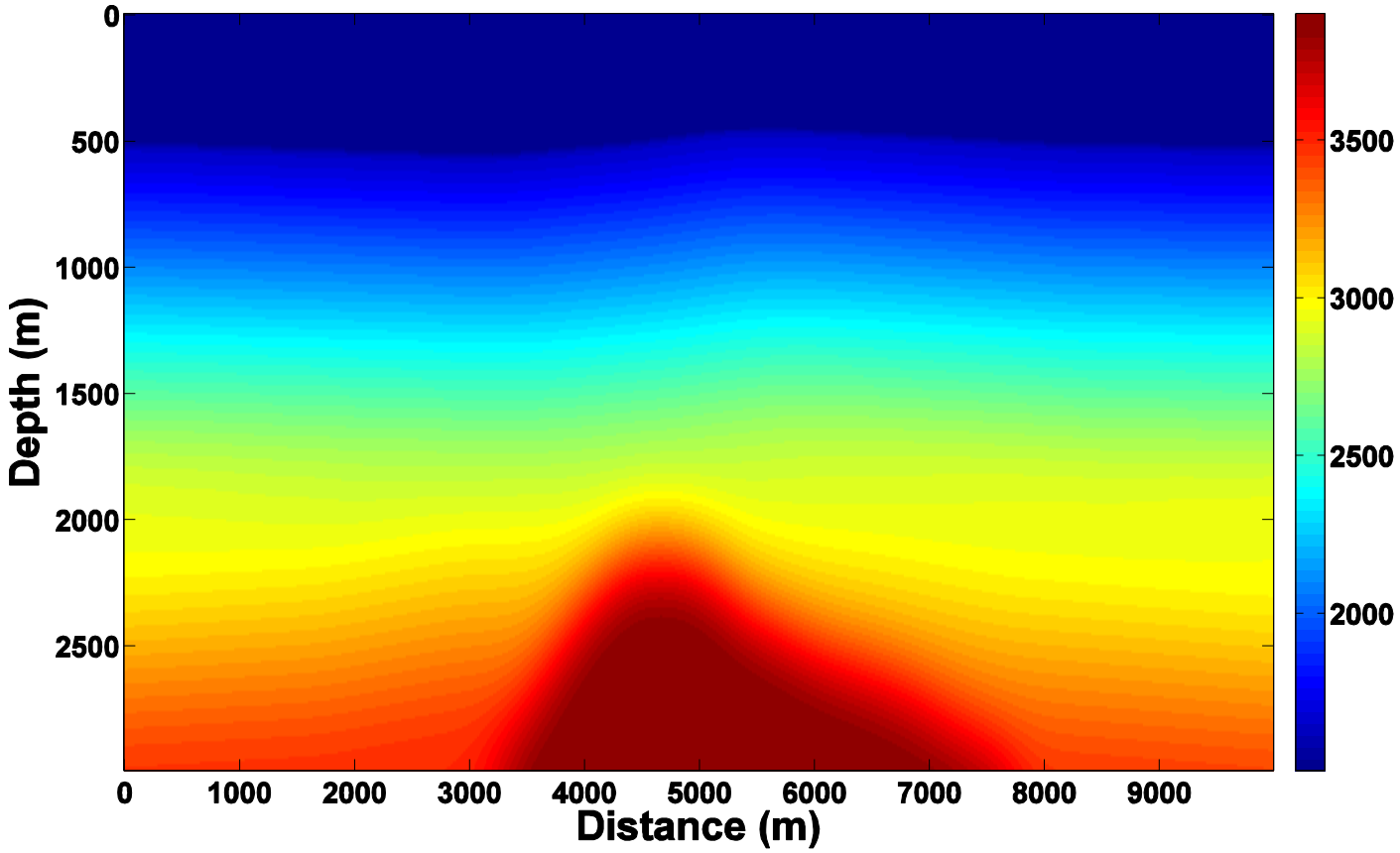
- Introduction
- Synthetic survey
- Mute Tests
- Constant Initial Velocity Model
- Conclusions
- Future work
- Acknowledgments

Introduction

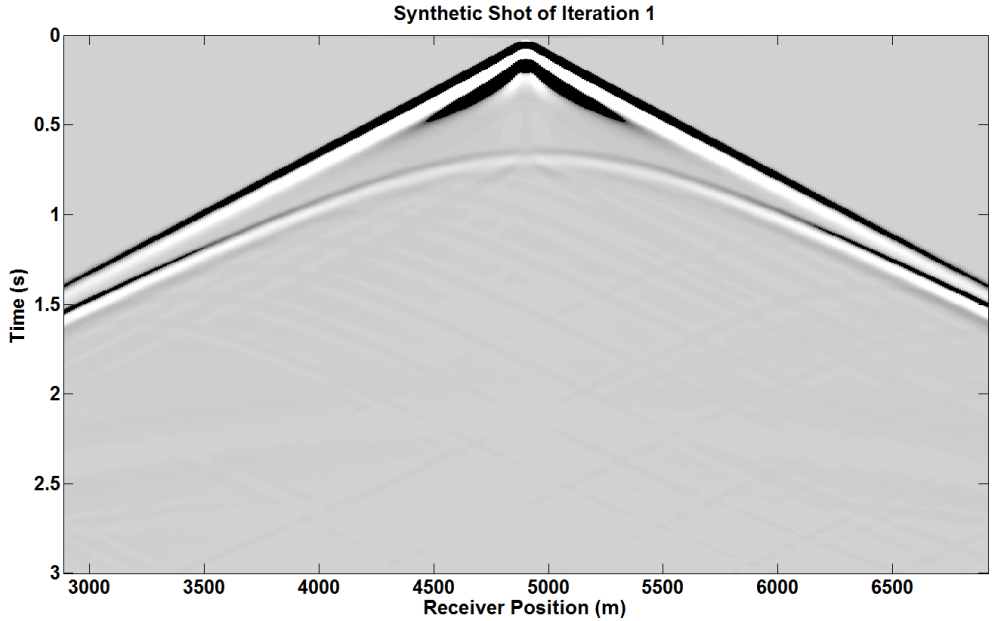
- Iterative

Introduction

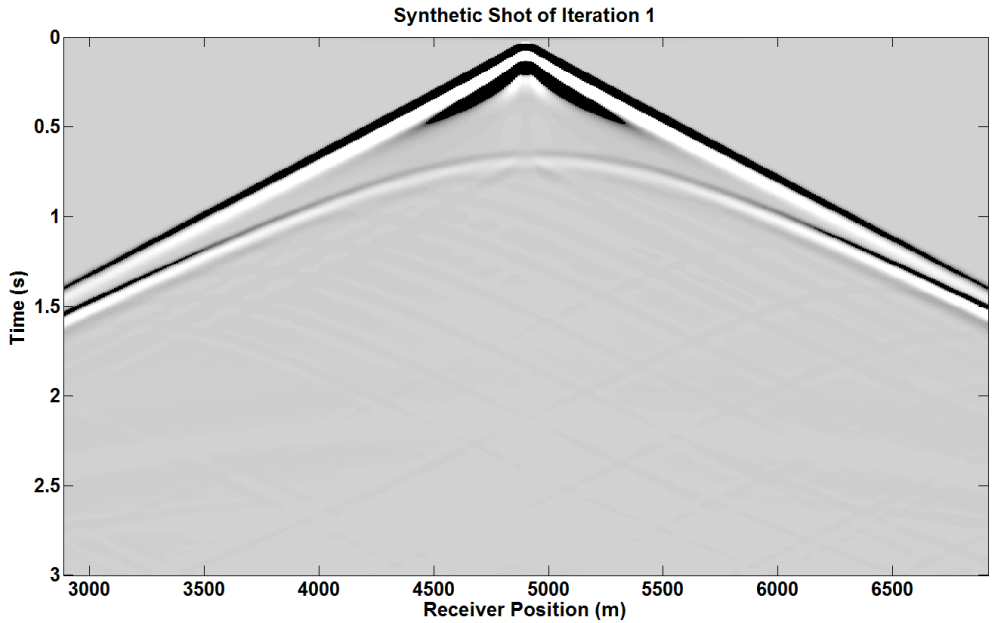
- Iterative

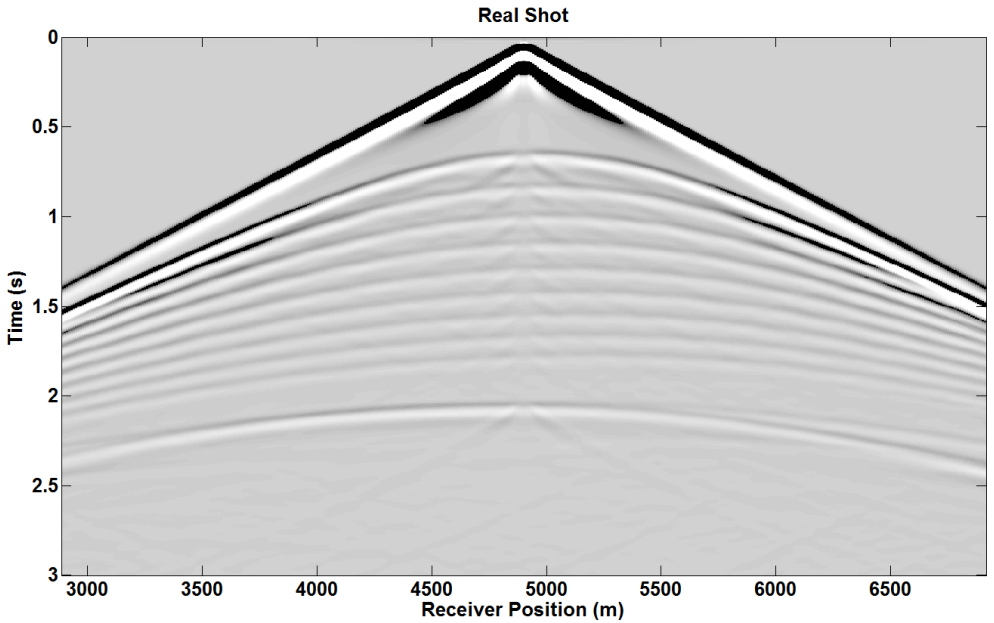


Introduction

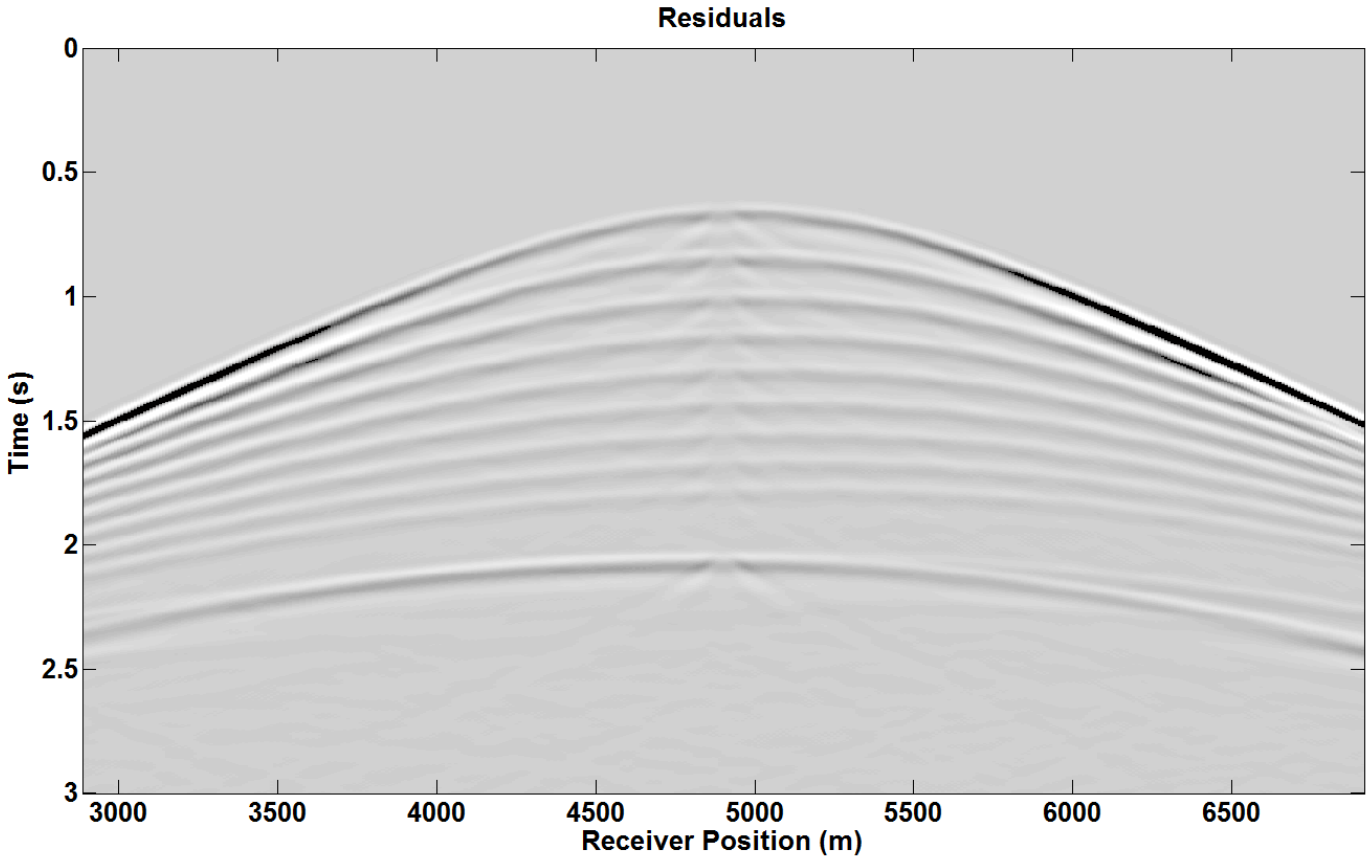


Introduction



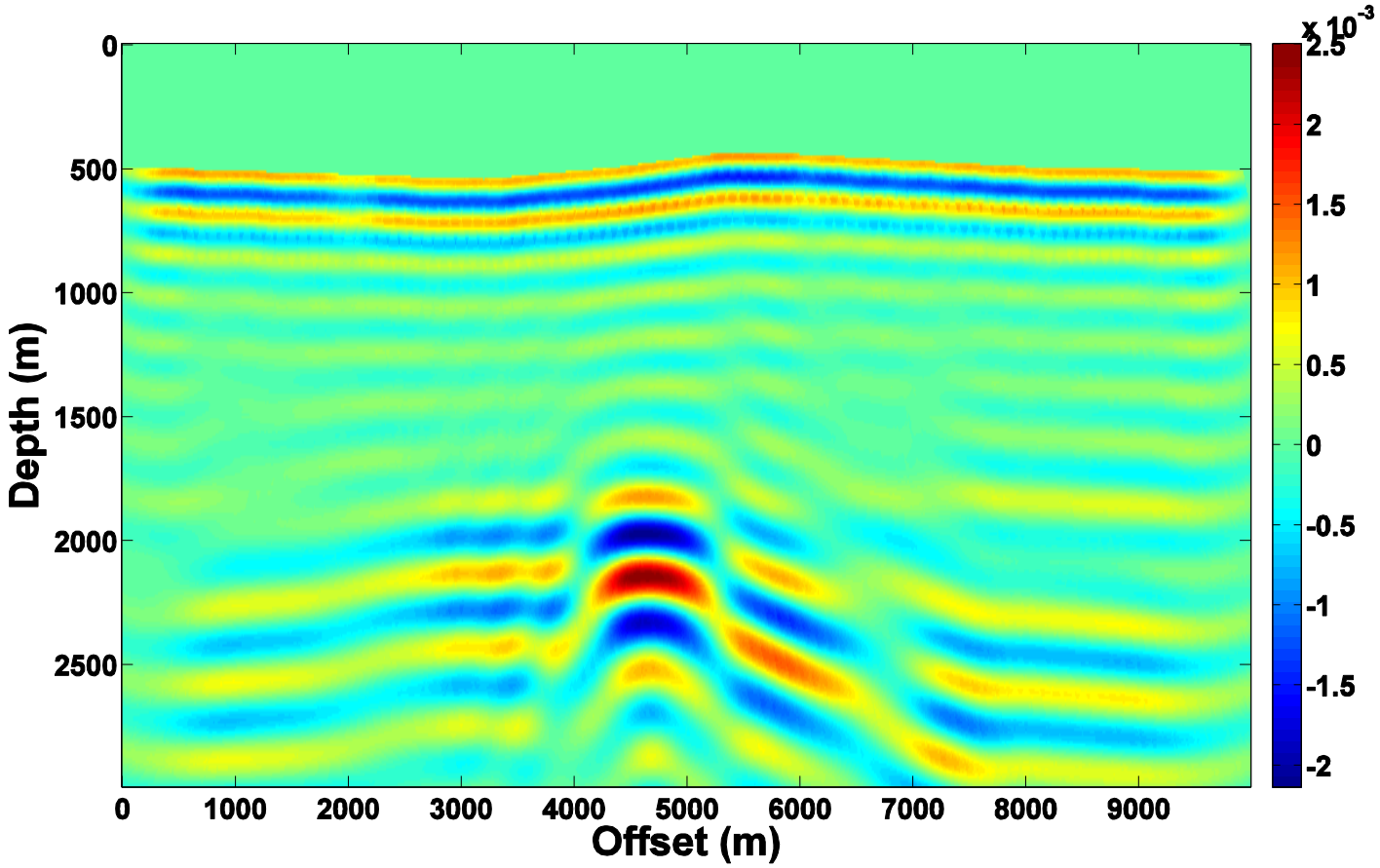


Introduction



Introduction

- Iterative
- Model update (gradient)



Introduction

- Iterative
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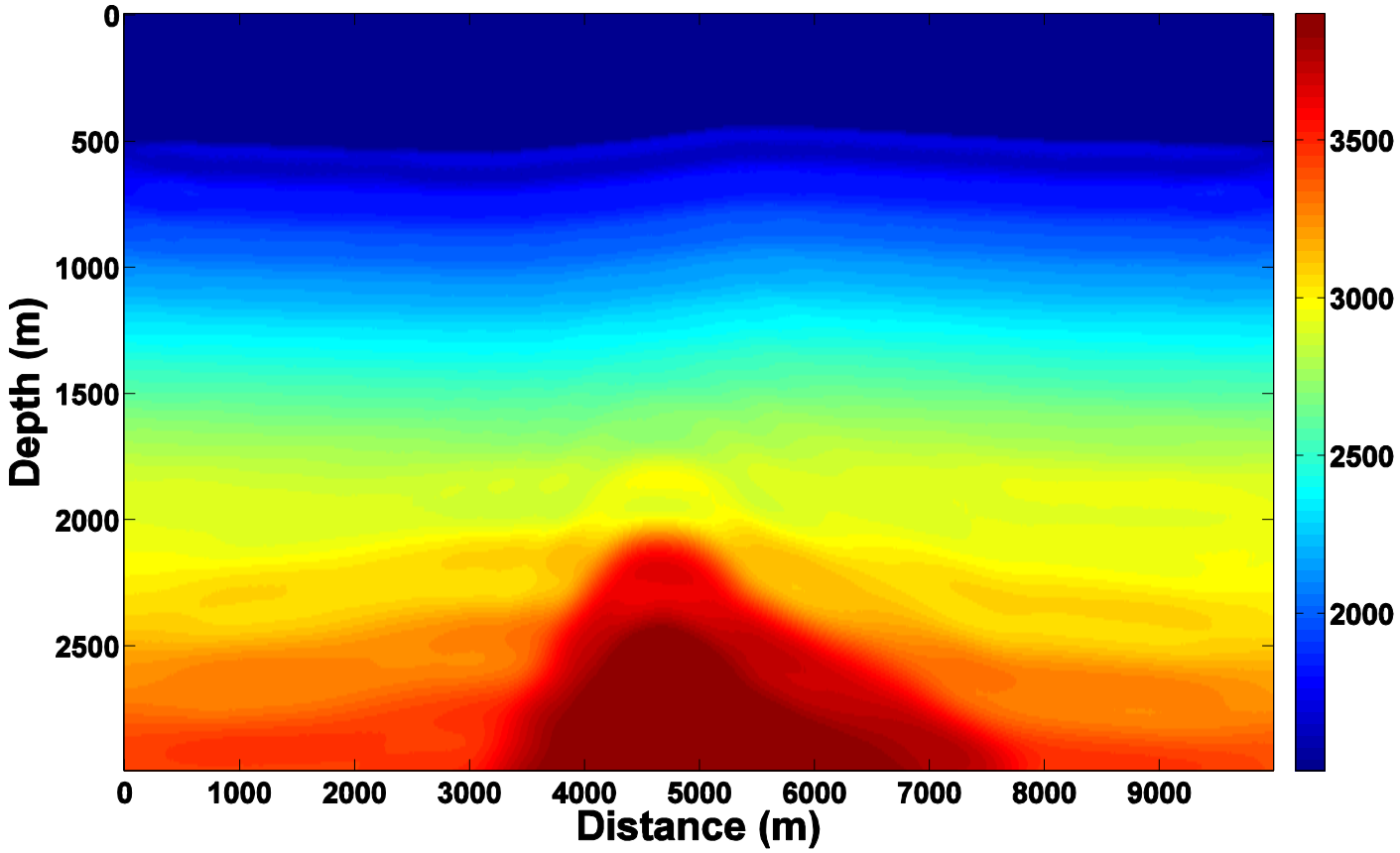
- New velocity model



Introduction

- Iterative
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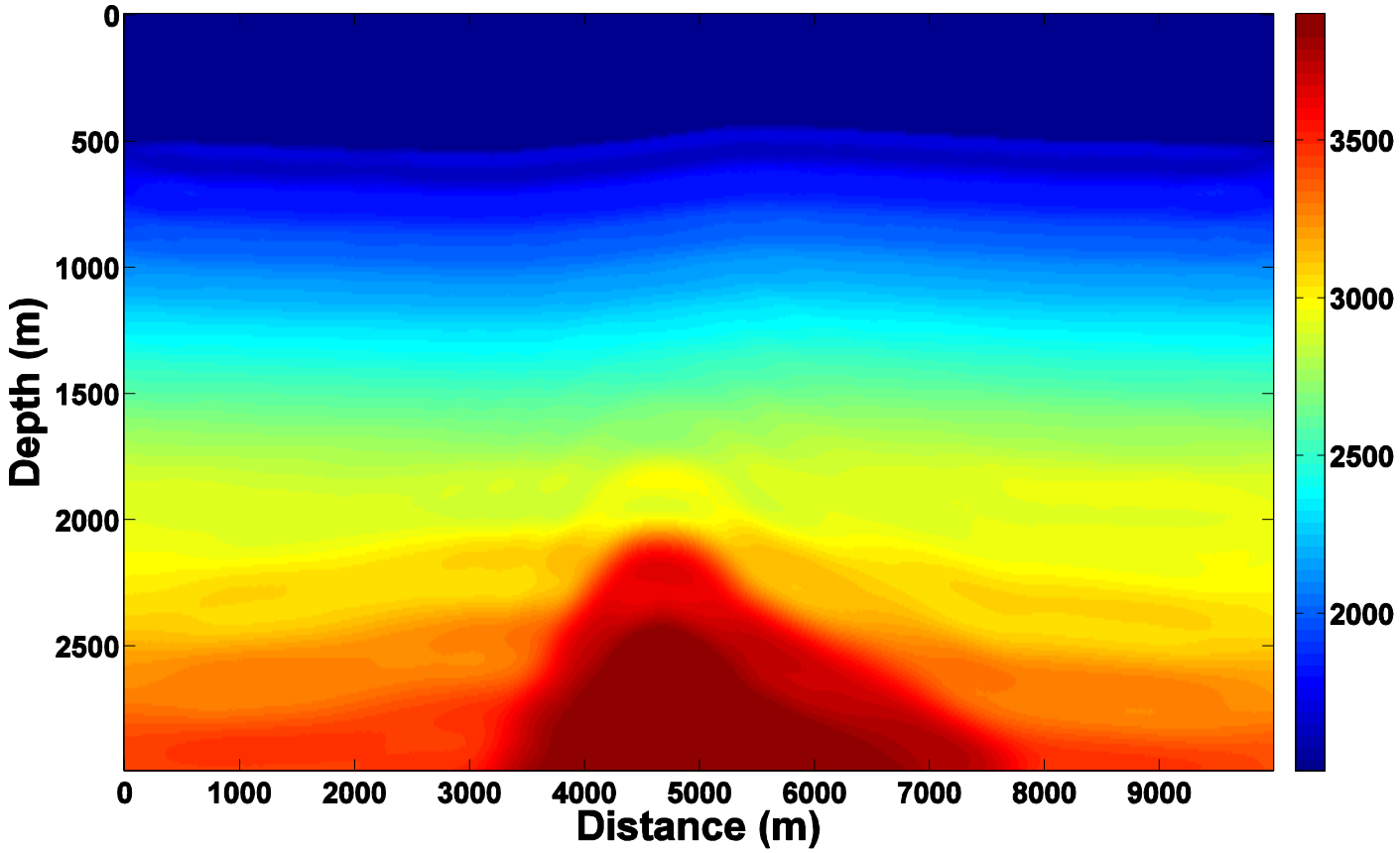
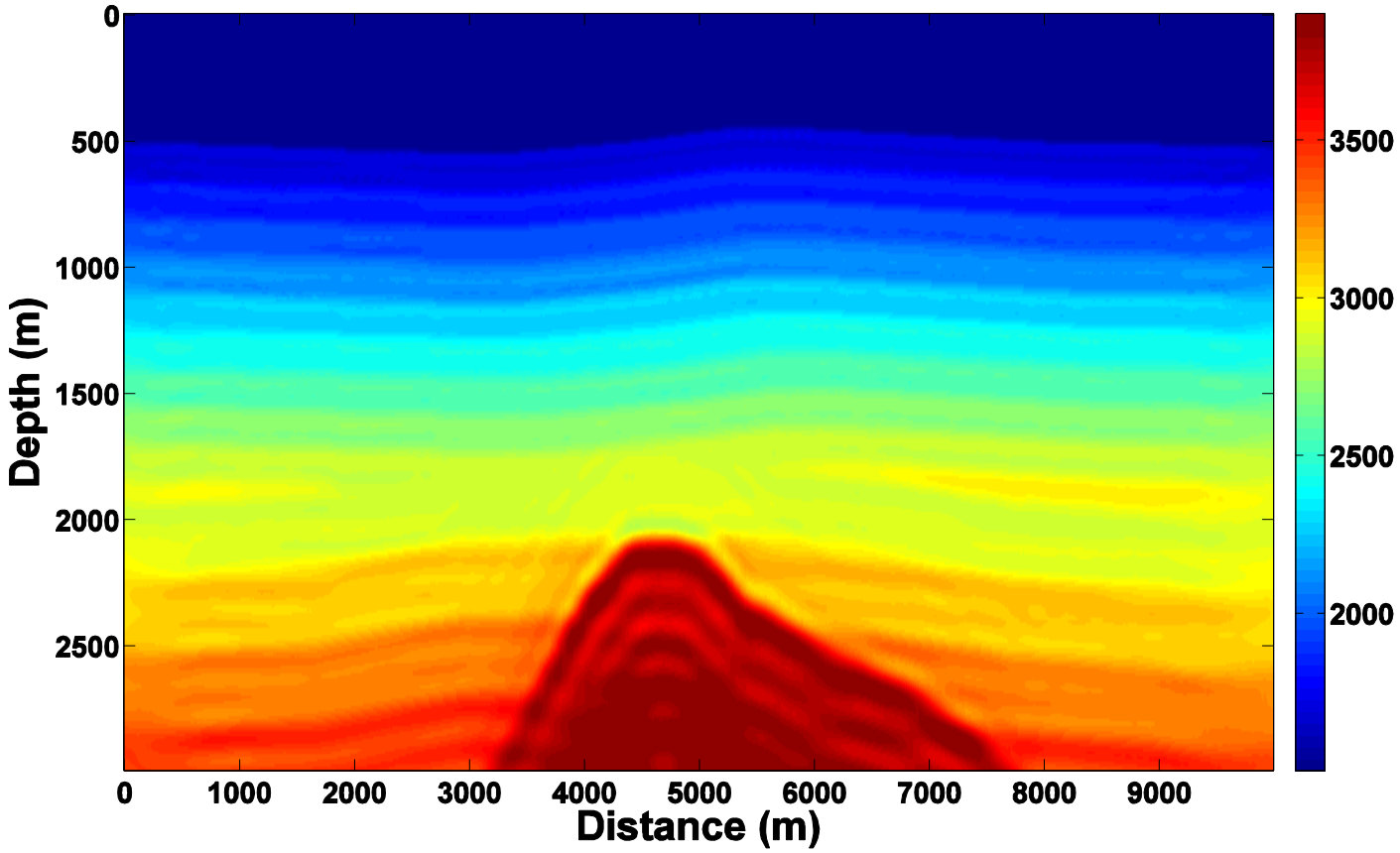
- New velocity model
- Repeat process



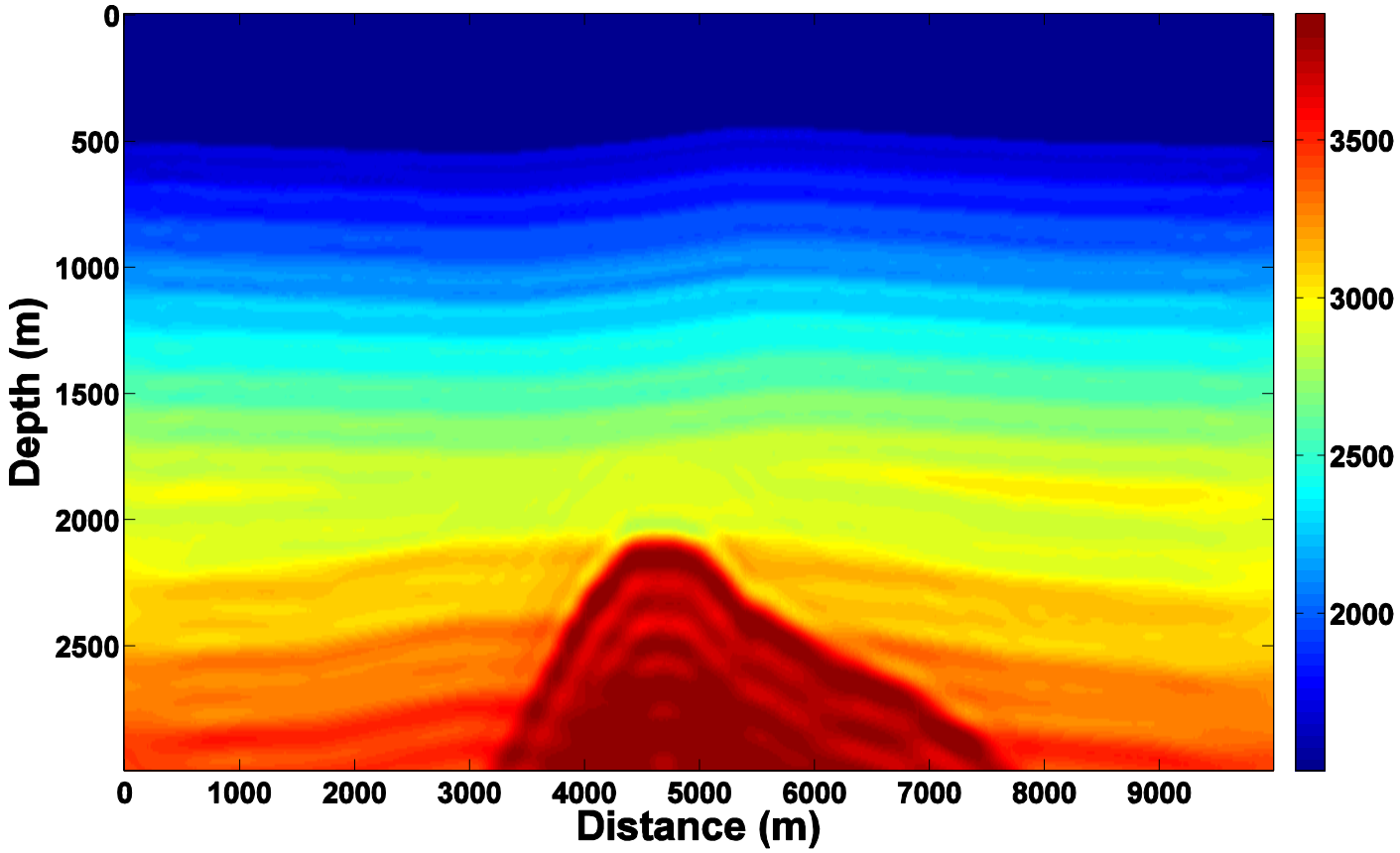
Introduction

- Iterative
- Model update (gradient)
- New velocity model
- Repeat process
- Convergence



Introduction

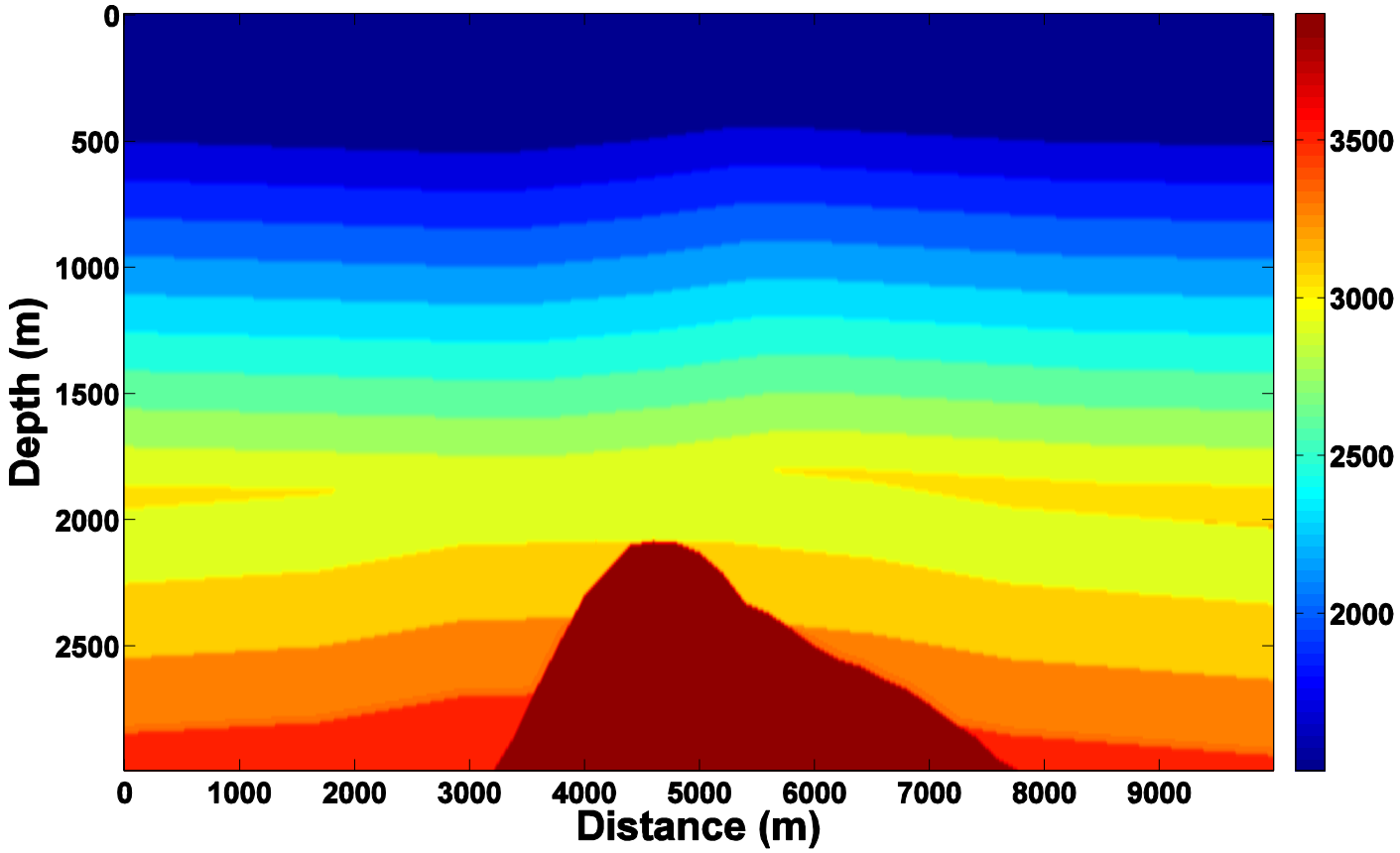
- Iterative
- Model update (gradient)
- New velocity model
- Repeat process
- Convergence
- Real model **(?)**

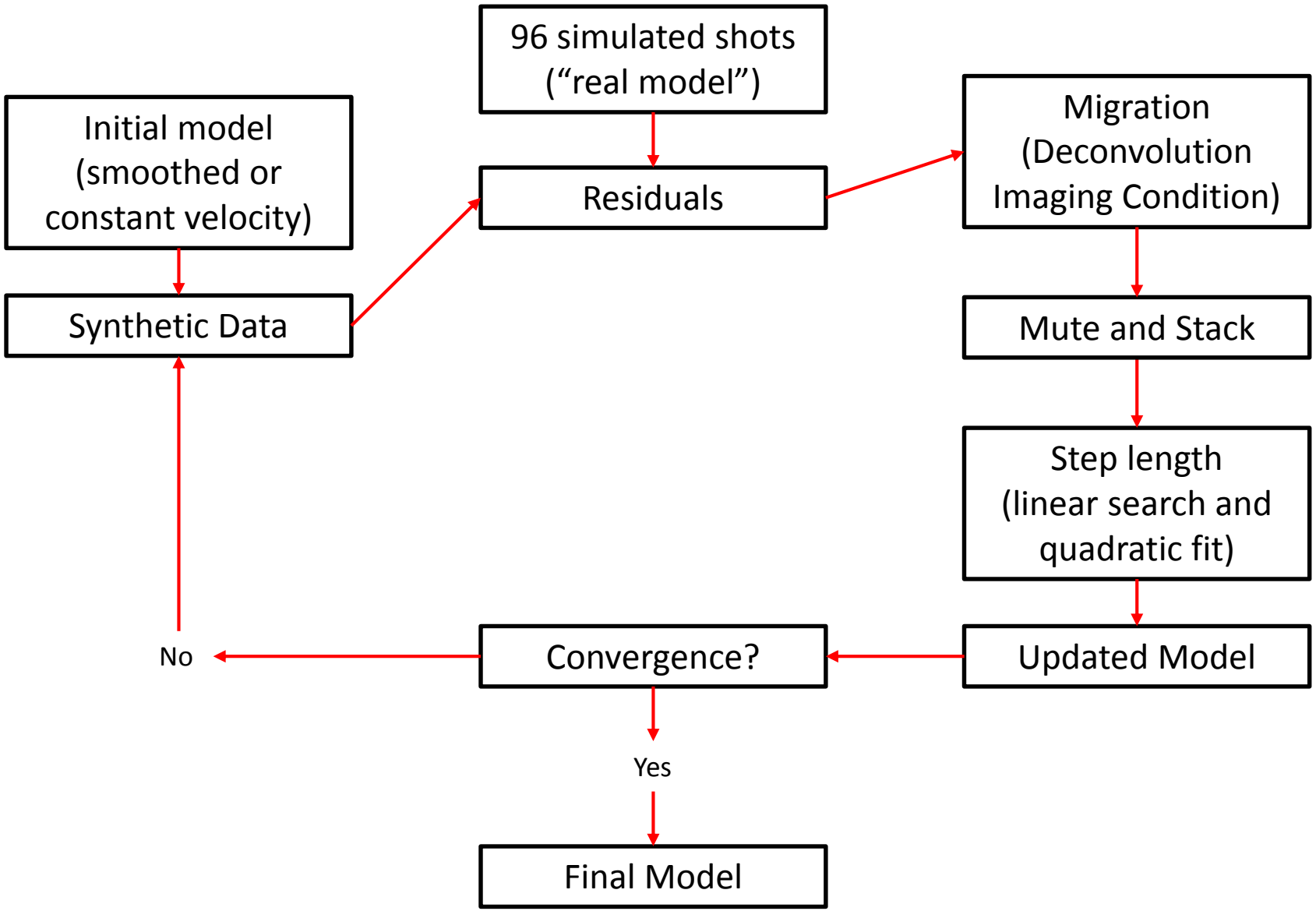


Introduction

- Iterative
- Model update (gradient)
- New velocity model
- Repeat process
- Convergence
- Real model **(?)**

Close…

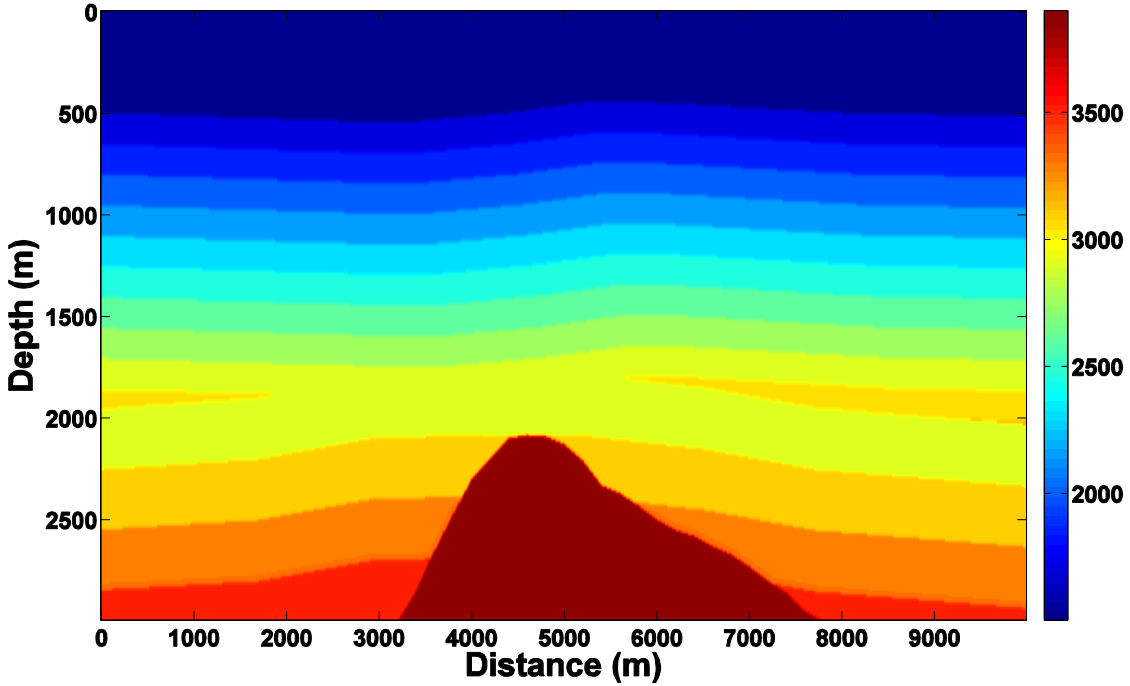



96 simulated shots
("real model")
Initial model
(smoothed or
constant velocity)
Residuals
Migration
(Deconvolution
Imaging Condition)
Synthetic Data
Mute and Stack
Step length
(linear search and
quadratic fit)
No
Convergence?
Updated Model
Yes
Final Model

Synthetic Survey

- Marine acquisition simulation
- 96 shots – 100m spacing and 30m depth, with dominant frequency of 10 Hz
- 401 receivers (split-spread) with 10m spacing
- No free surface multiples in the data
- Pspi_shot migration with frequency range starting at 1 to 6Hz and increasing maximum frequency by 1 each 10 iterations (1 – 6 Hz, 1 – 7 Hz and so on), with a deconvolution imaging condition
- Muting and stacking
- Water bottom mute
- First guess for step length (order of the difference between migrated residuals and initial model)
- Linear Search for best (21 points)
- Next iteration

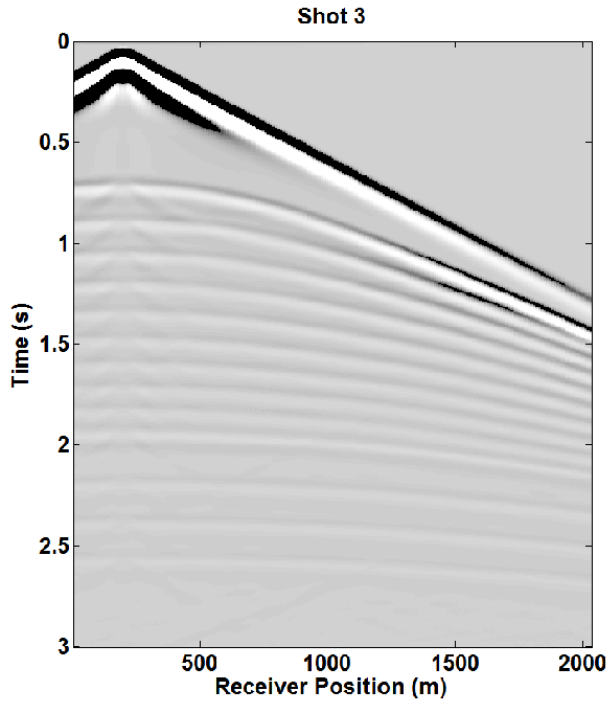
Synthetic Survey – Velocity Model



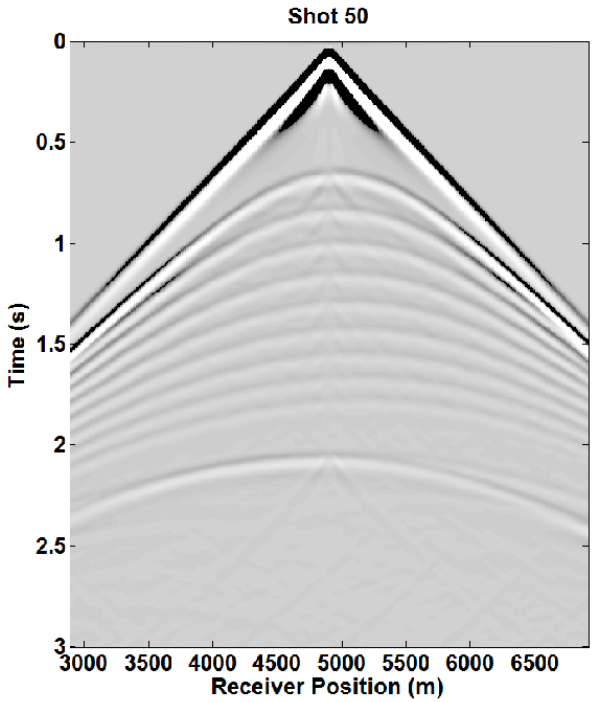
- Marine
- 3 km depth
- 10 km width
- 10x10 m resolution
- Minimum velocity of 1500 m/s
- Maximum velocity of 3900 m/s

Synthetic Survey –"Real" Shots

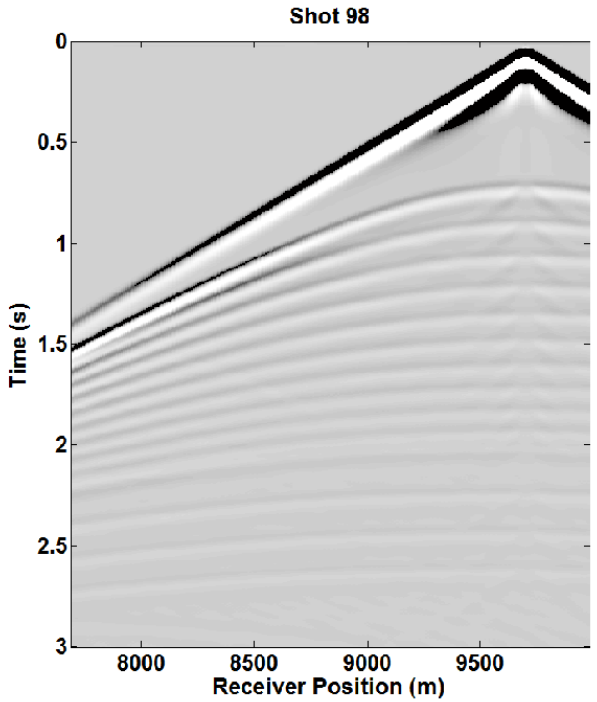
a)



b)

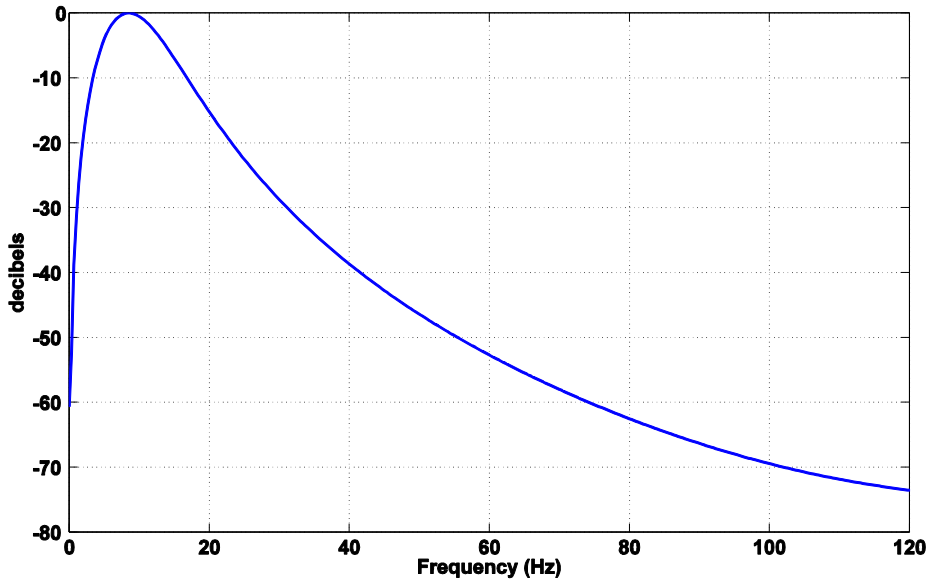


c)

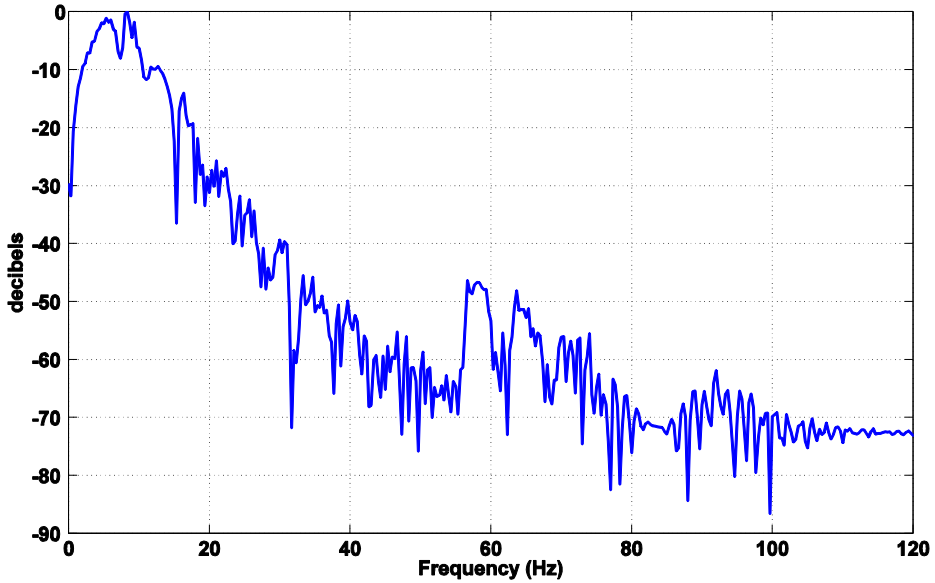


Synthetic Survey – Spectrum

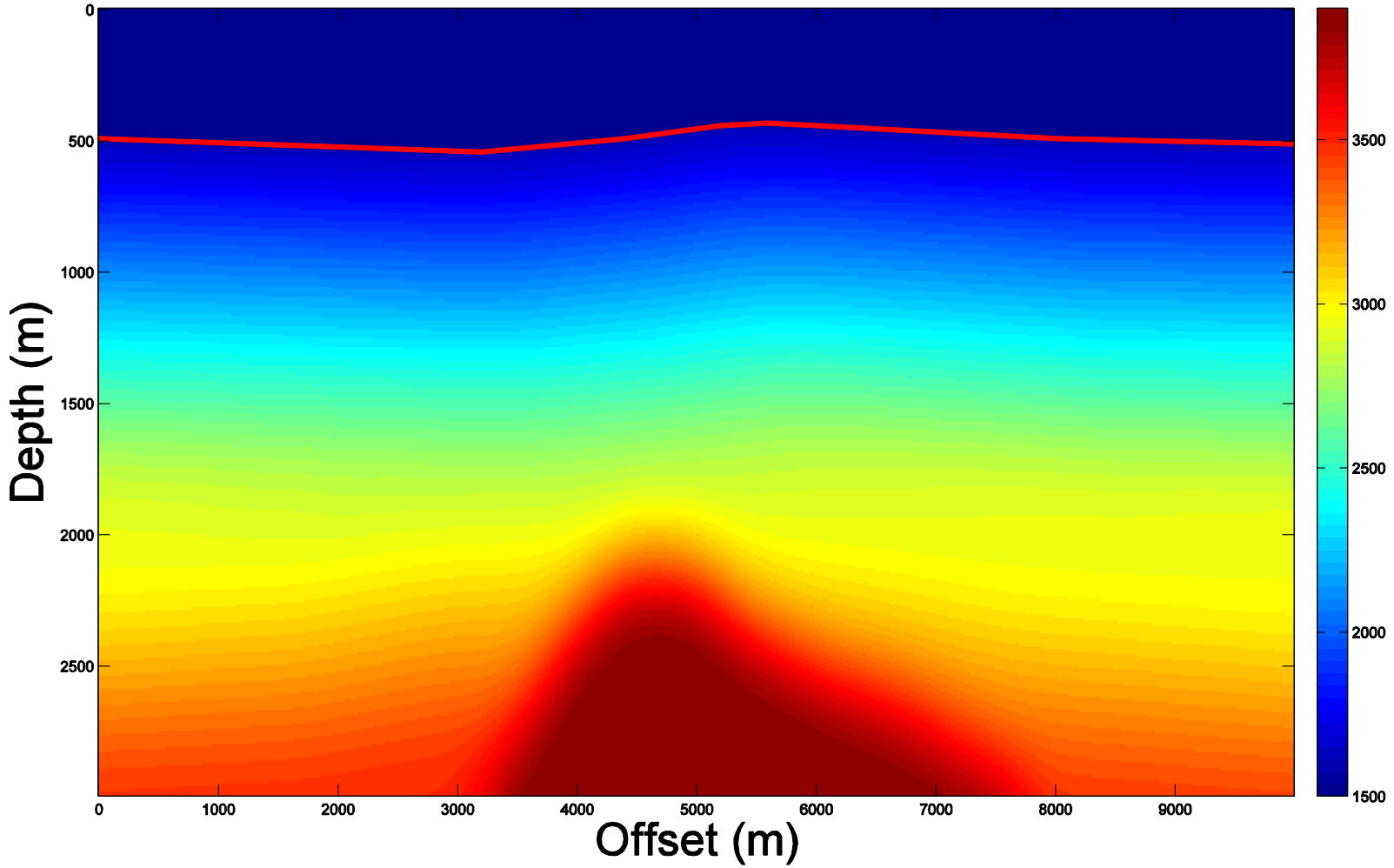
Wavelet



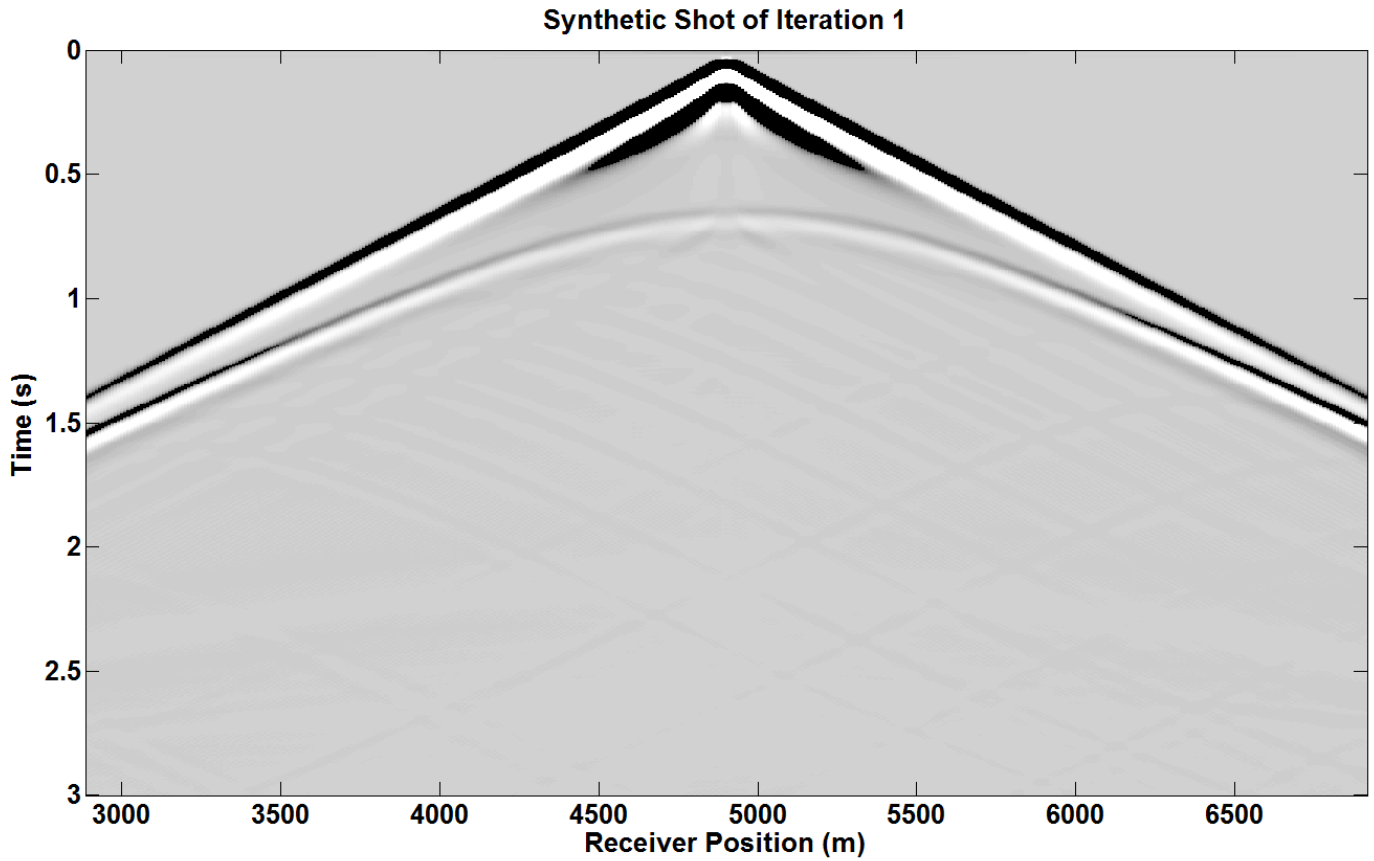
Shot



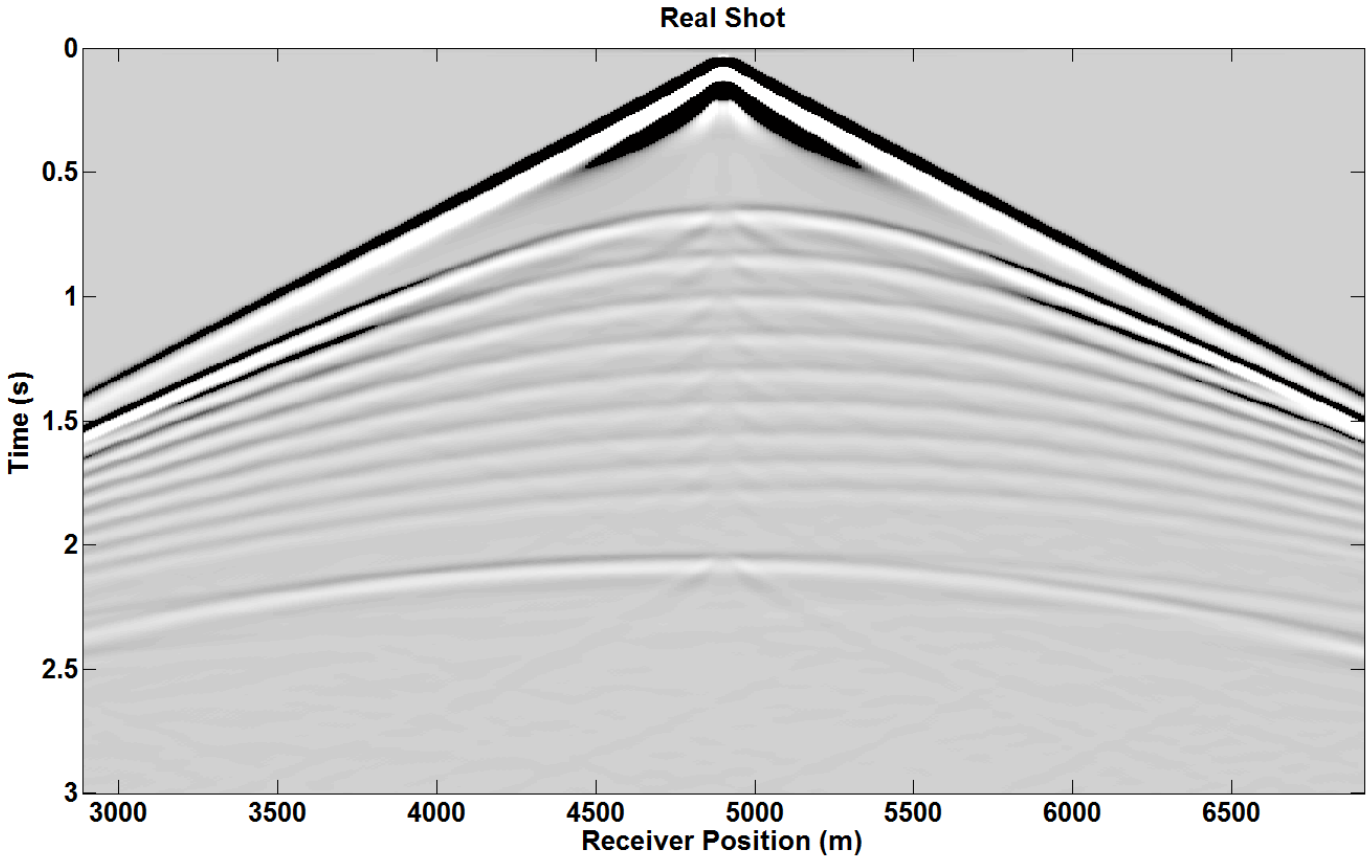
Initial Model



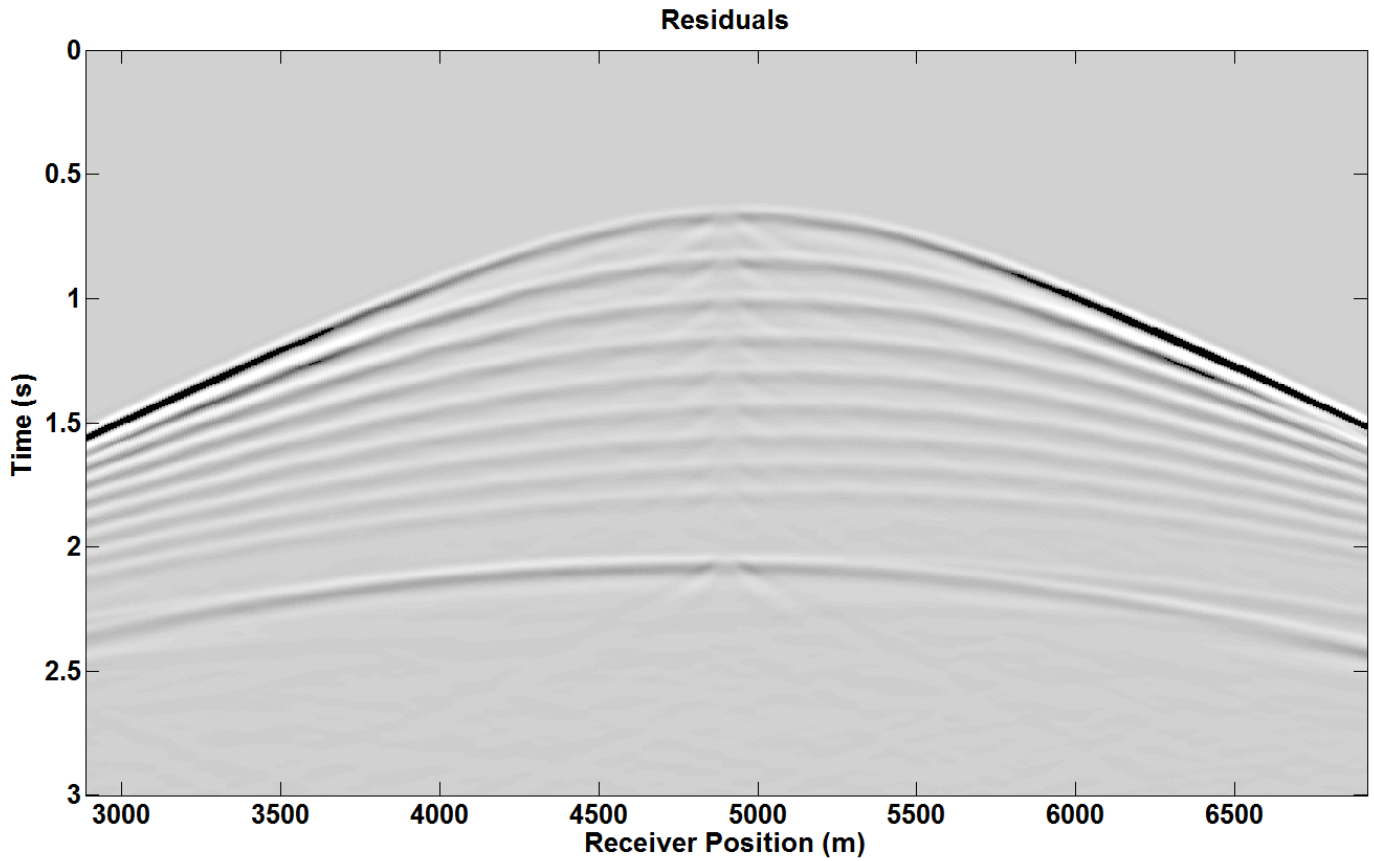
Synthetic Shot (first iteration)



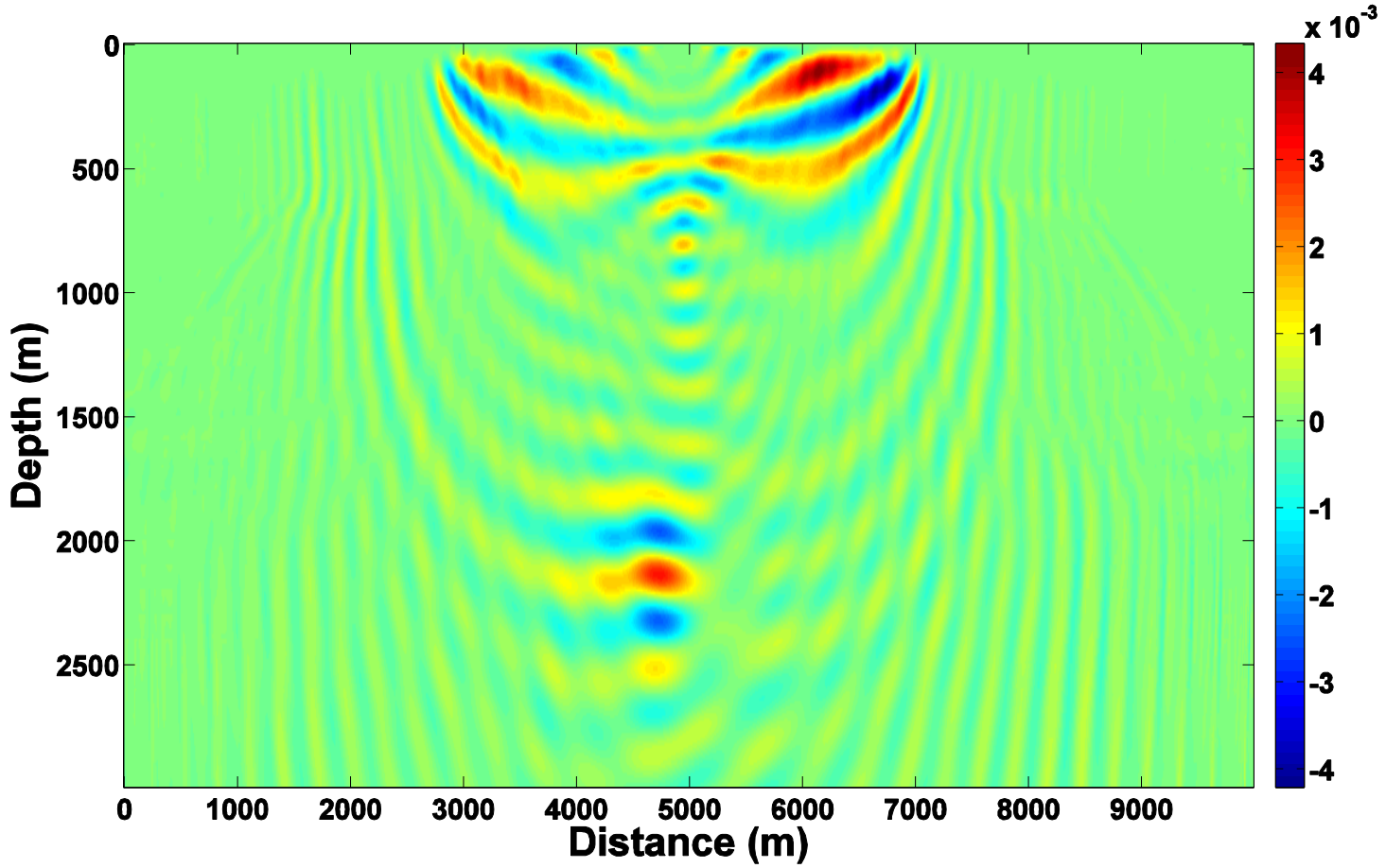
Real Shot (shot 50)



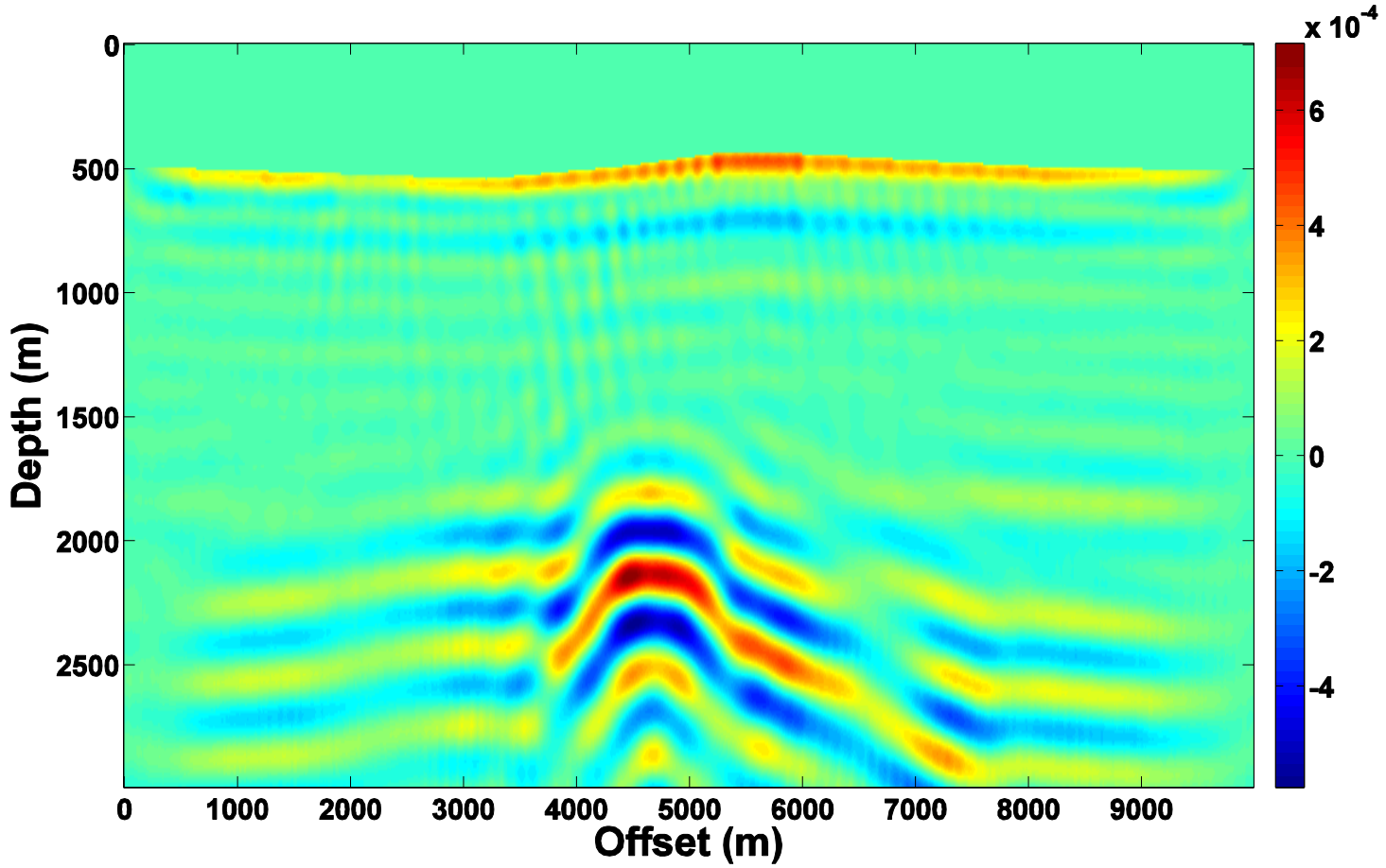
Residuals (first iteration)



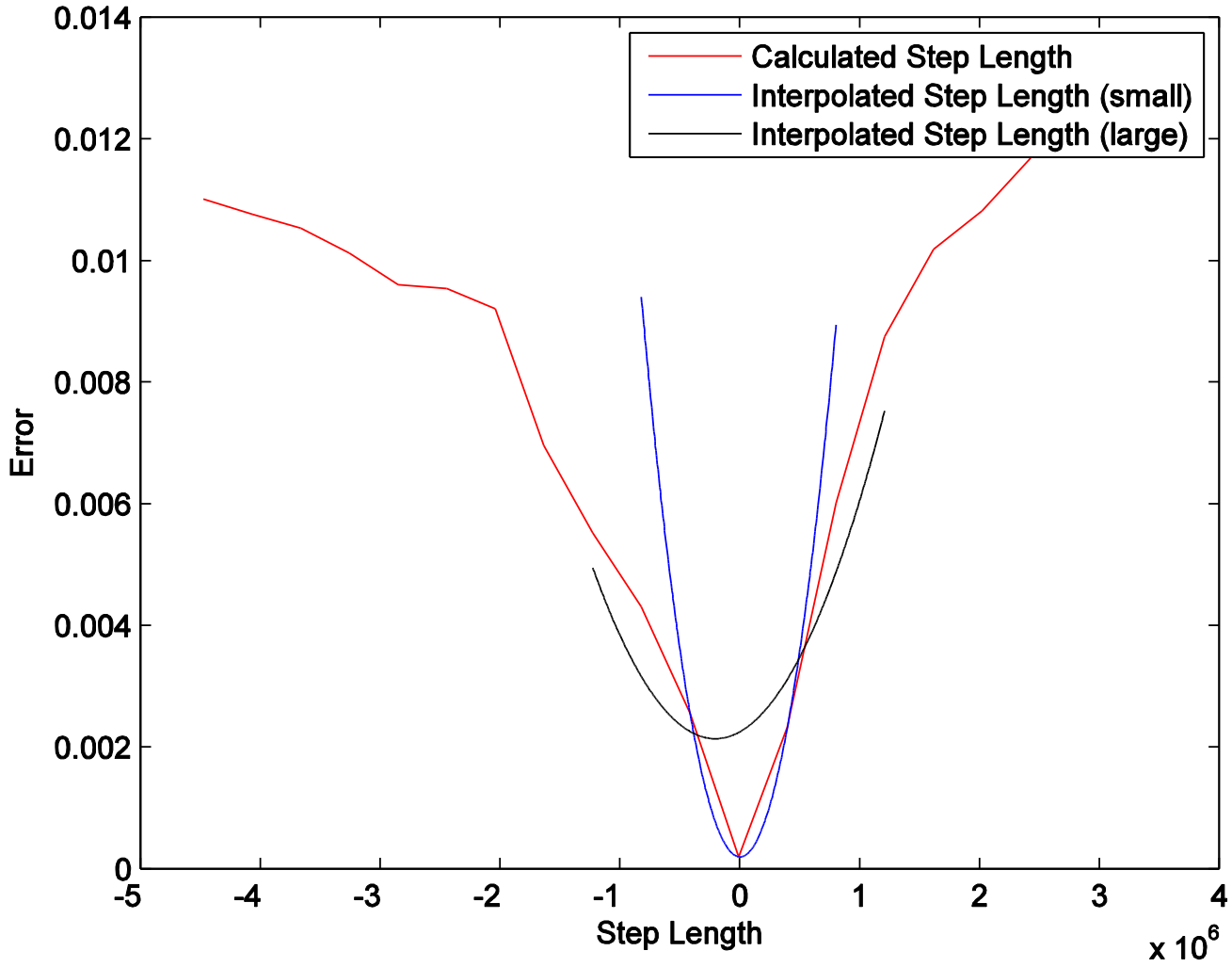
Migrated Residuals – Shot 50



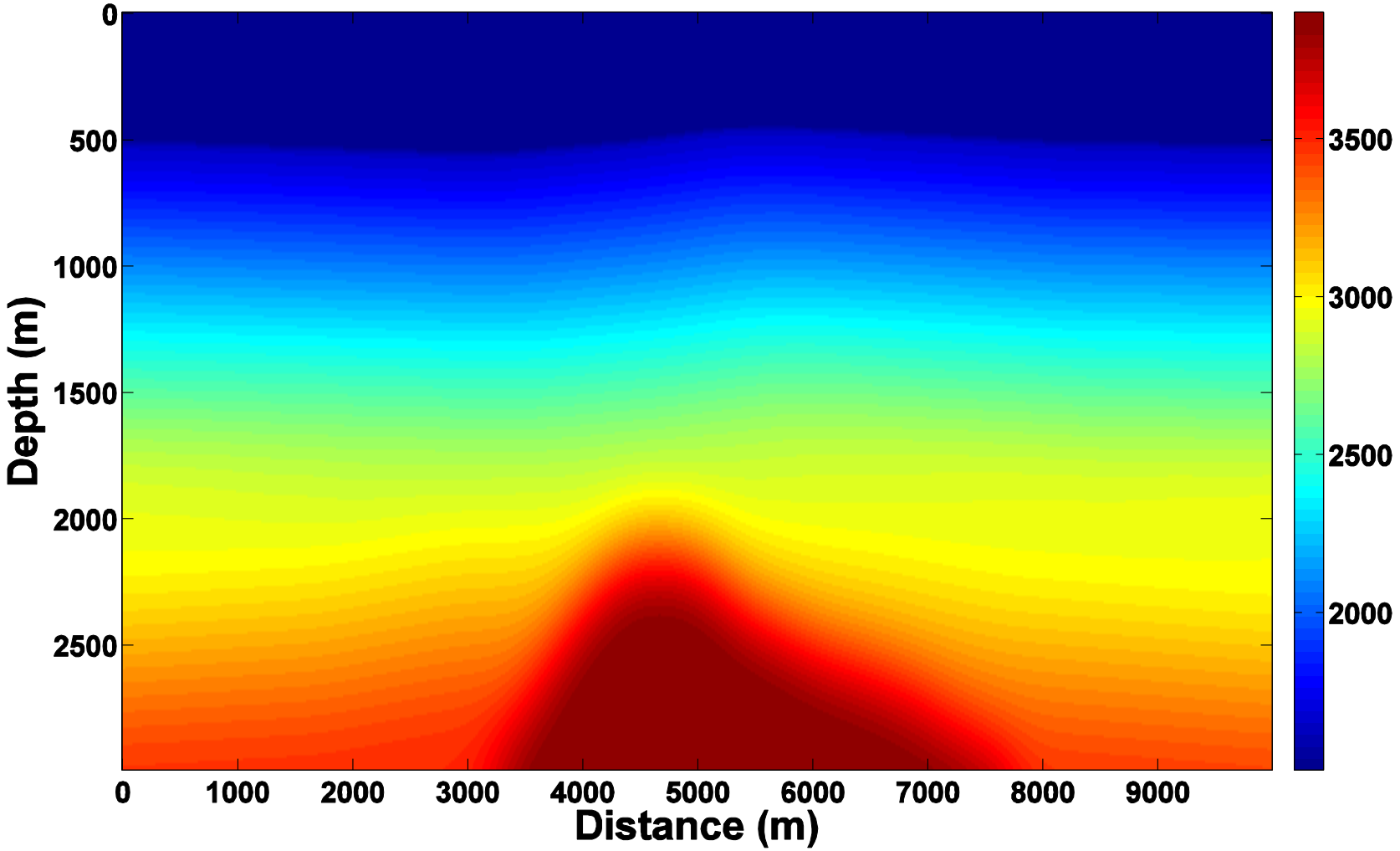
Stacked Migrated Residuals– Iteration 1



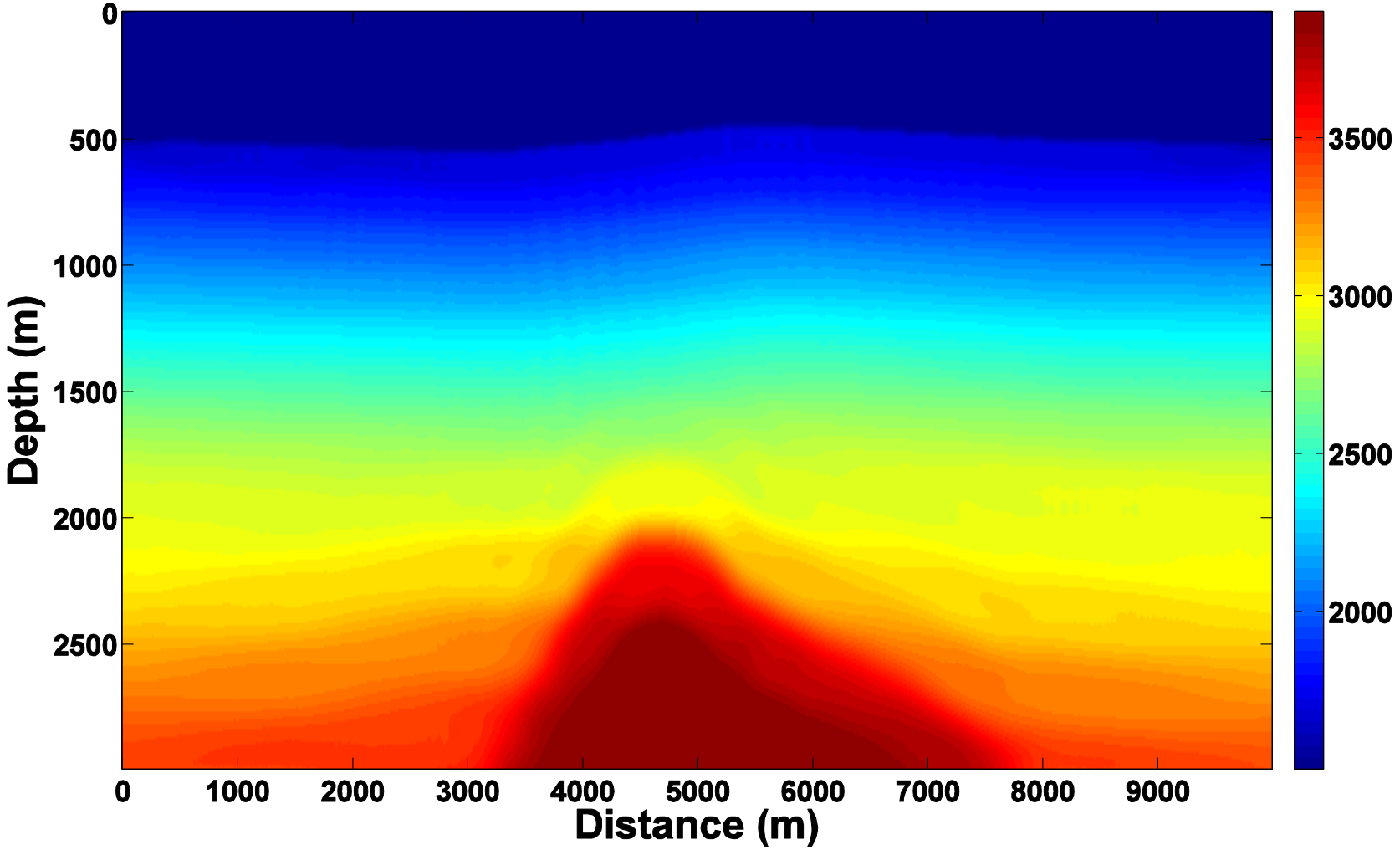
Line Search – Step Length



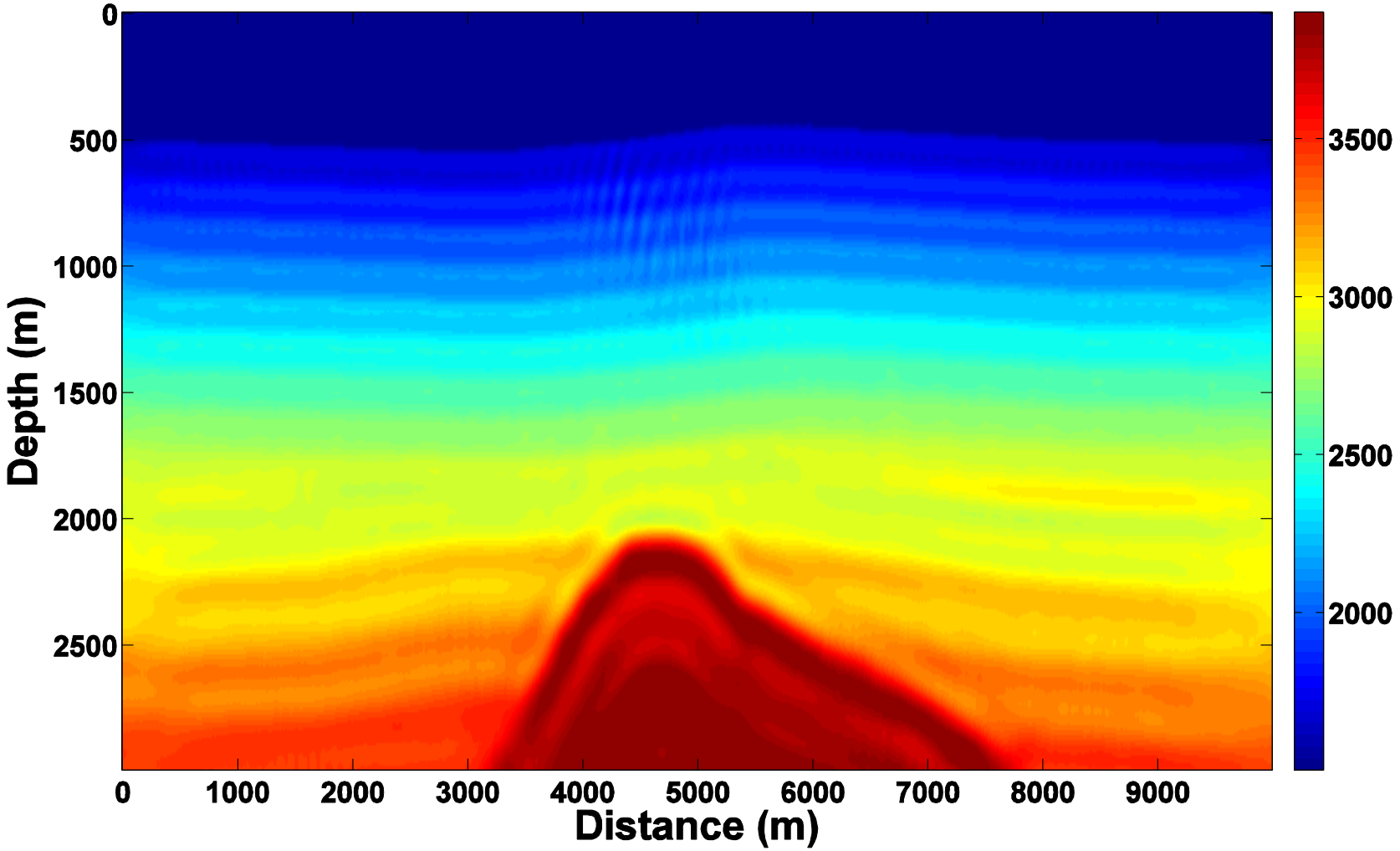
Initial Model



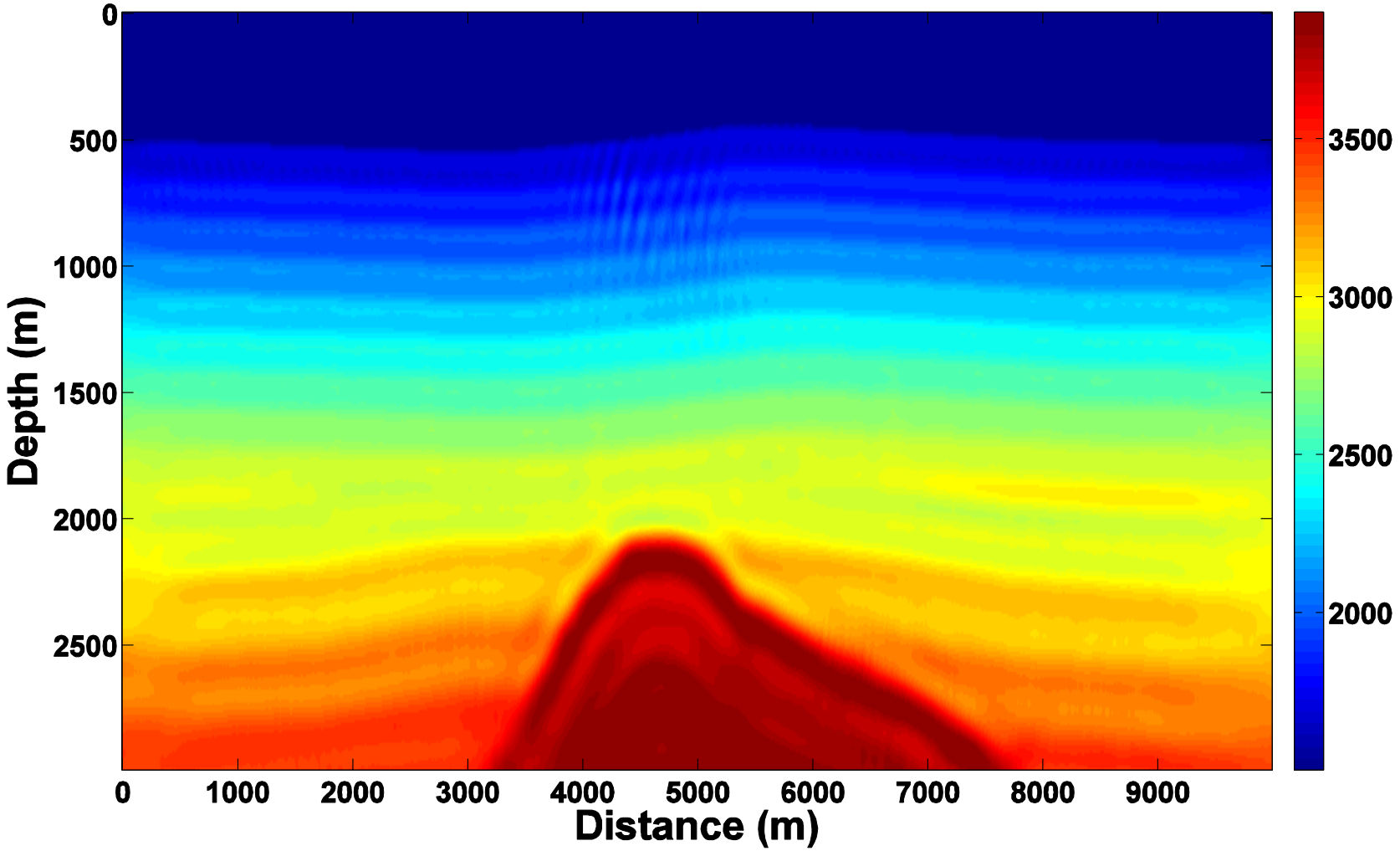
Iteration 1 (1 – 6 Hz)



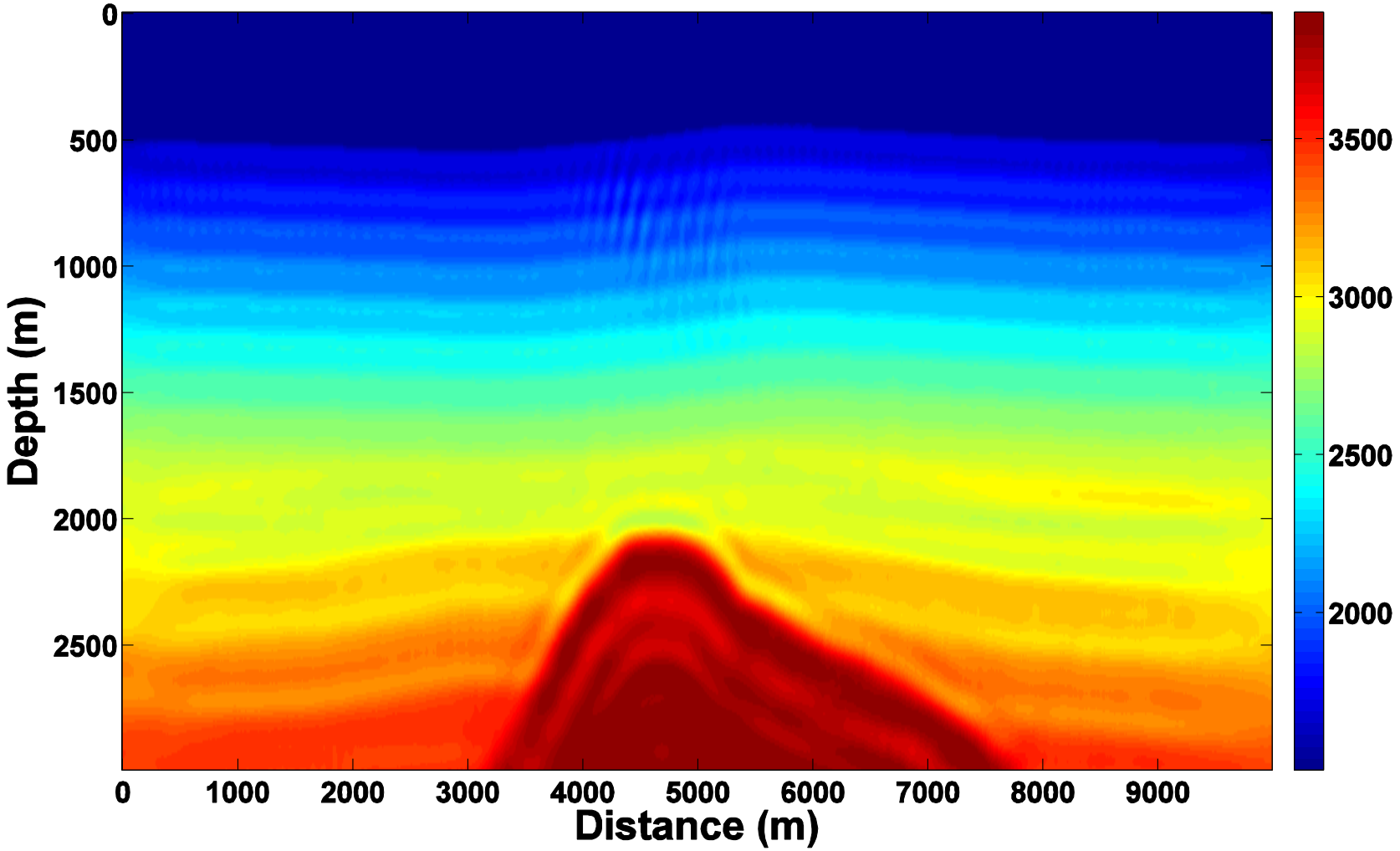
Iteration 40 (1 – 10 Hz)



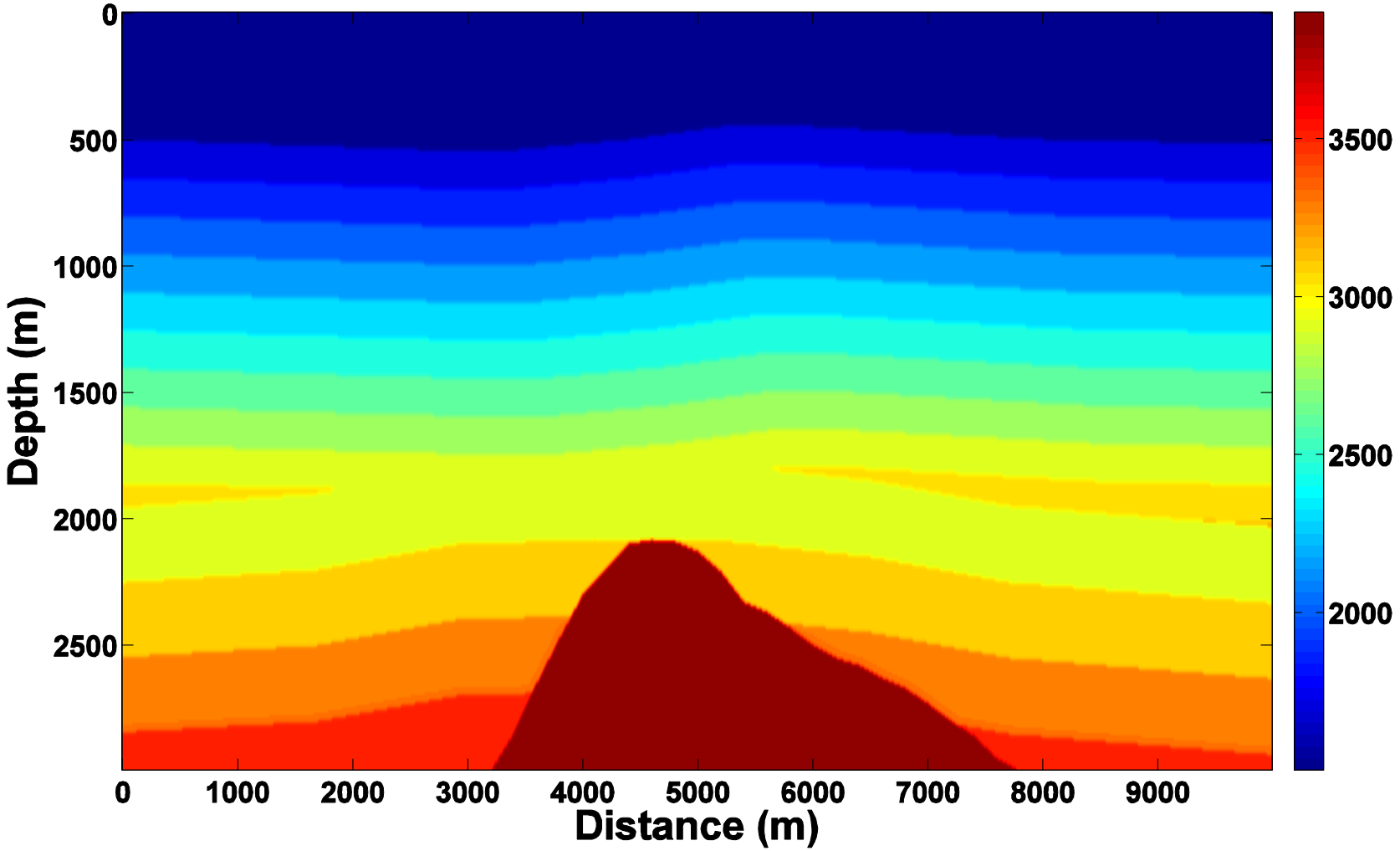
Iteration 50 (1 – 11 Hz)



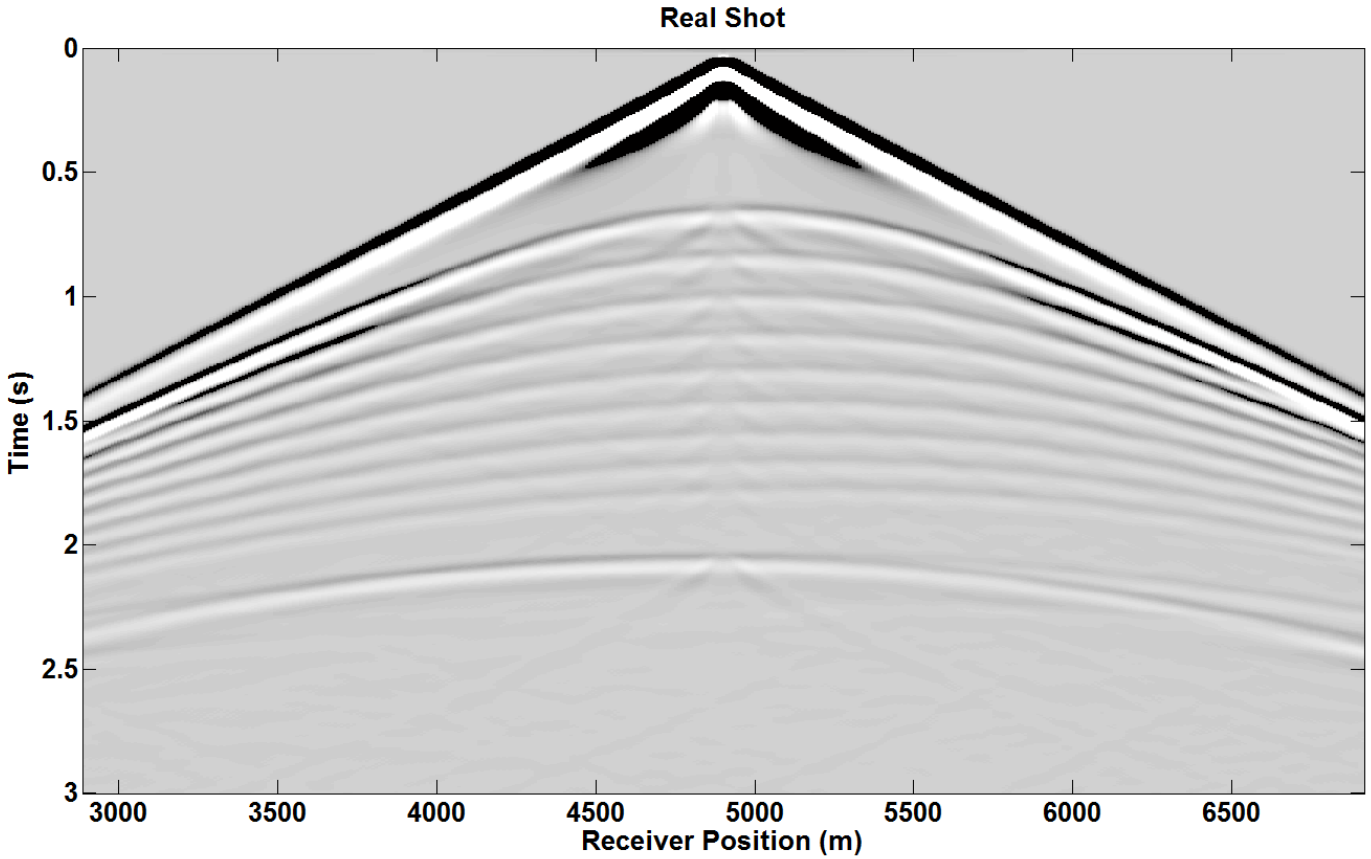
Iteration 79 (1 – 13 Hz)



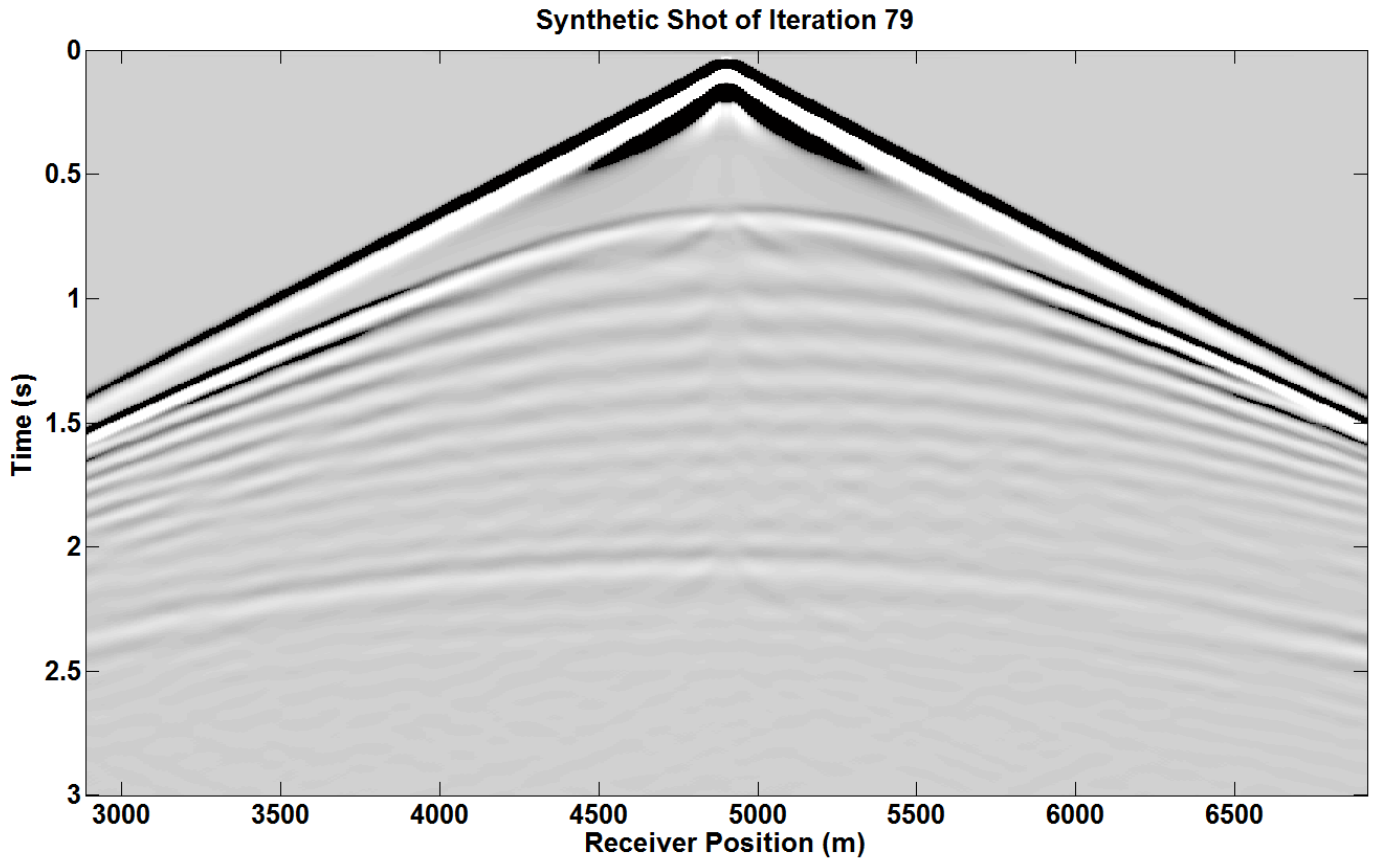
Real Model


0
500
1000
1500
2000
2500
Depth (m)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Distance (m)
3500
3000
2500
2000

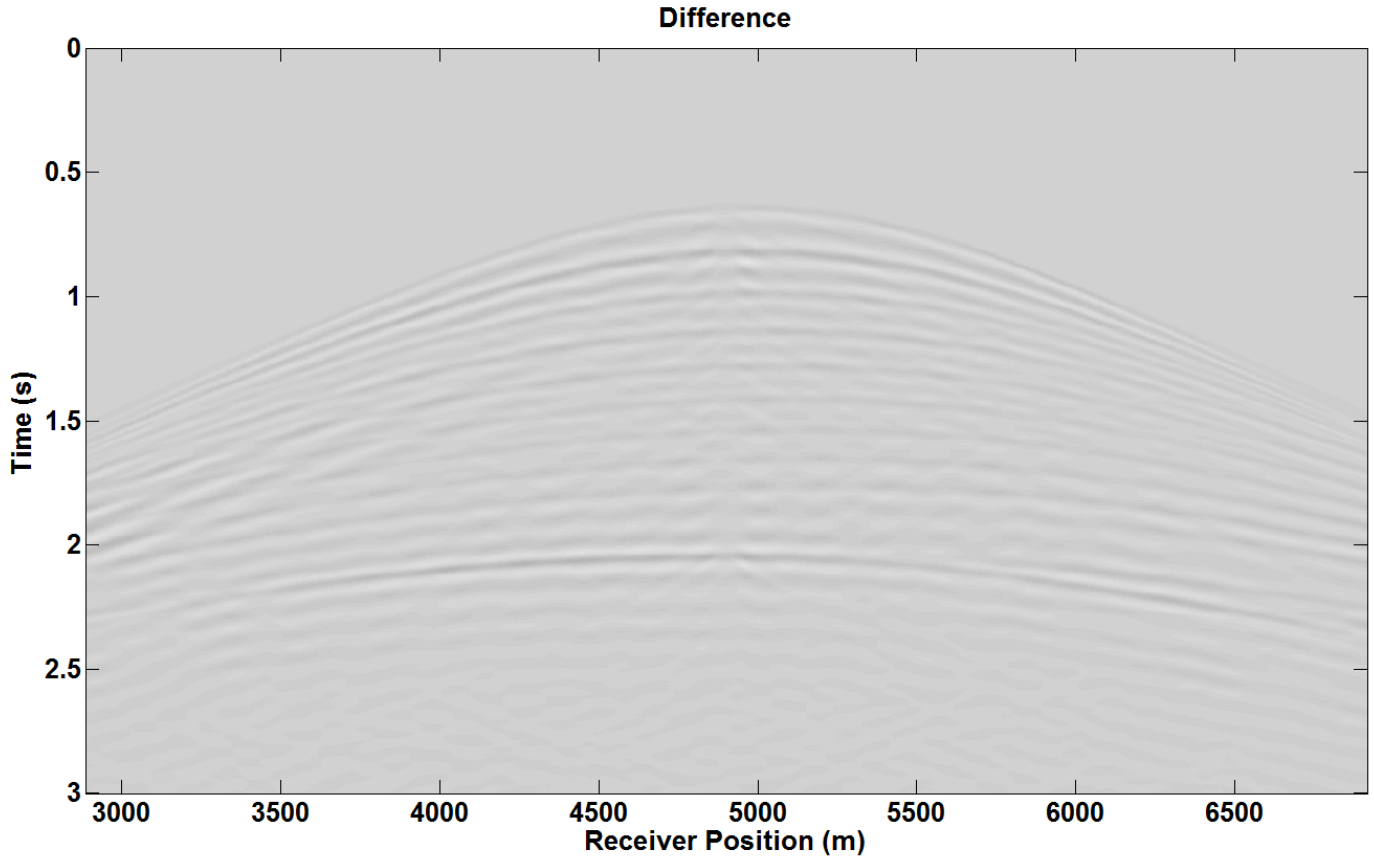
Real Shot (shot 50)



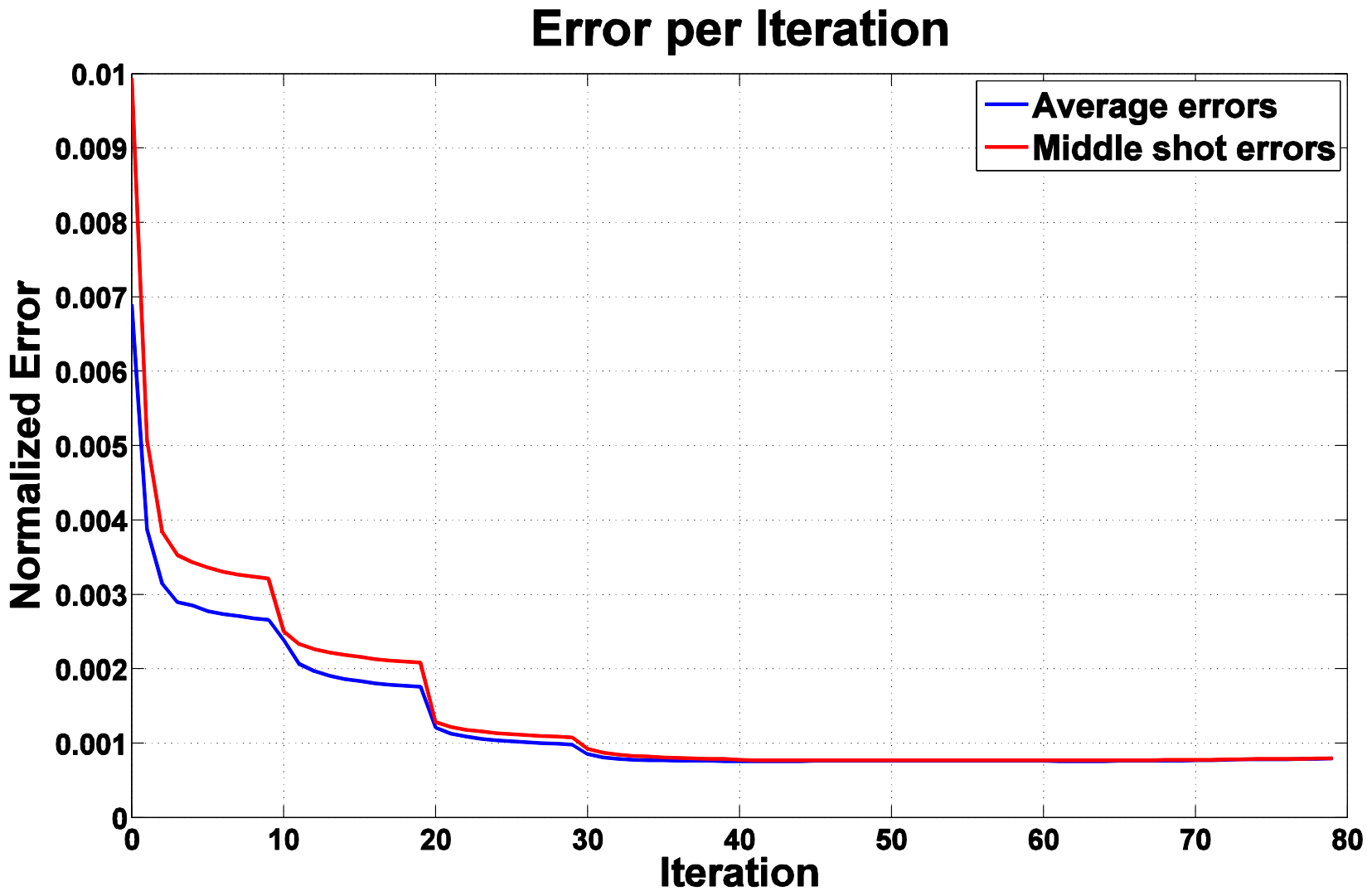
Synthetic Shot of Iteration 79



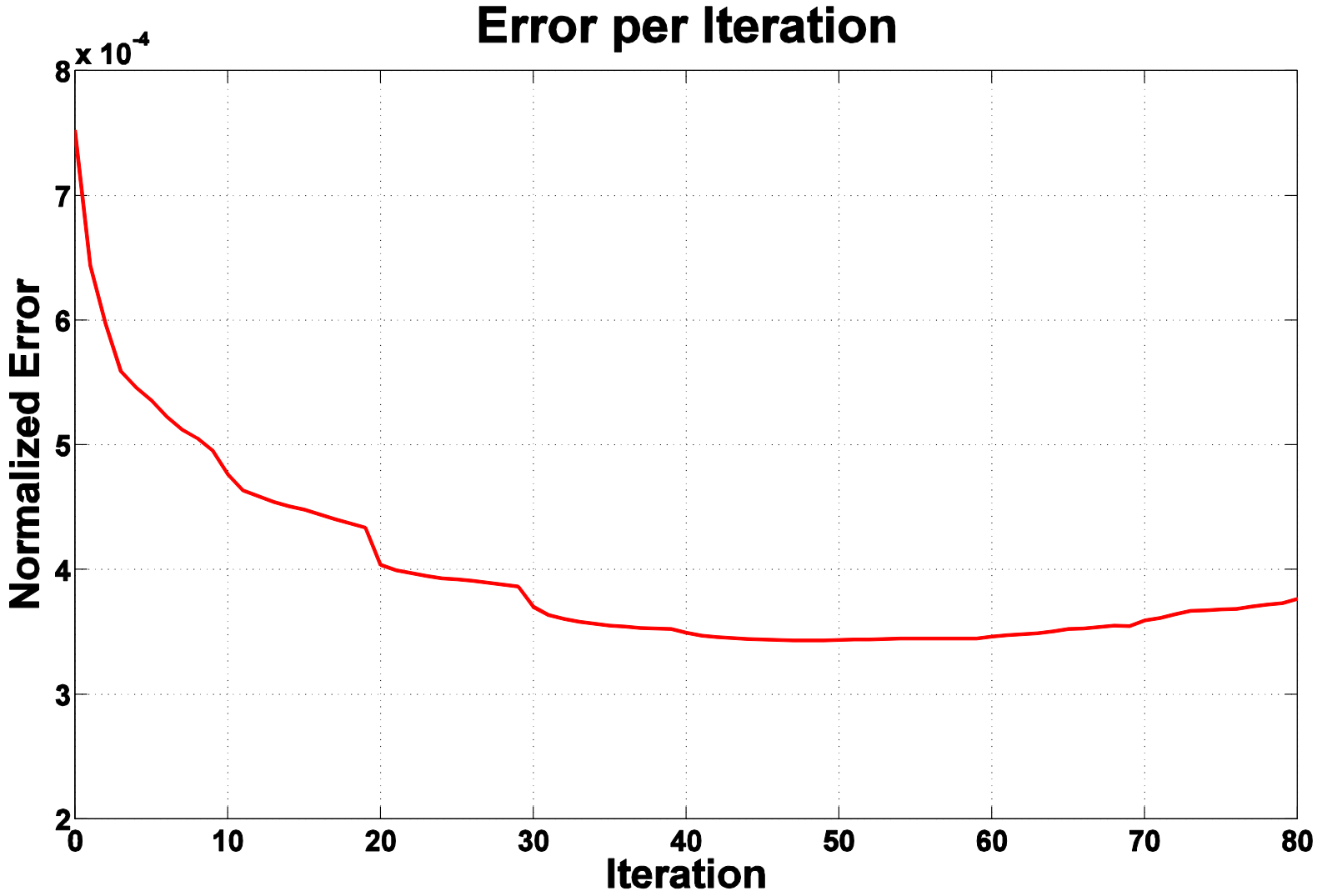
Difference


Difference
Time (s)
0
0.5
1
1.5
2
2.5
3
3000
3500
4000
4500
5000
5500
6000
6500
Receiver Position (m)

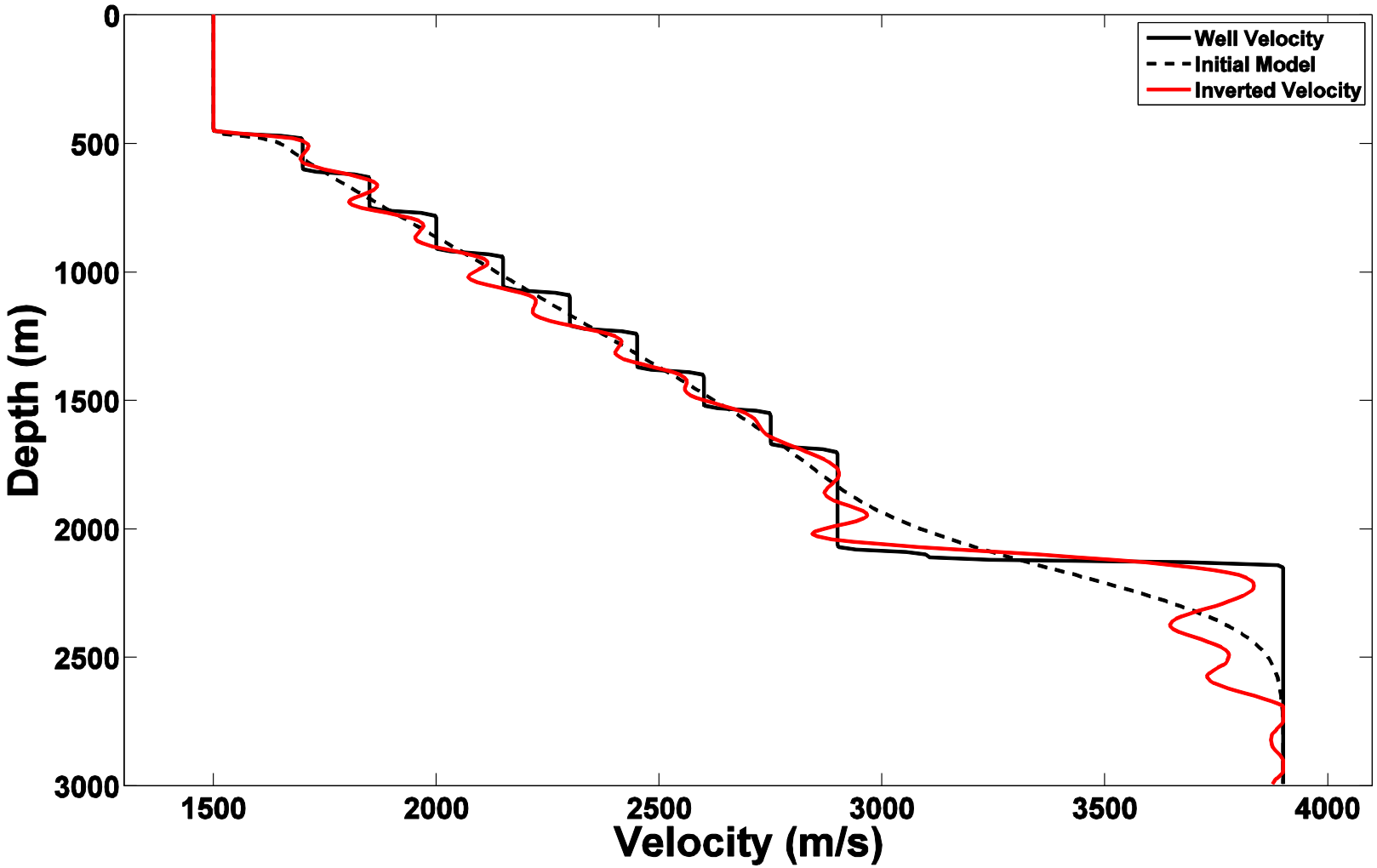
Error per Iteration (shots)



Error per Iteration (model)

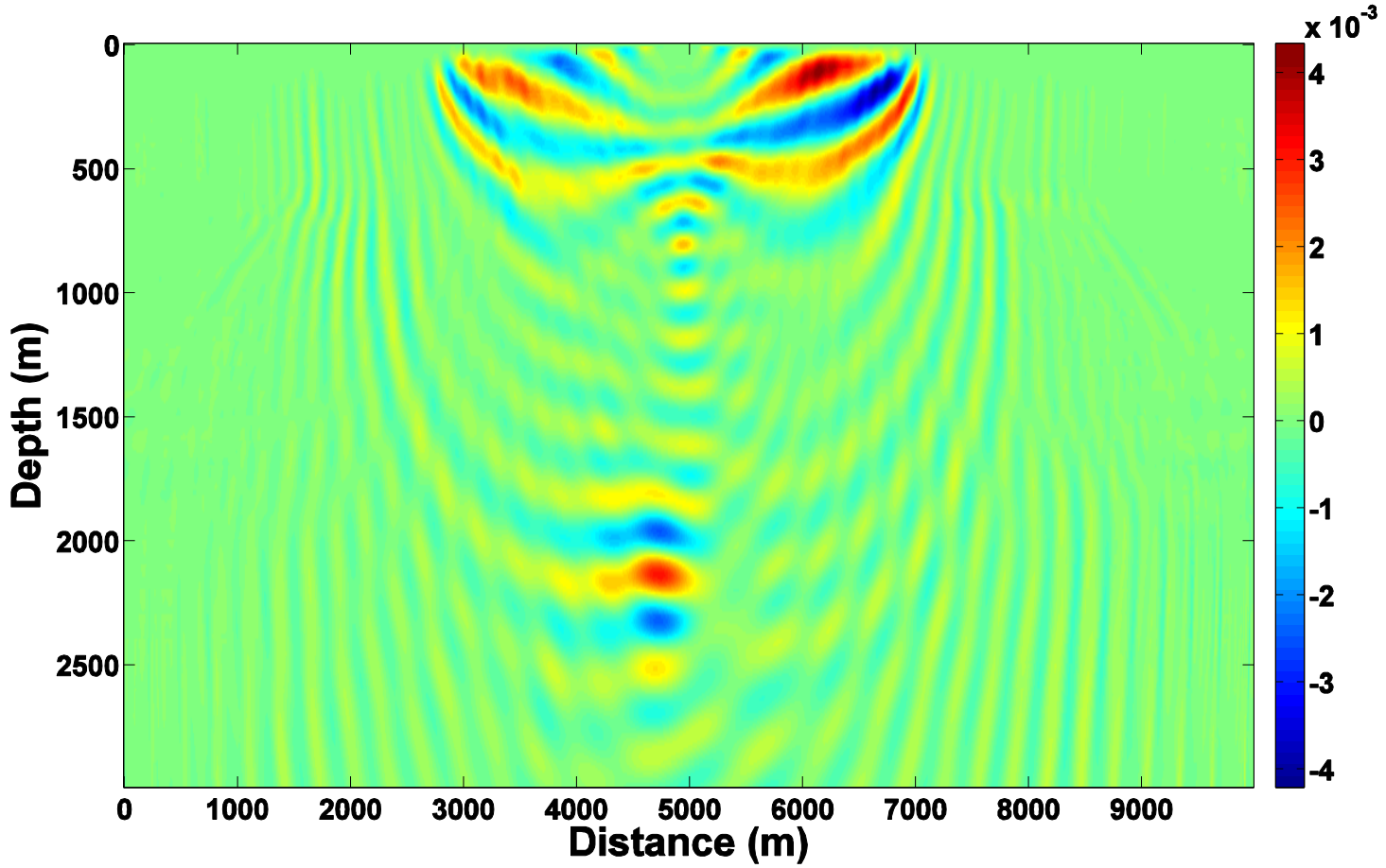


1D Velocity QC

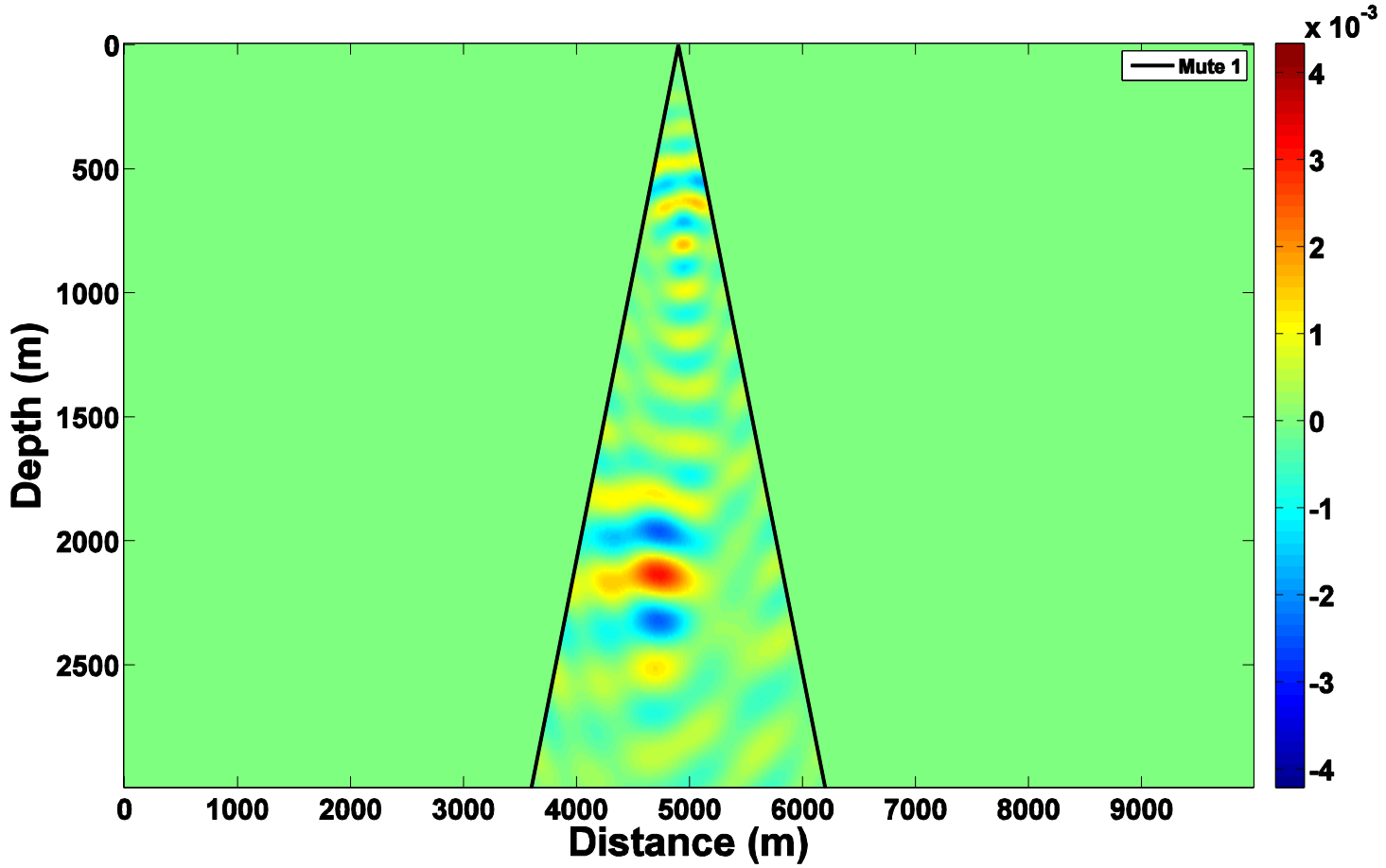


Mute – First Test

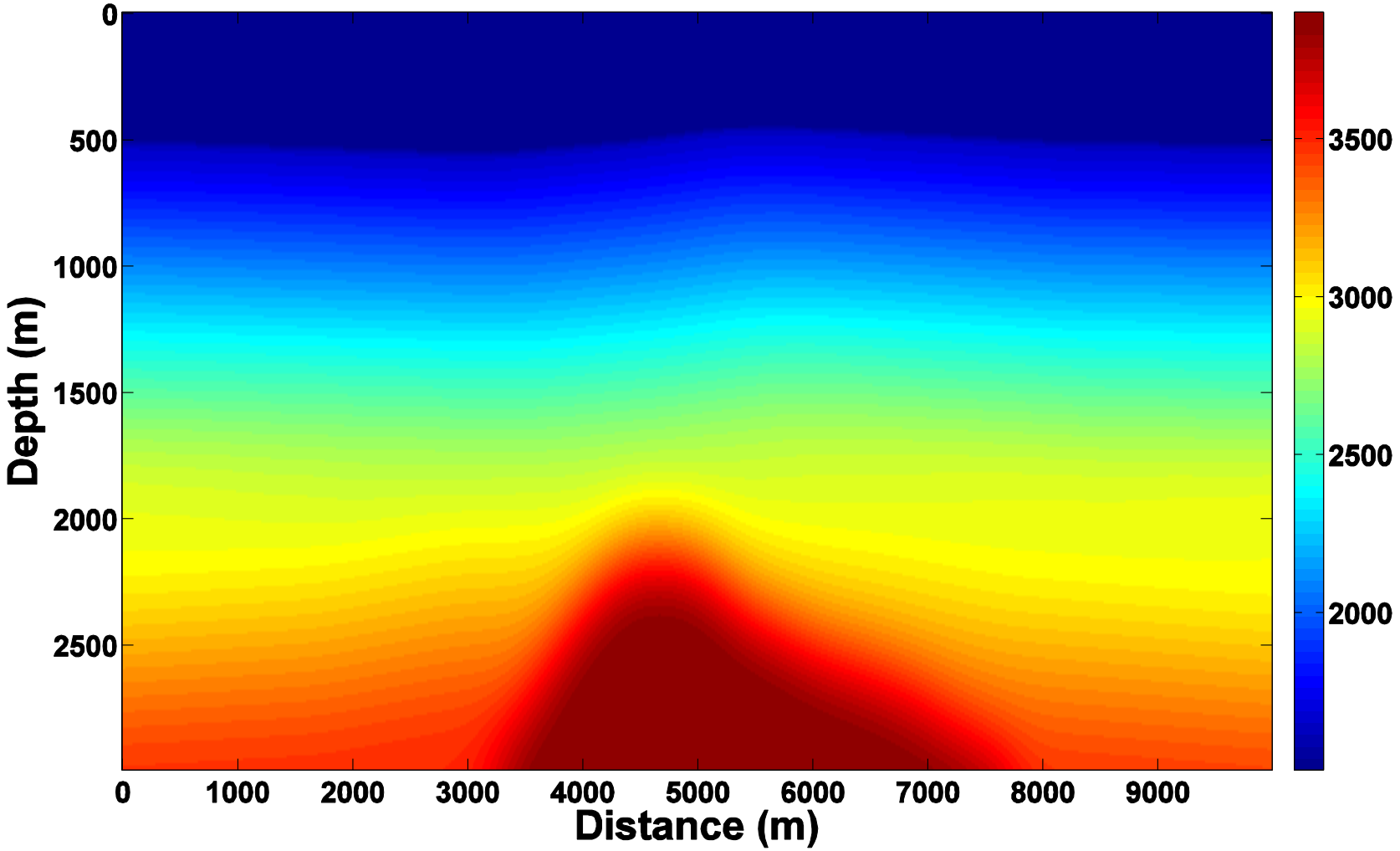
Migrated Residuals – Shot 50



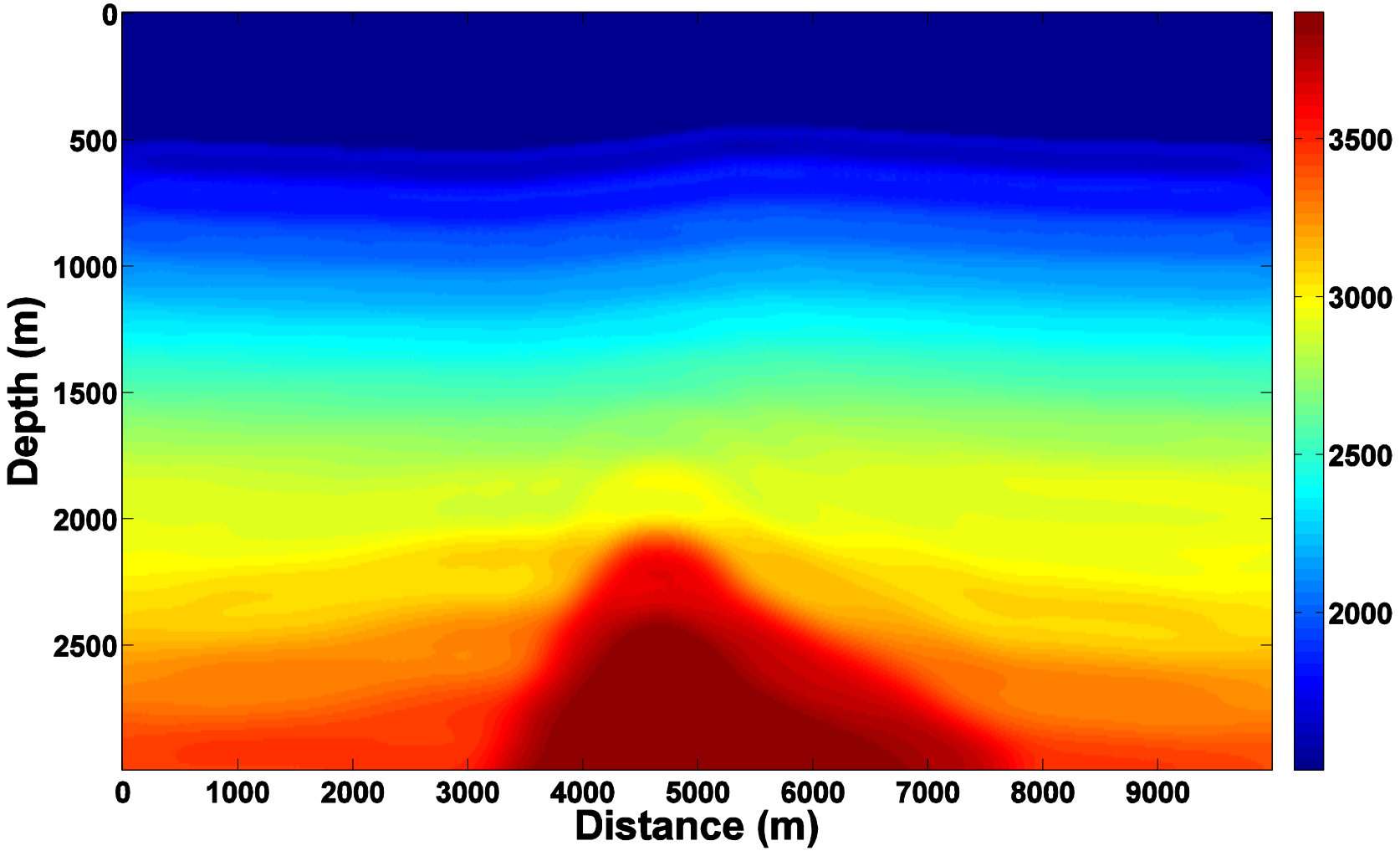
Muted Migrated Residuals – Shot 50



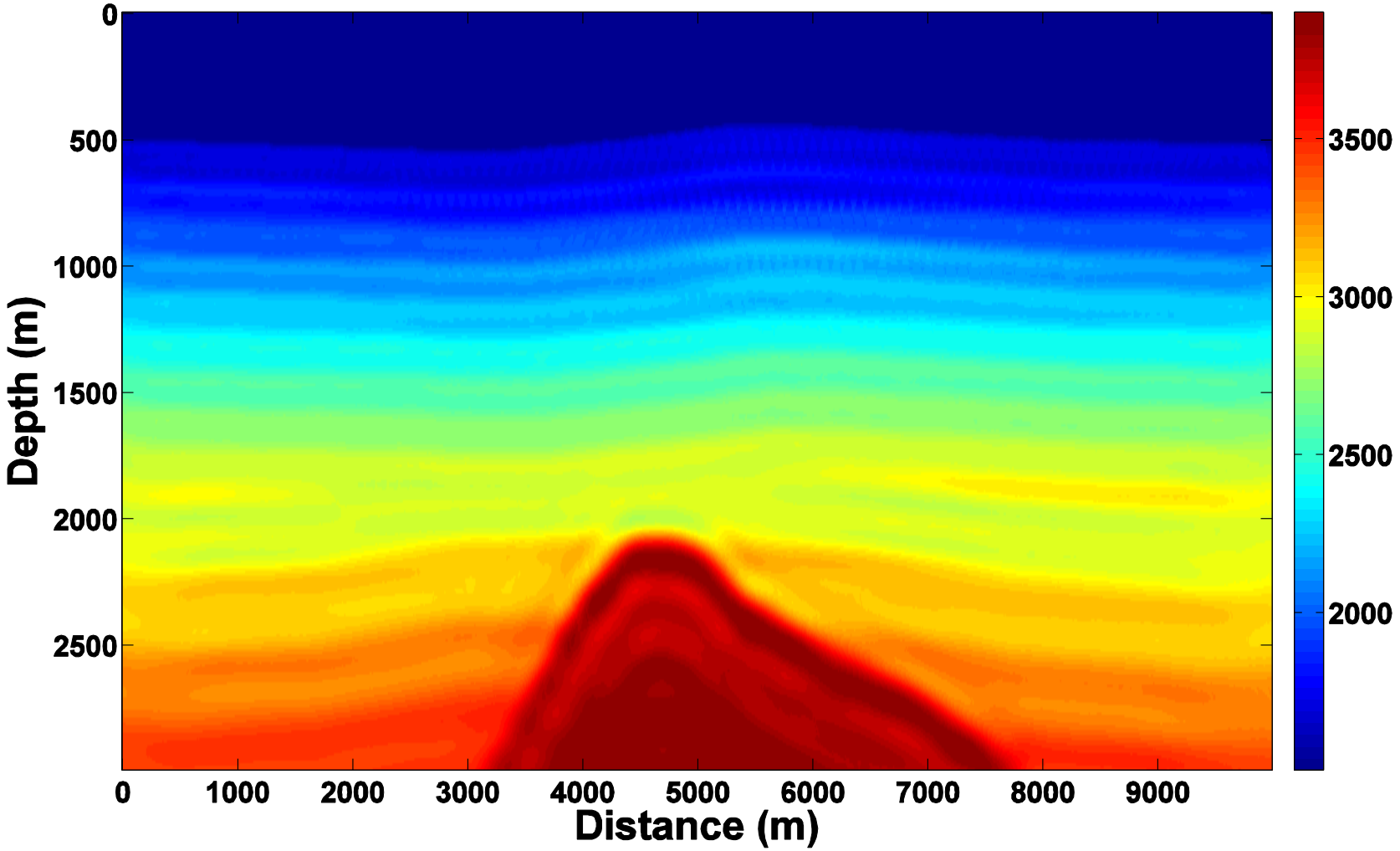
Initial Model



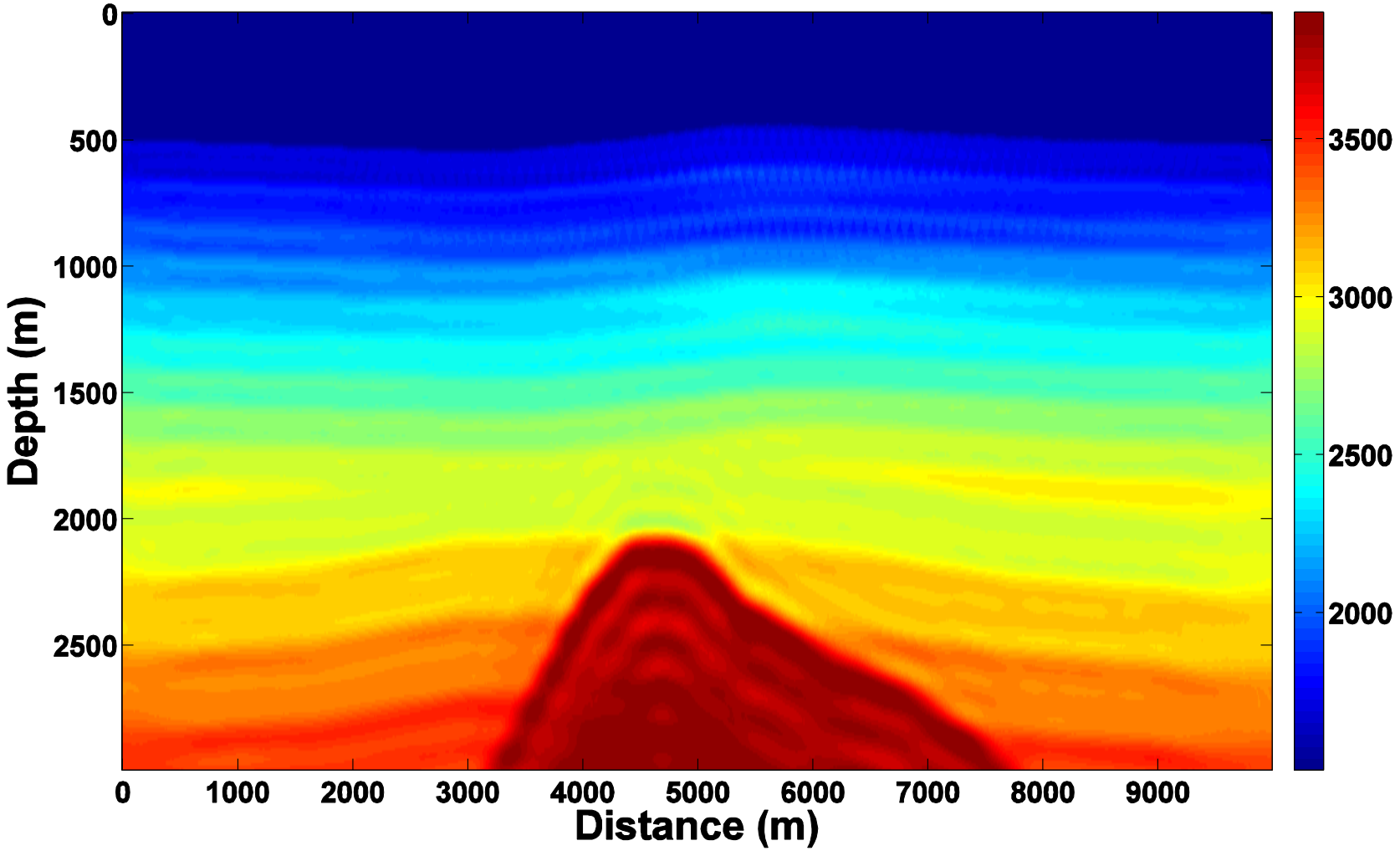
Iteration 1 (1 – 6 Hz)



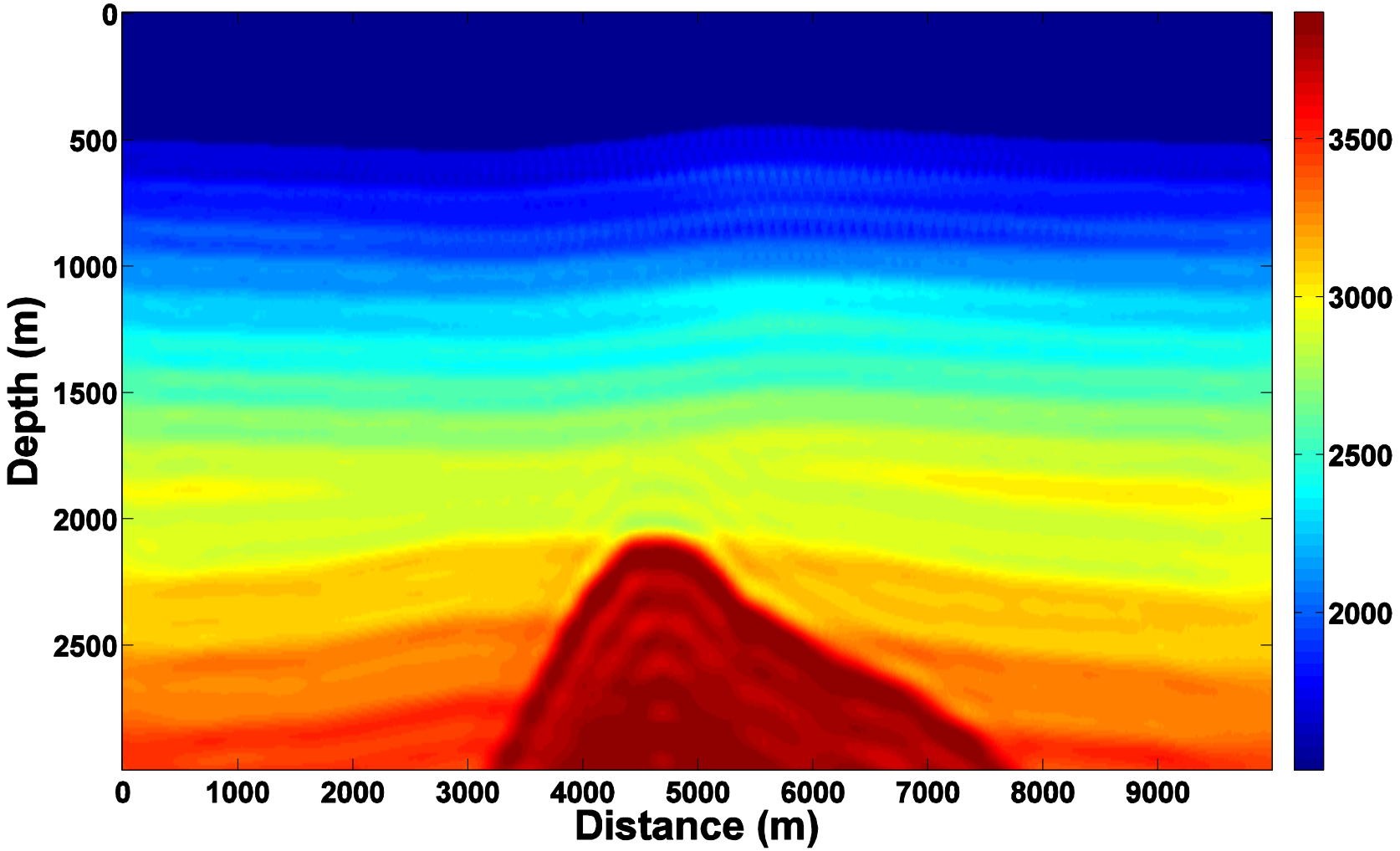
Iteration 40 (1 – 10 Hz)



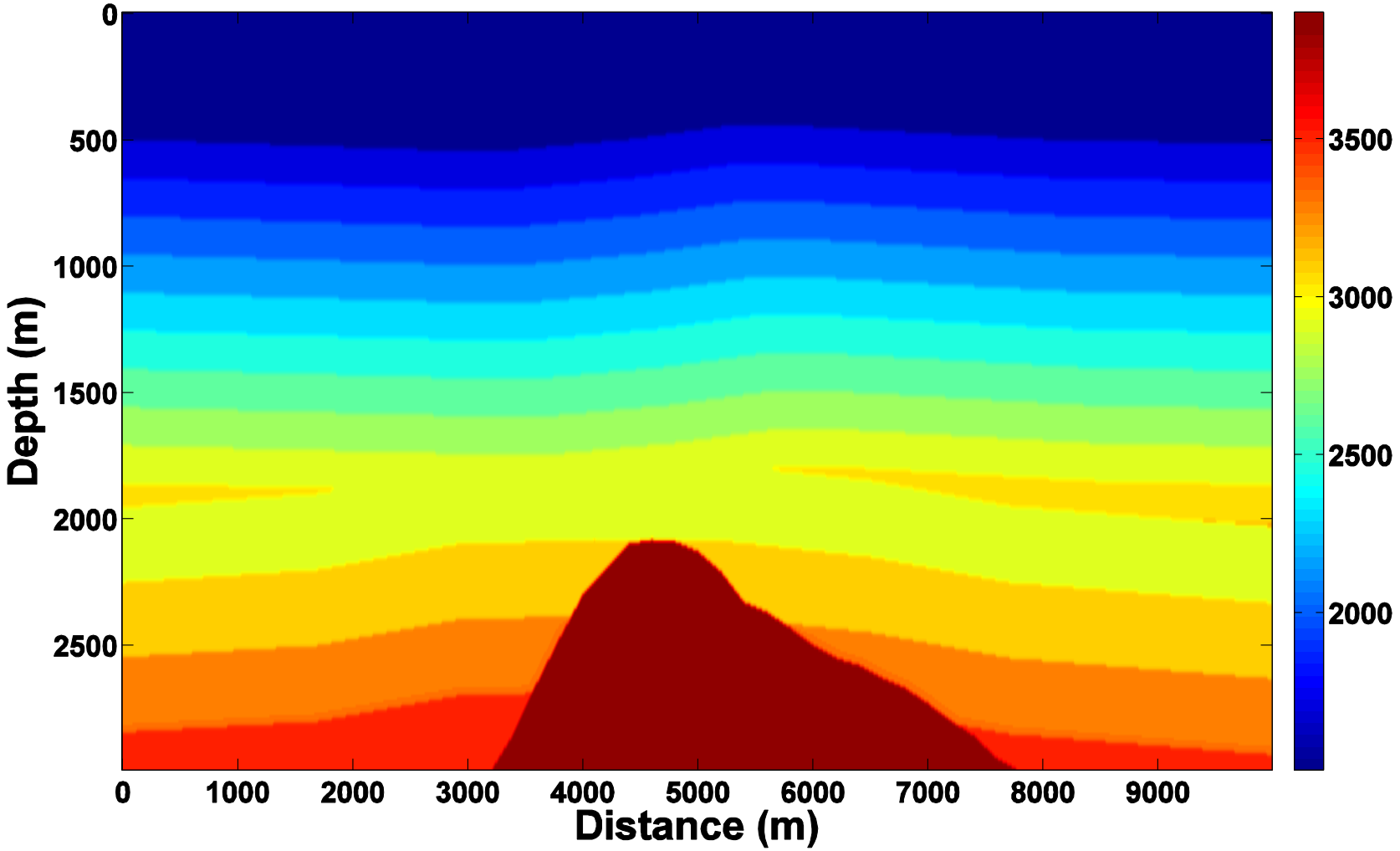
Iteration 85 (1 – 14 Hz)



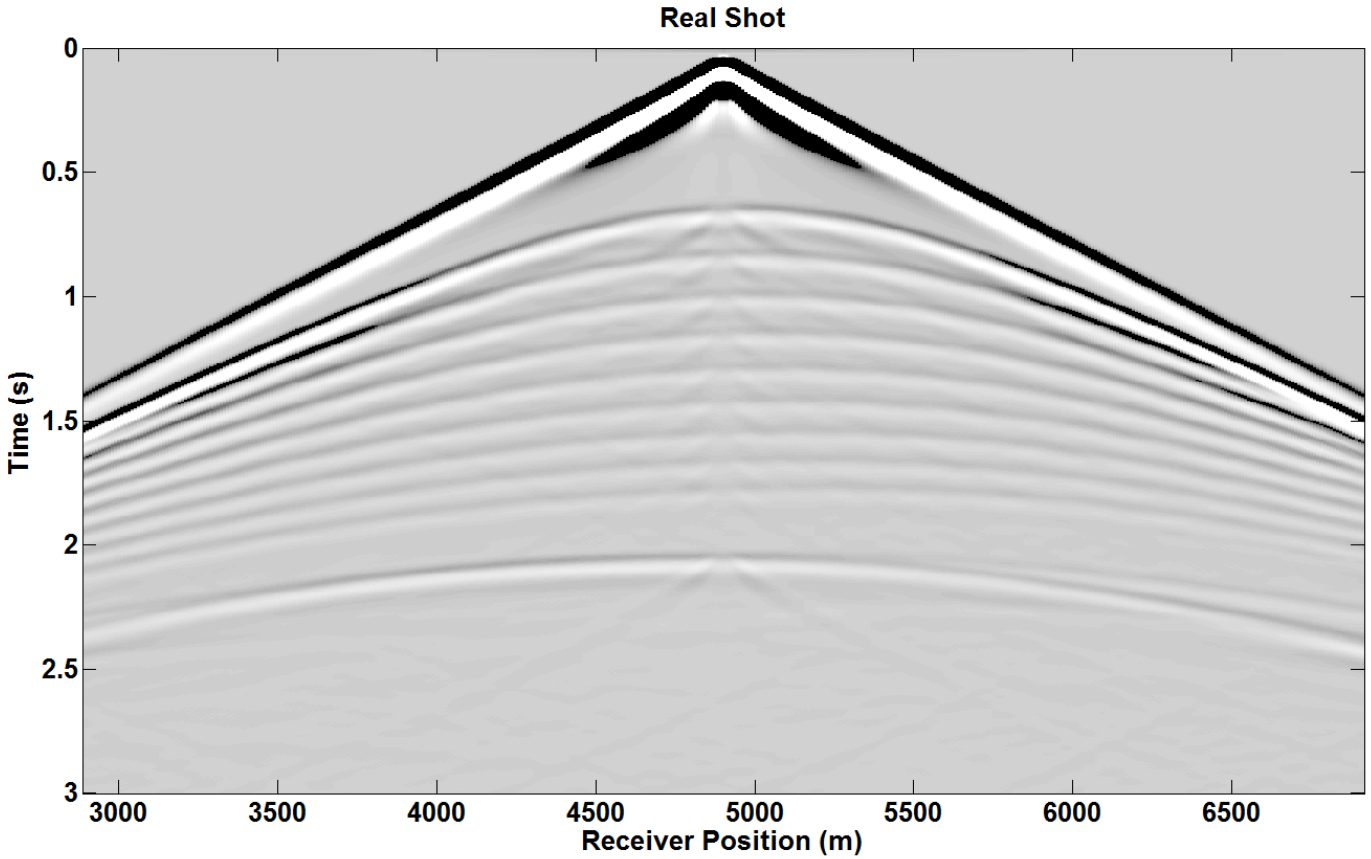
Iteration 101 (1 – 16 Hz)



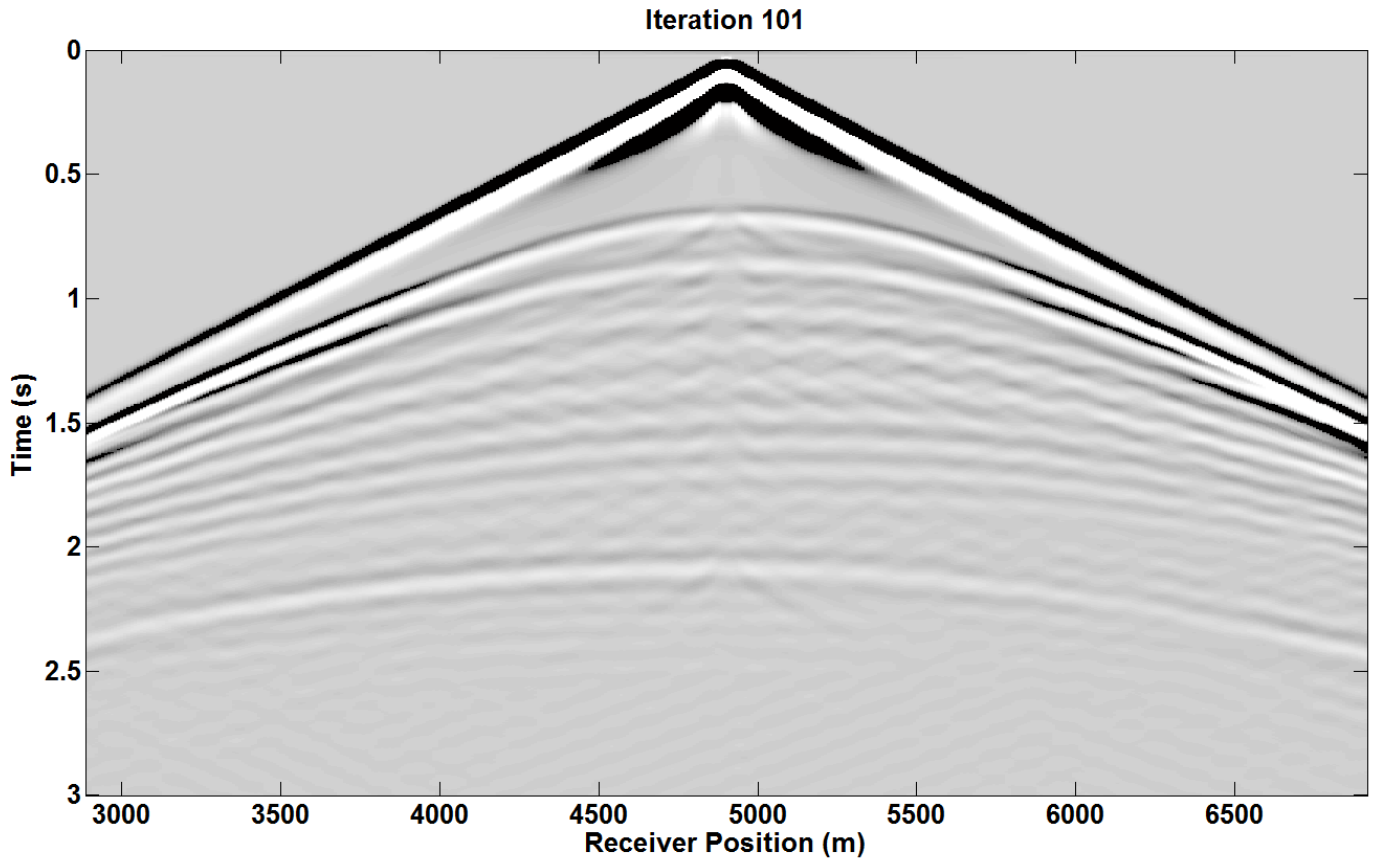
Real Model


0
500
1000
1500
2000
2500
Depth (m)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Distance (m)
3500
3000
2500
2000

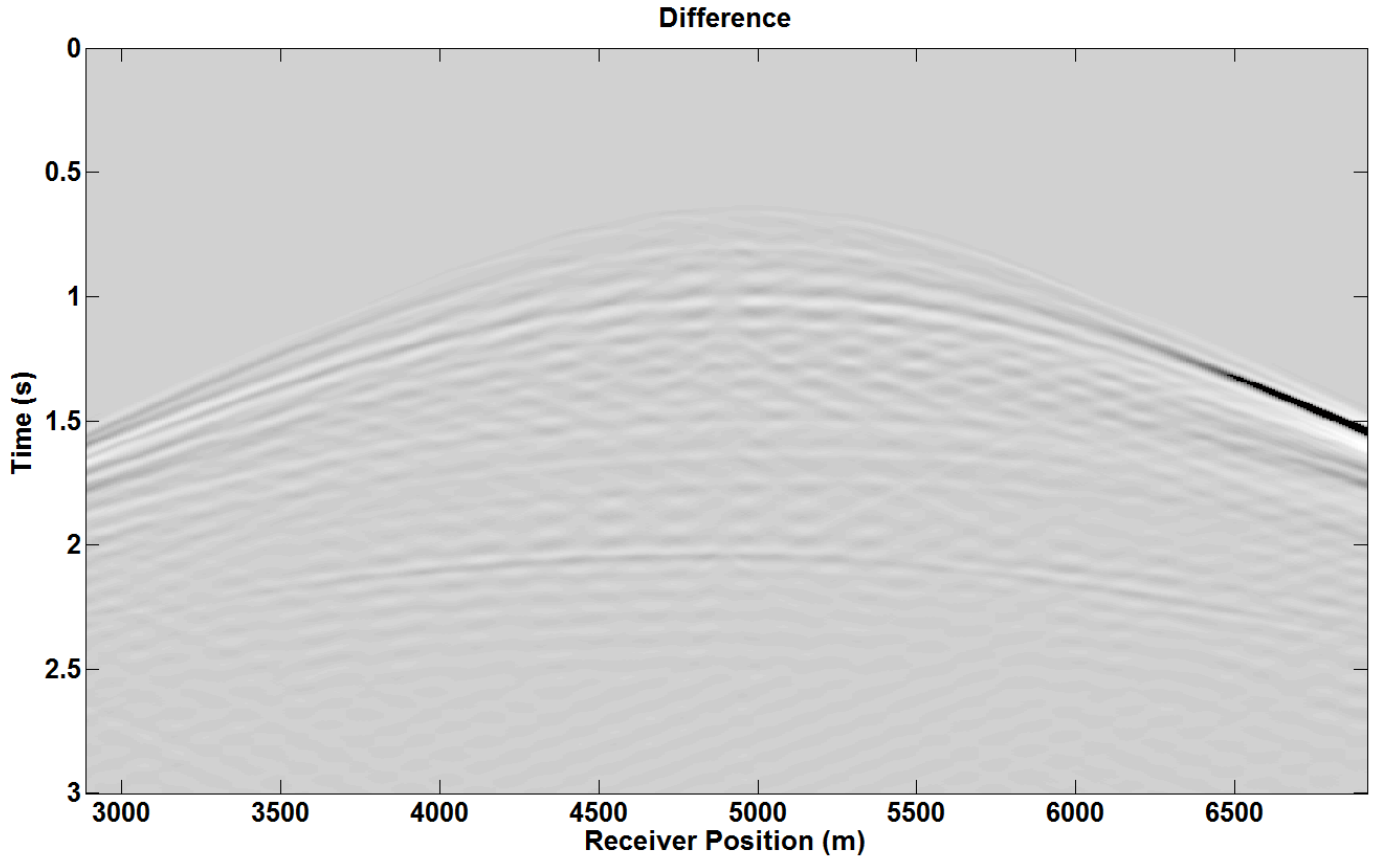
Real Shot (shot 50)



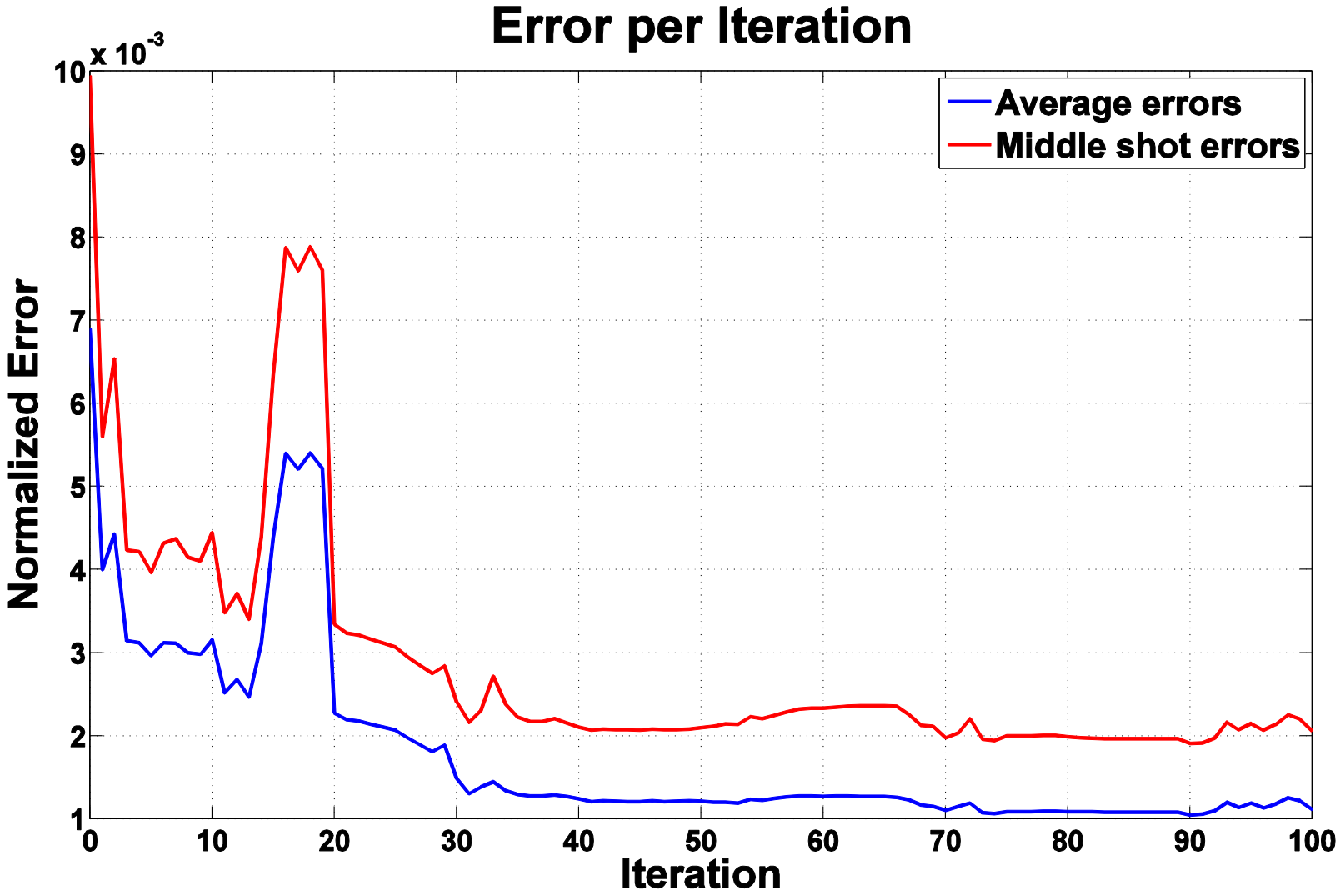
Synthetic Shot of Iteration 101



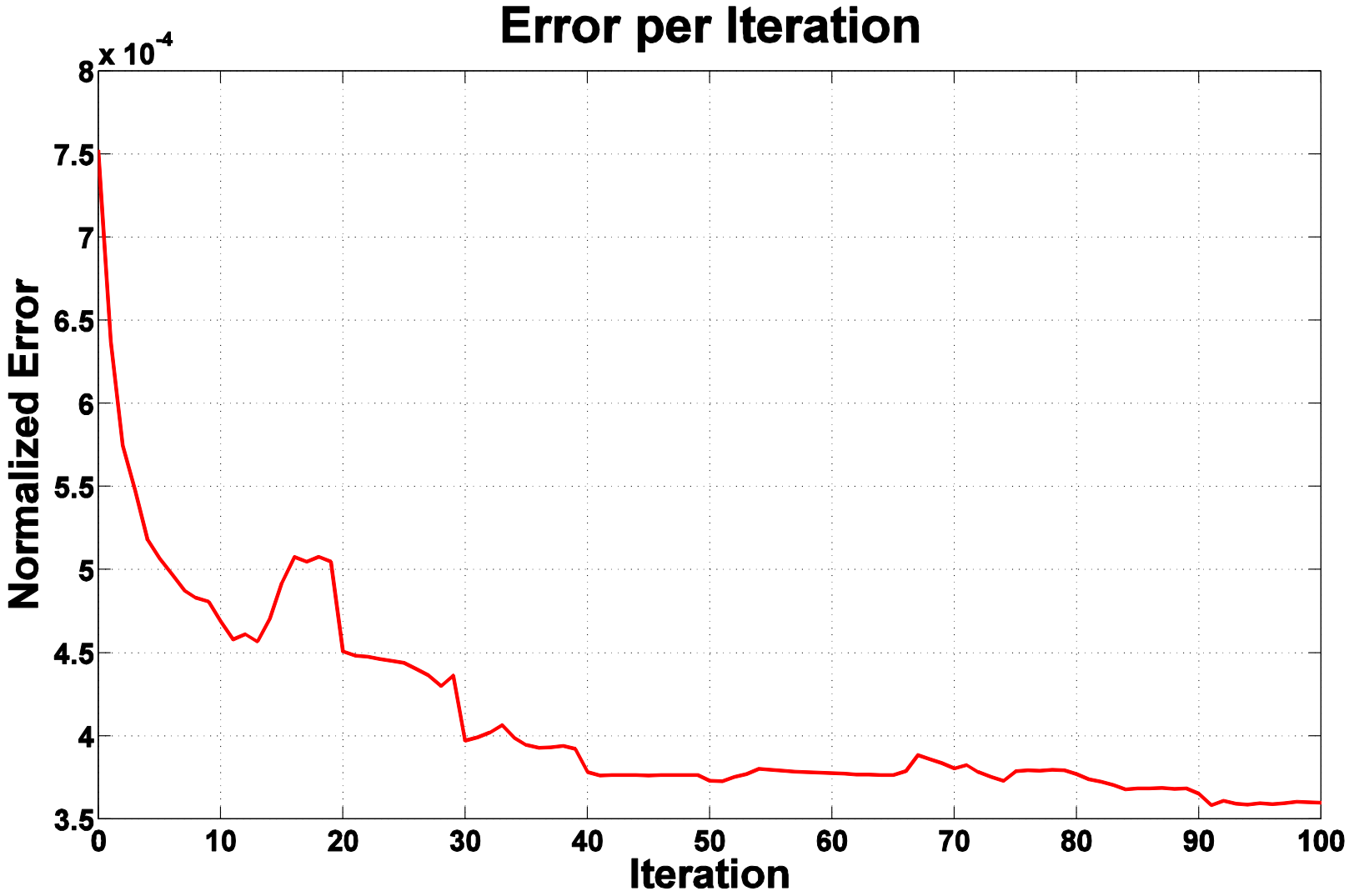
Difference


Difference
Time (s)
0
0.5
1
1.5
2
2.5
3
3000
3500
4000
4500
5000
5500
6000
6500
Receiver Position (m)

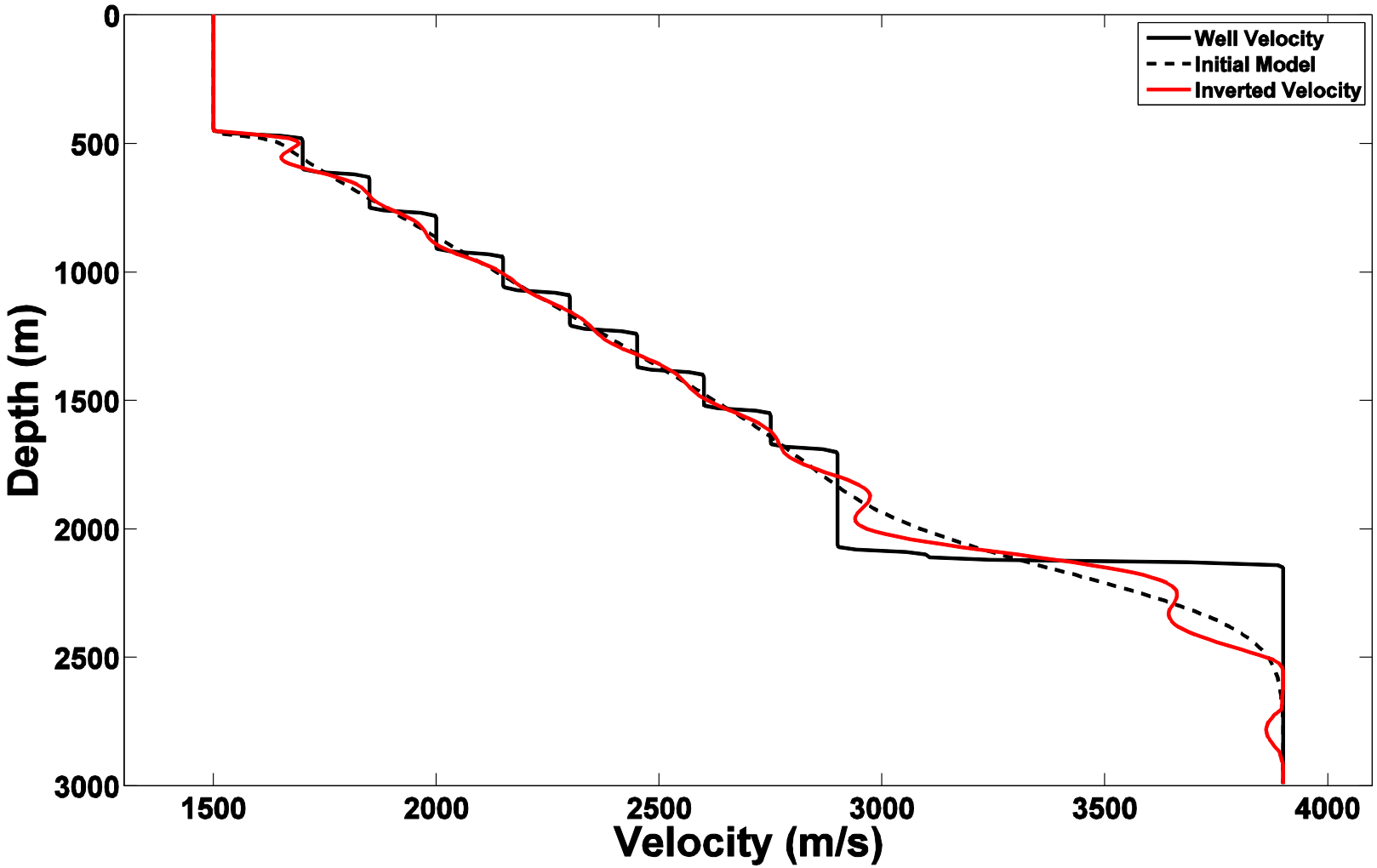
Error per Iteration (shots)



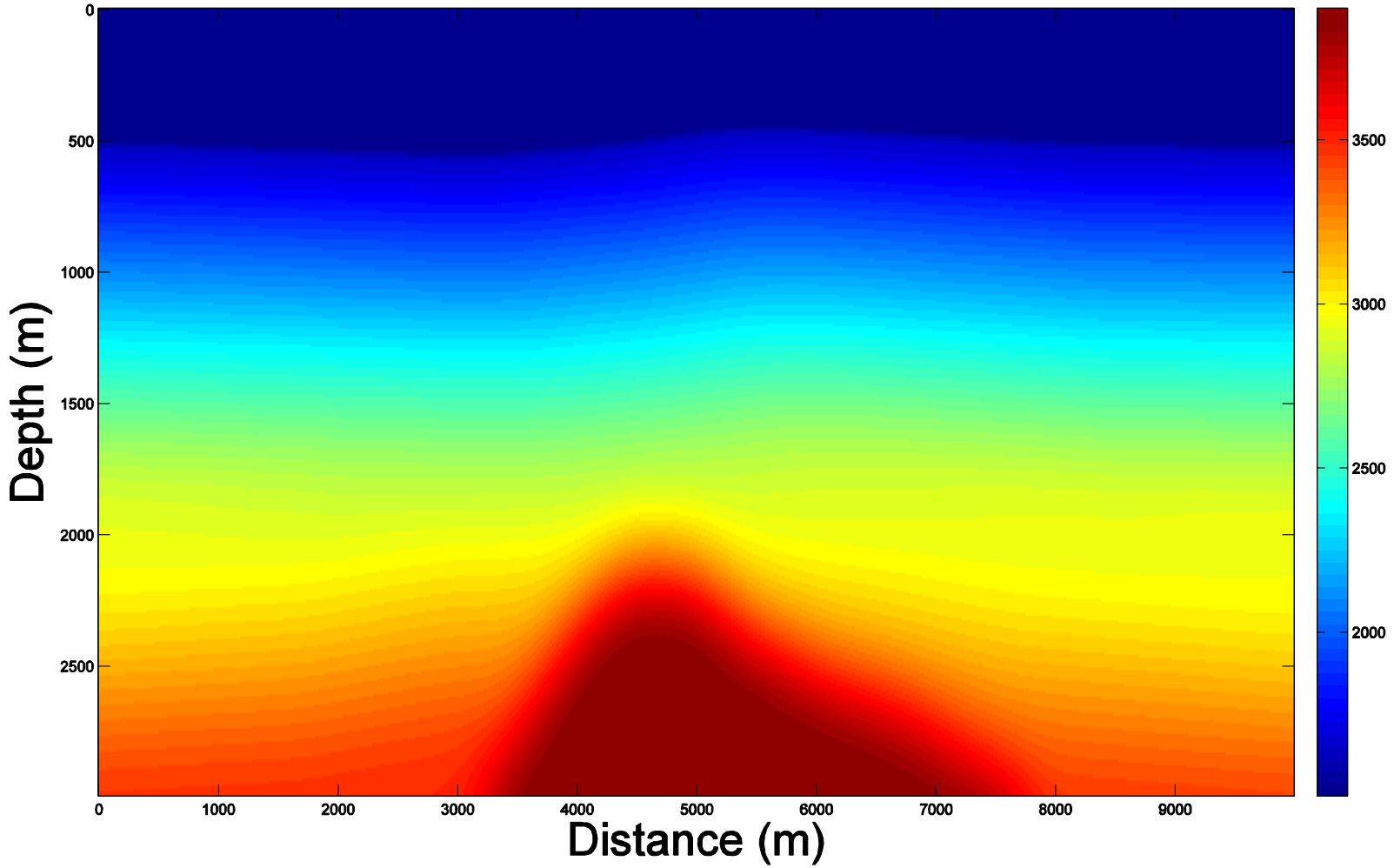
Error per Iteration (model)



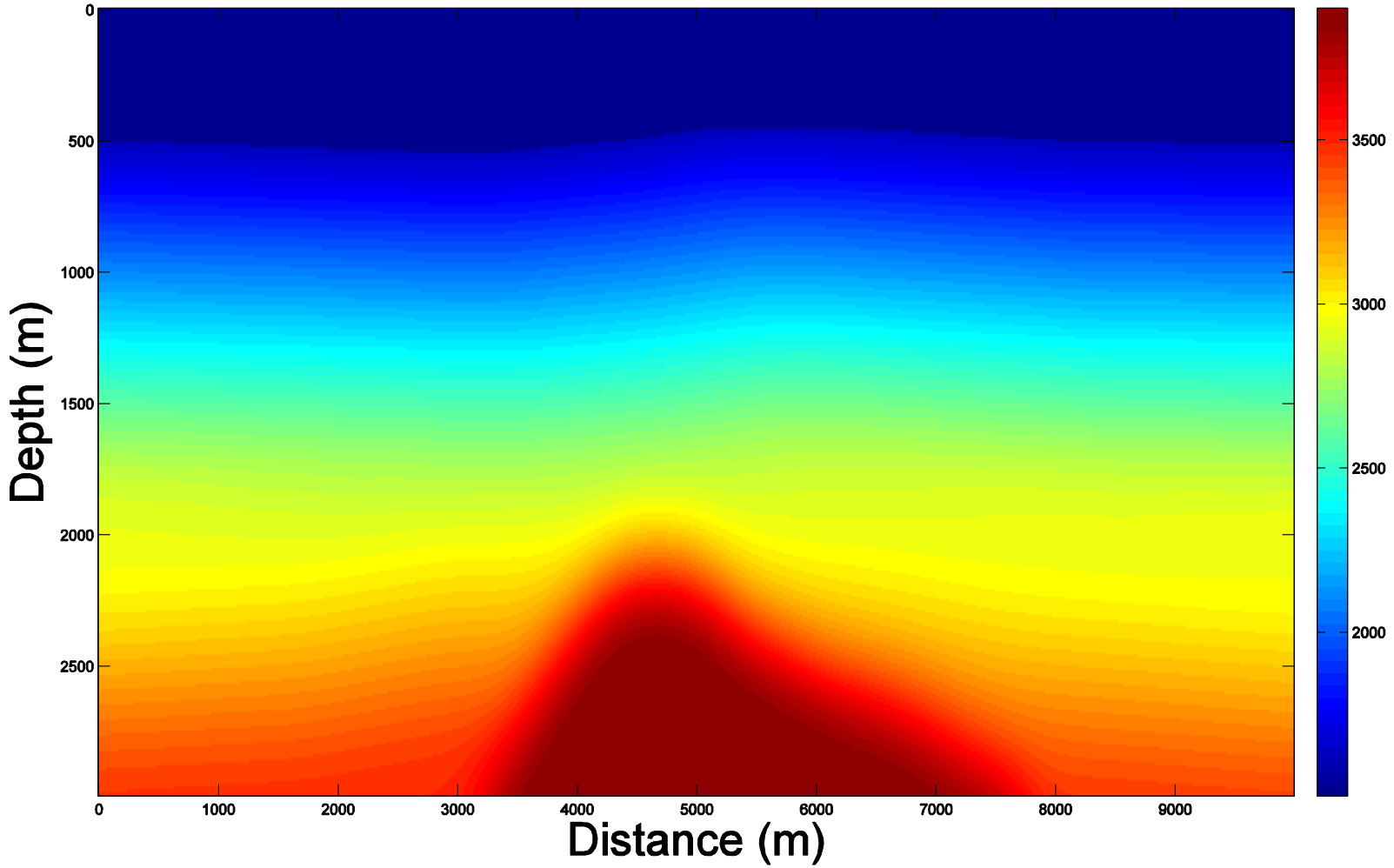
1D Velocity QC



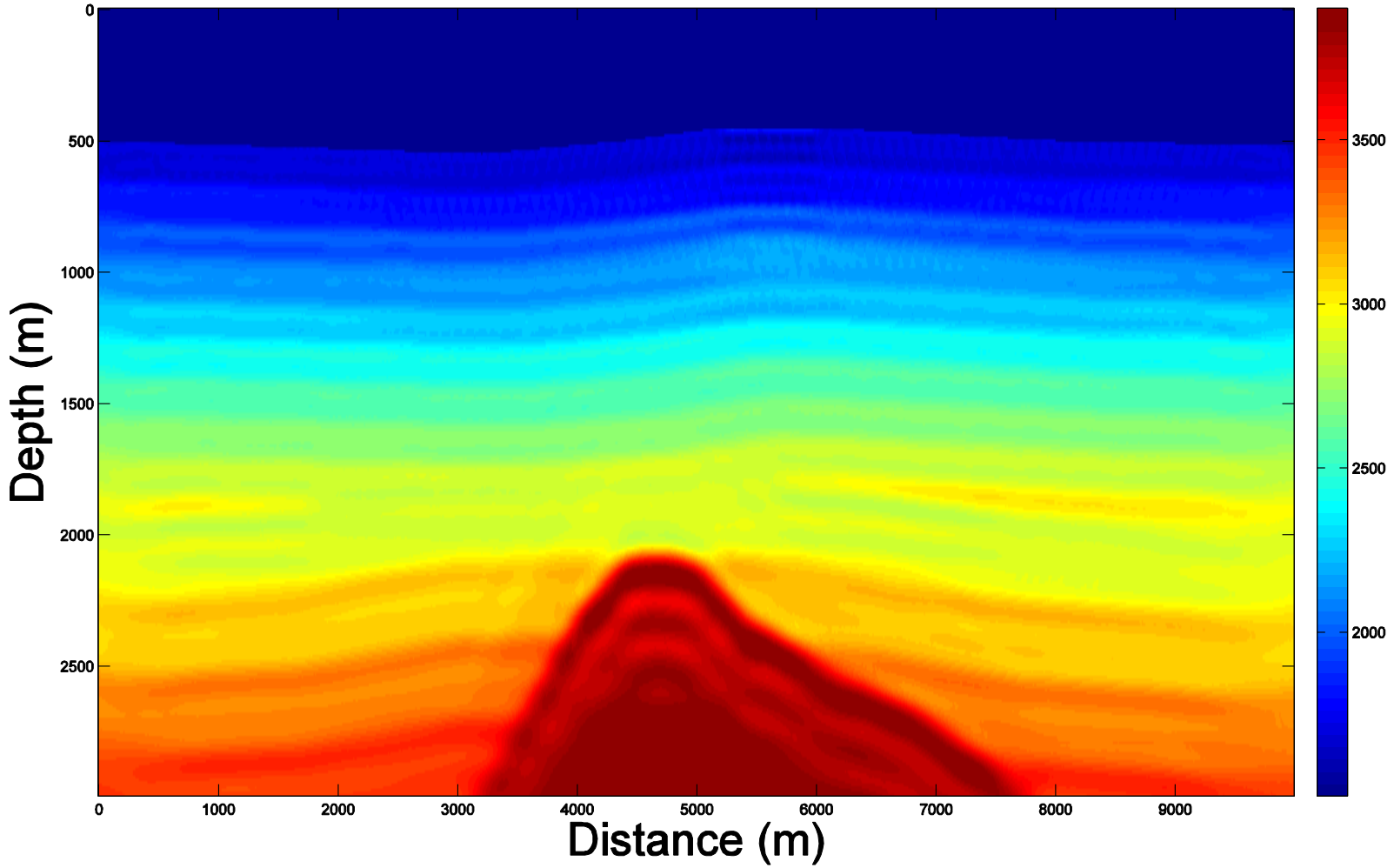
Initial Model – Correct WB Mute



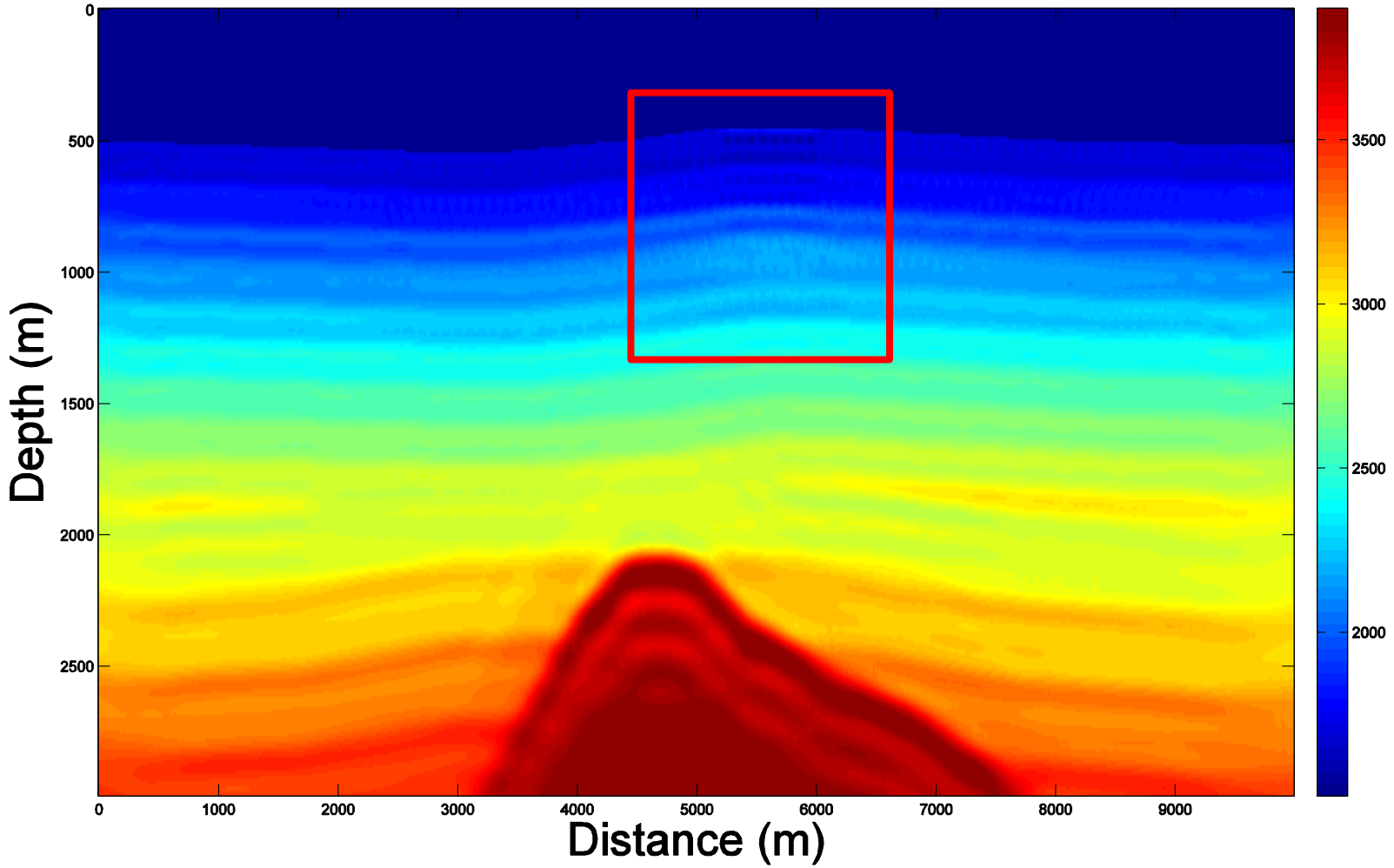
Initial Model – Wrong WB Mute



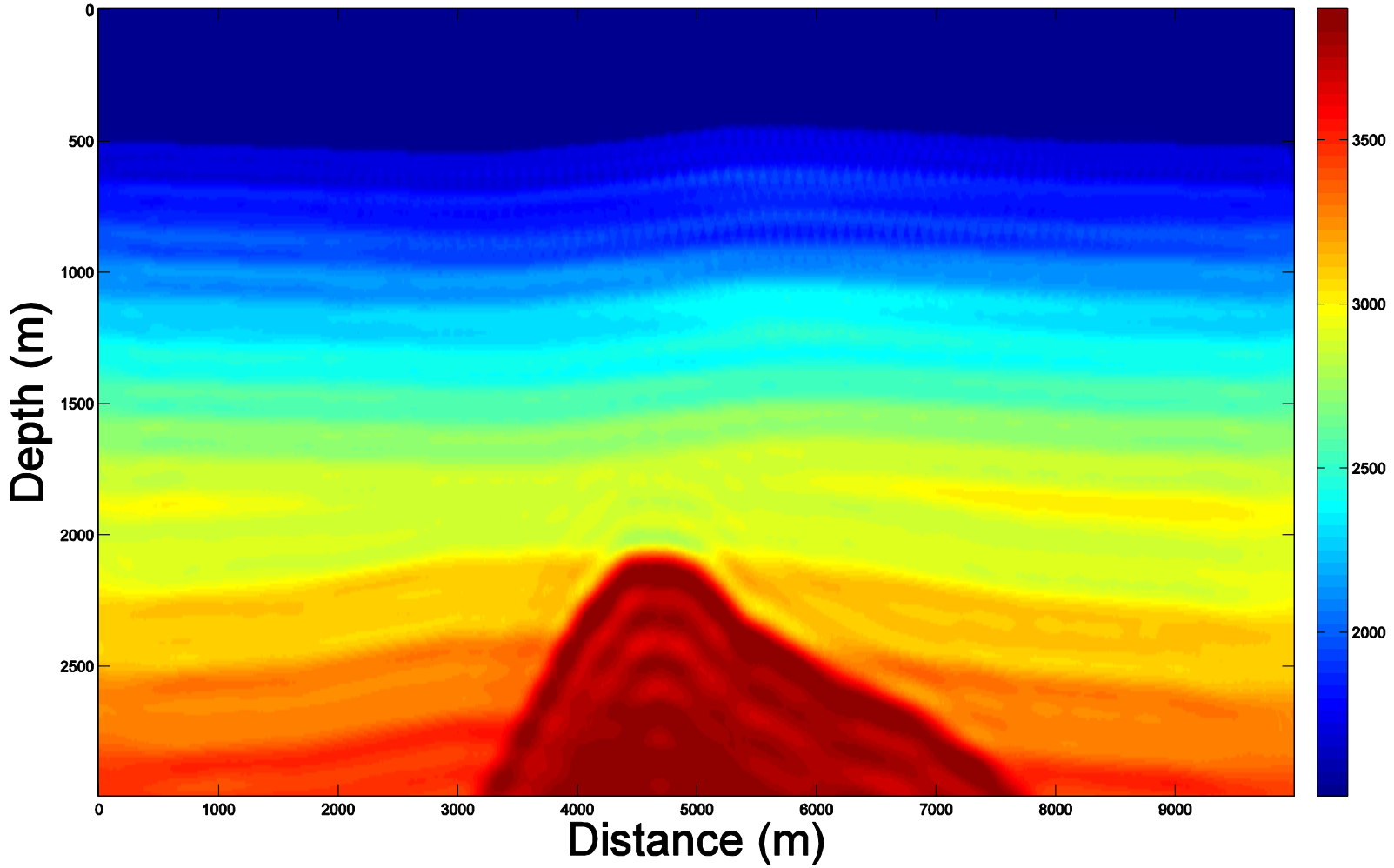
Iteration 85 – Wrong Mute



Iteration 85 – Wrong Mute

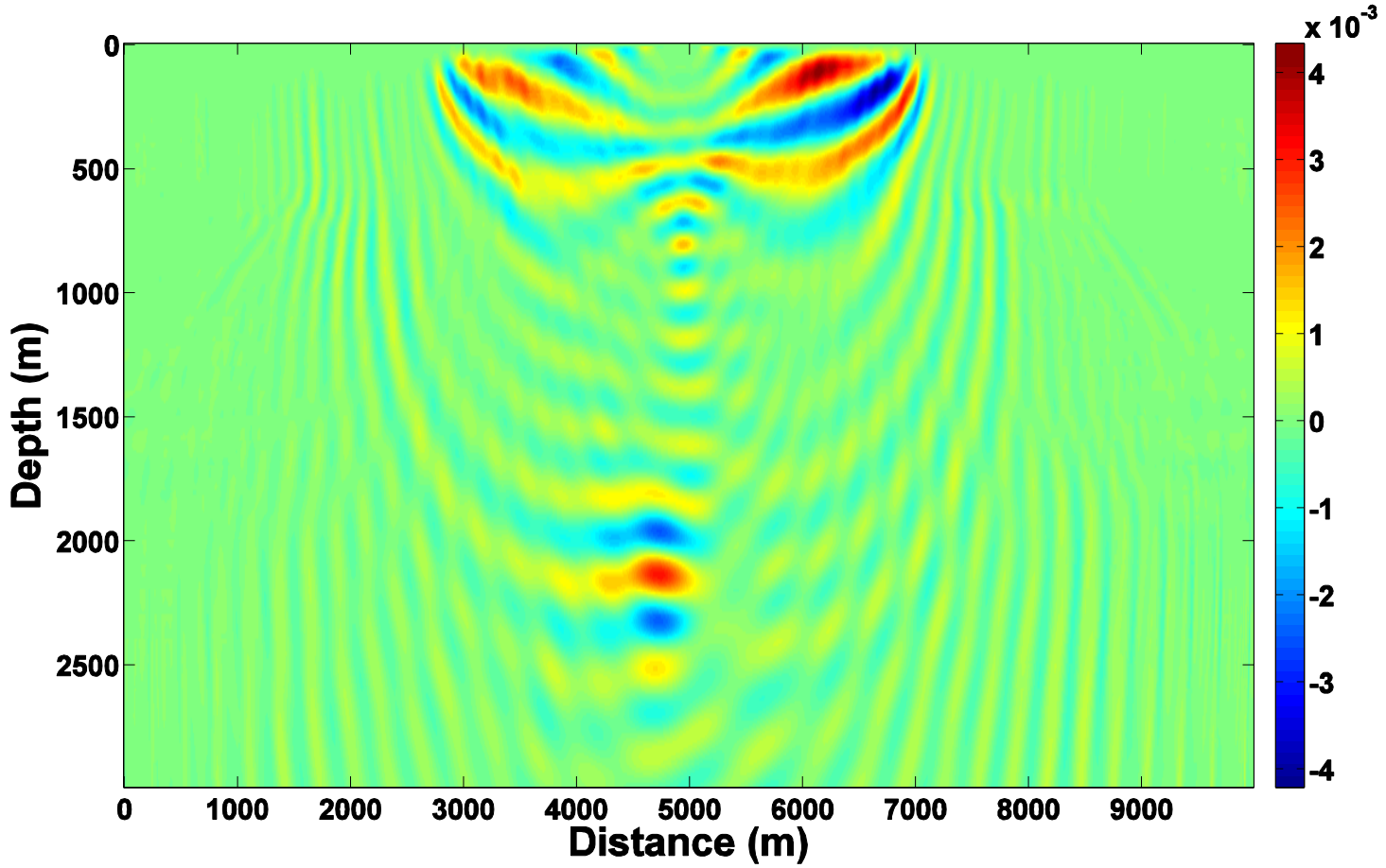


Iteration 85 – Correct Mute

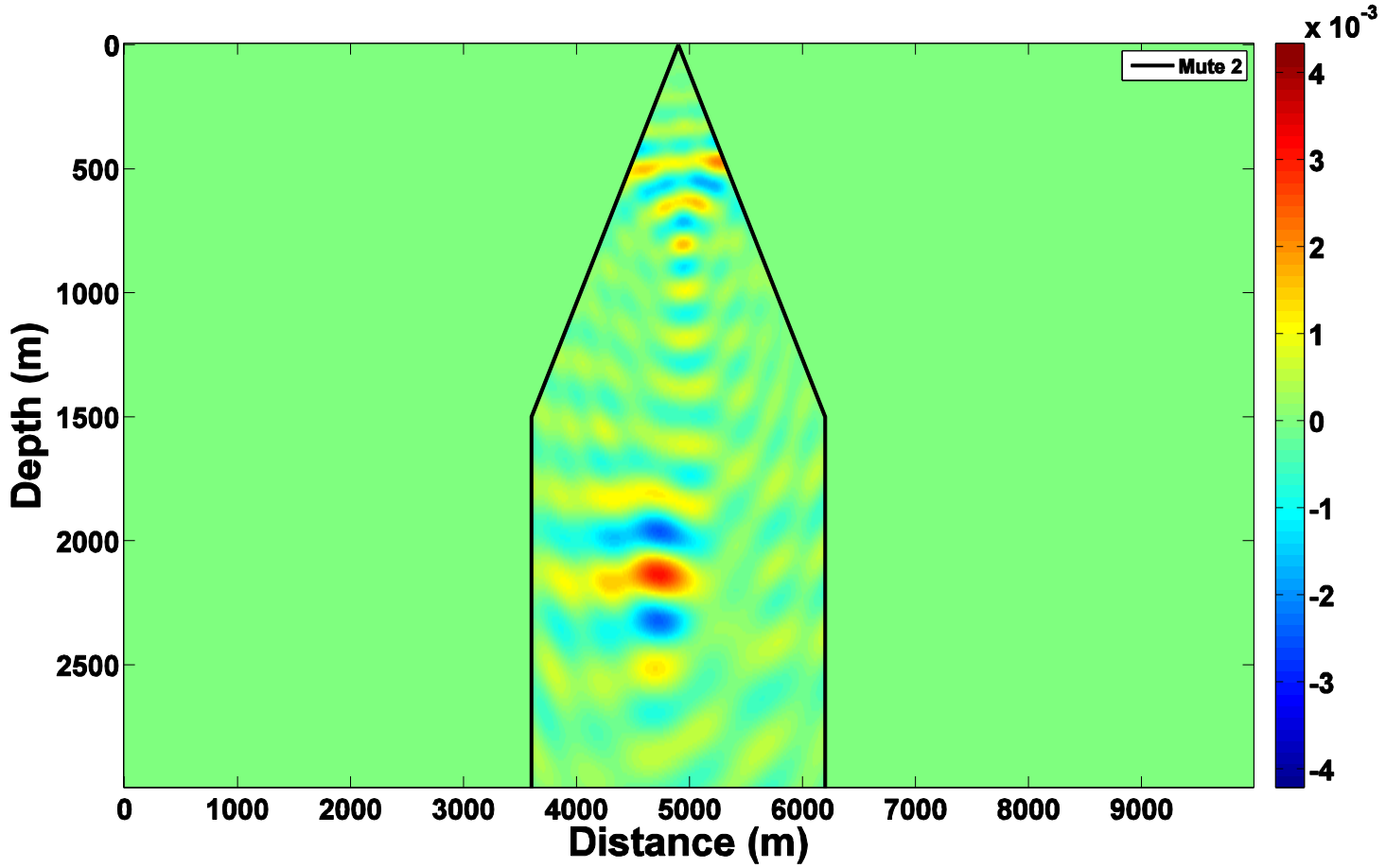


Mute – Second Test

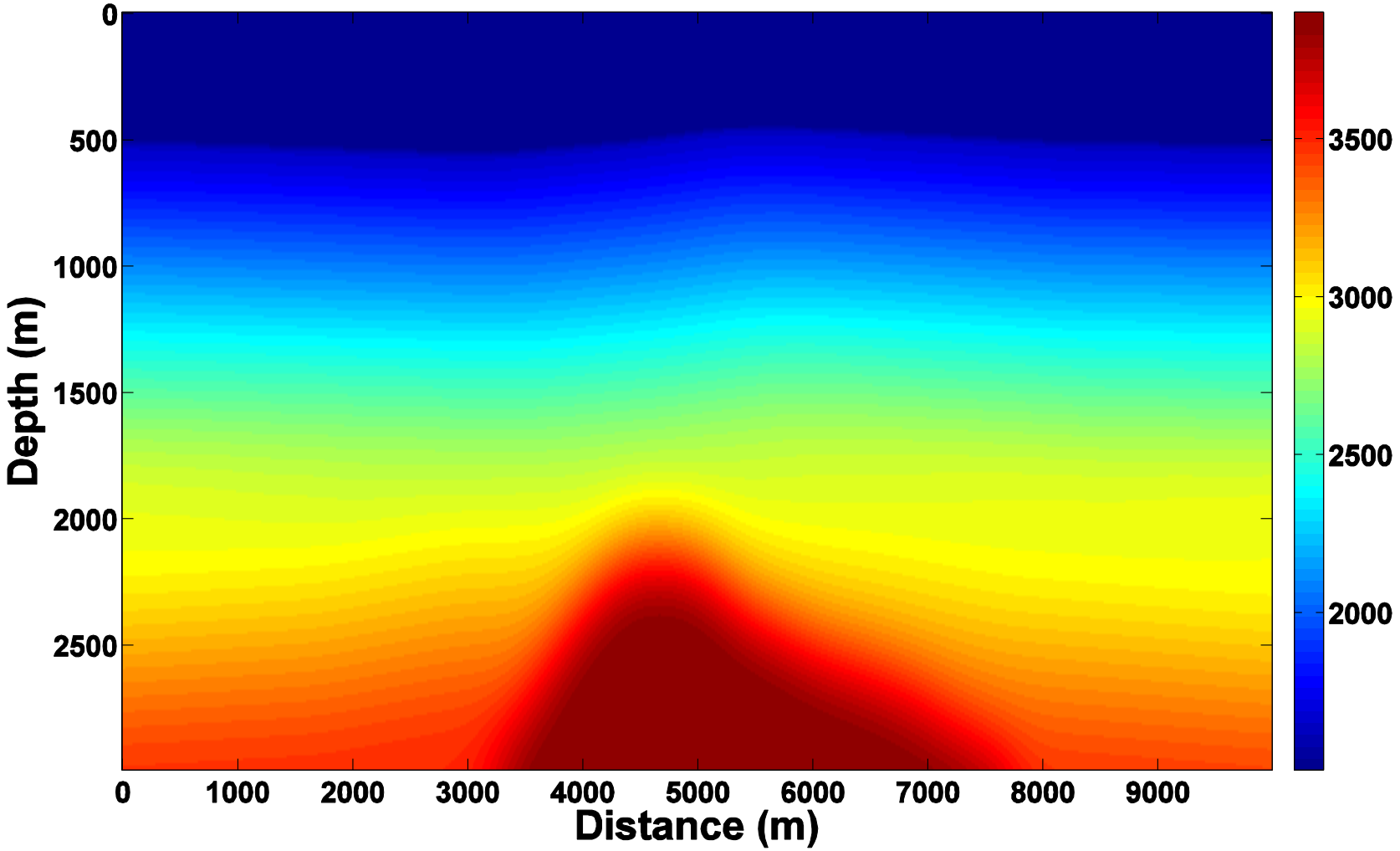
Migrated Residuals – Shot 50



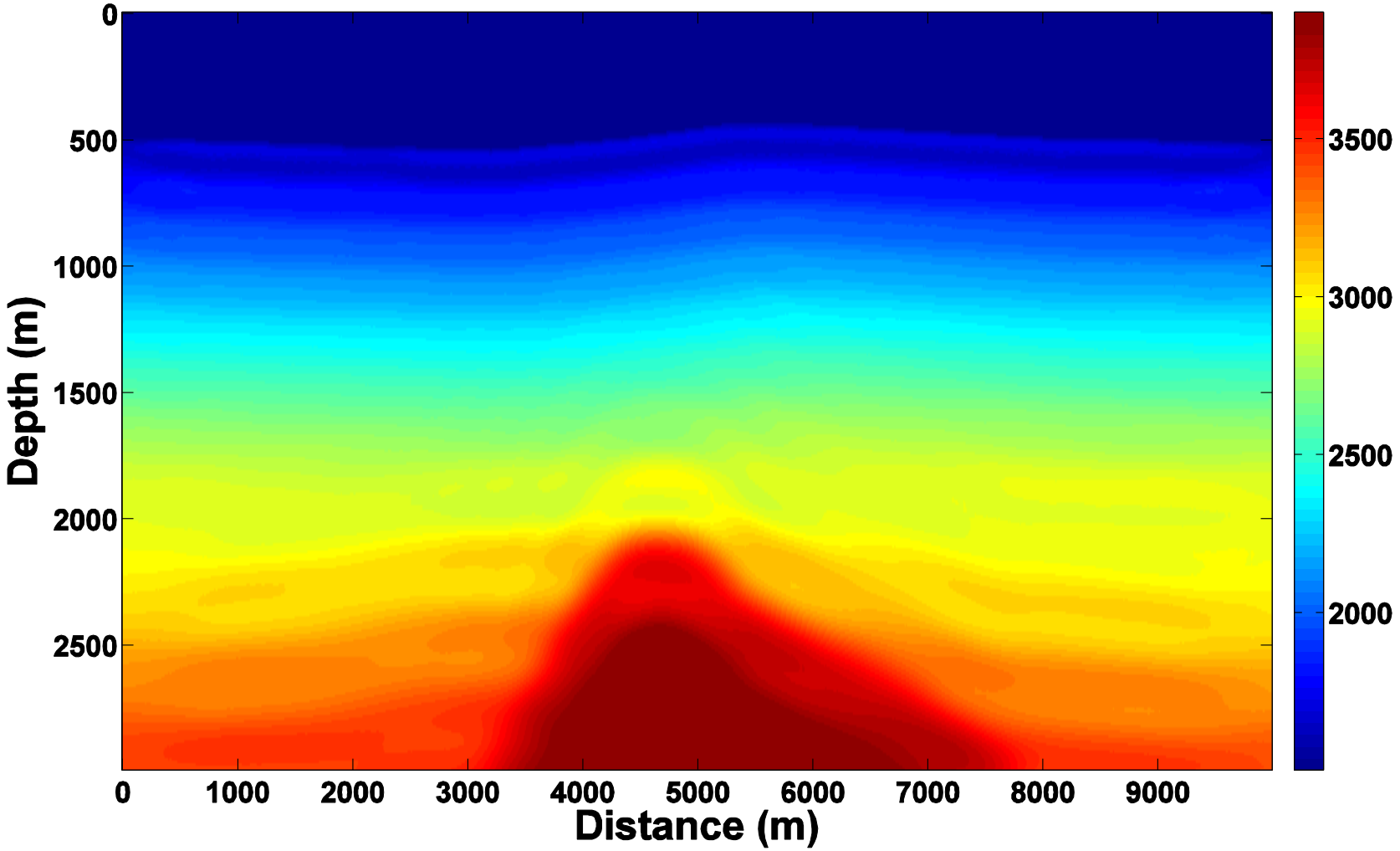
Muted Migrated Residuals – Shot 50



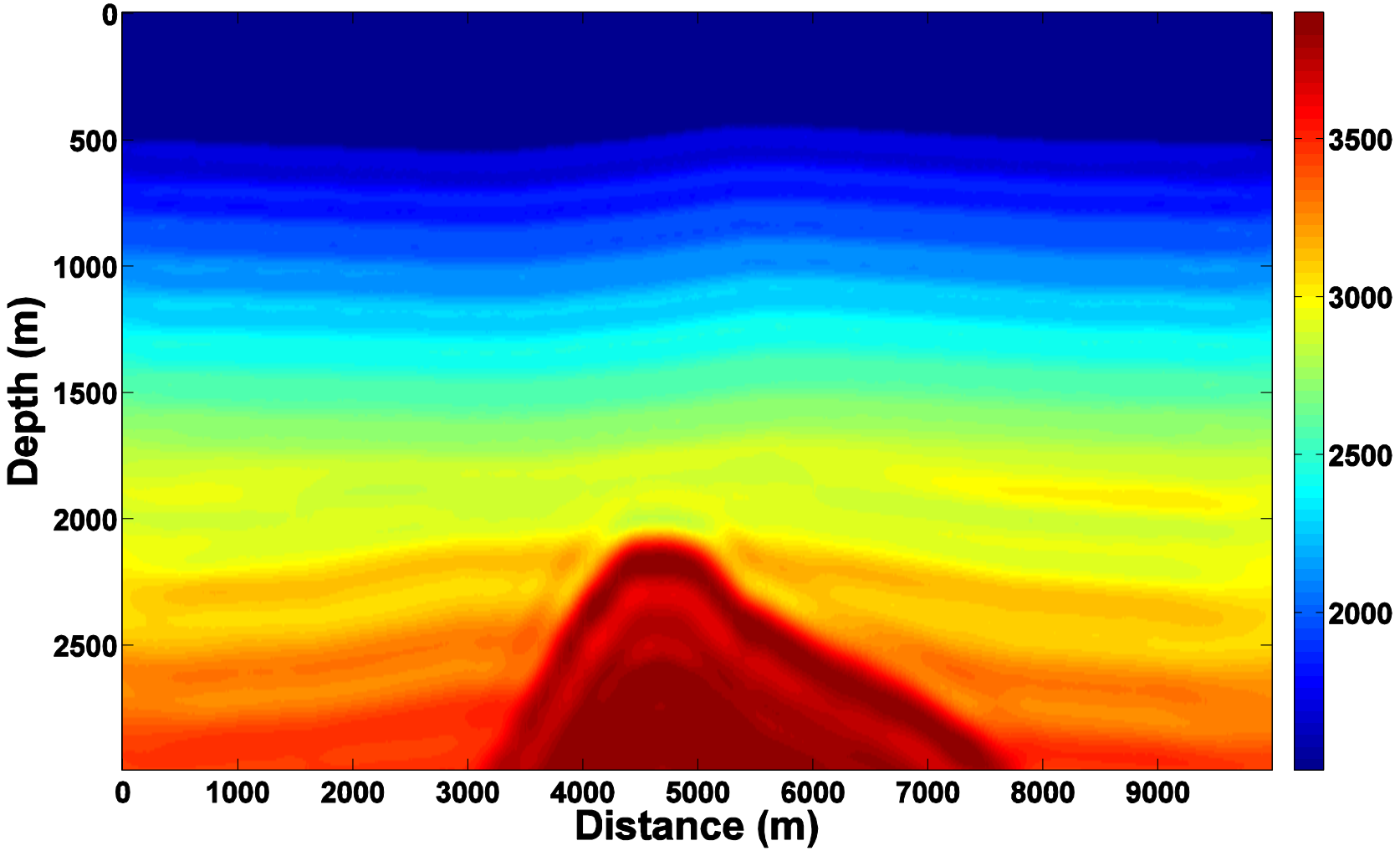
Initial Model



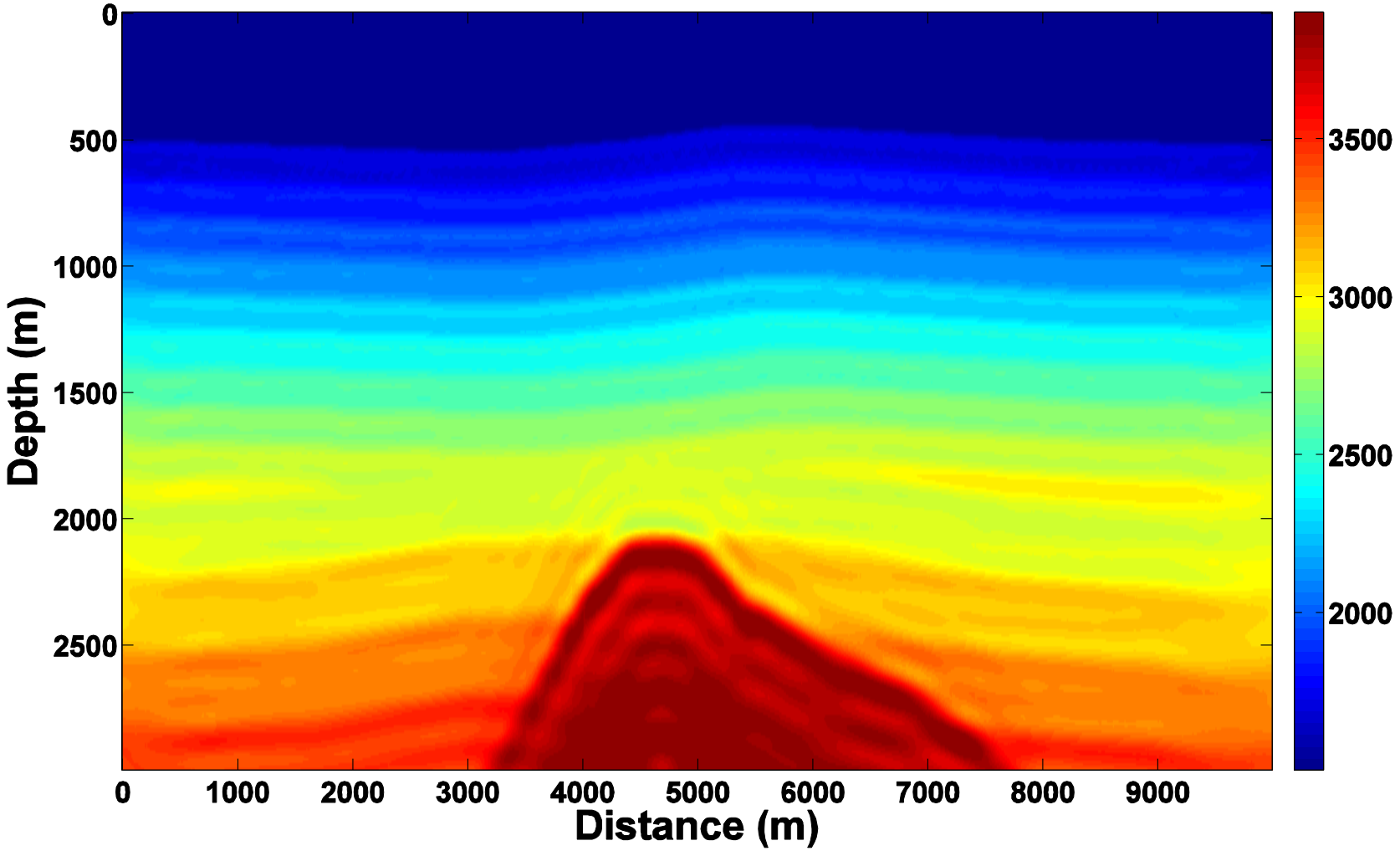
Iteration 1 (1 – 6 Hz)



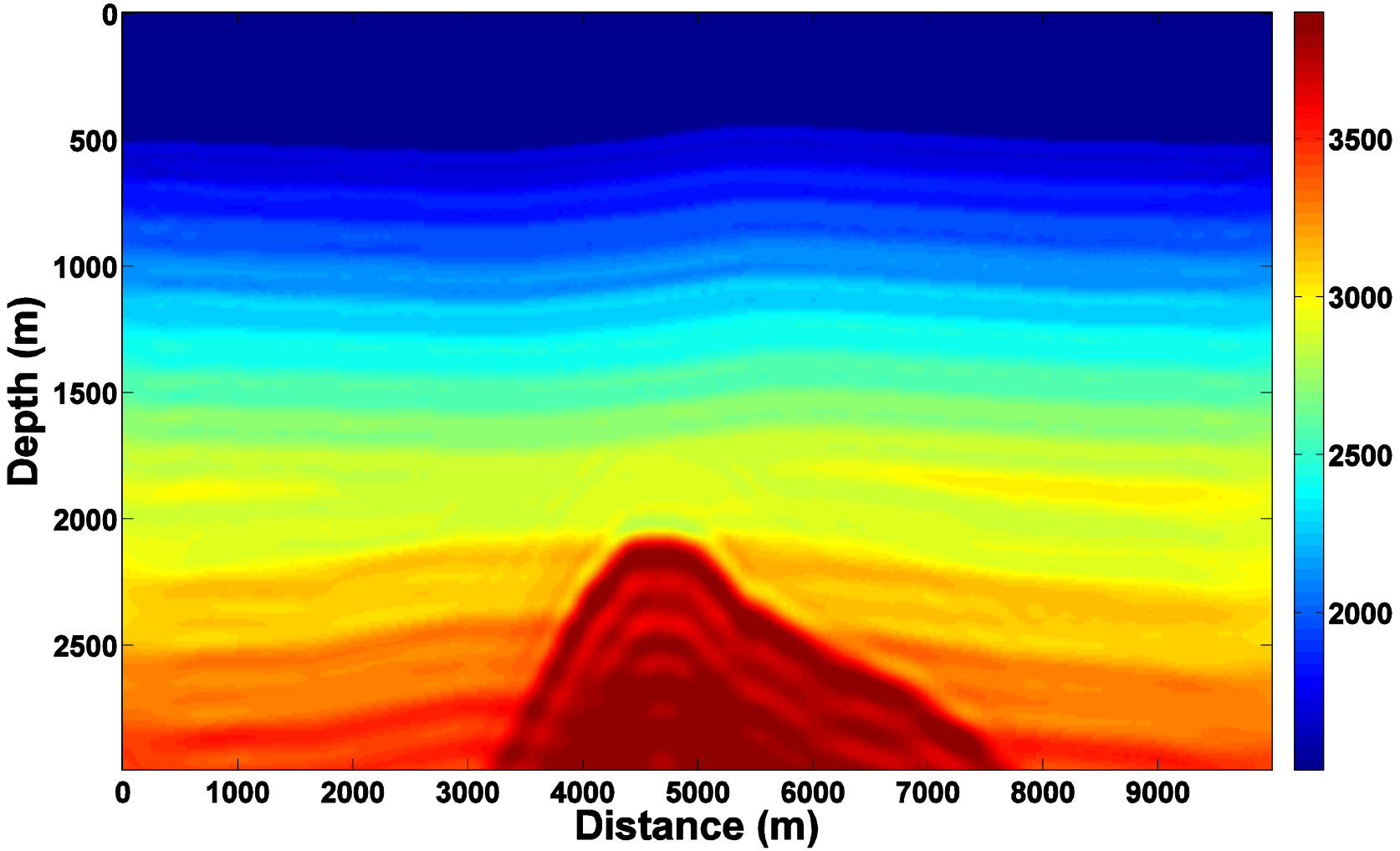
Iteration 30 (1 – 9 Hz)



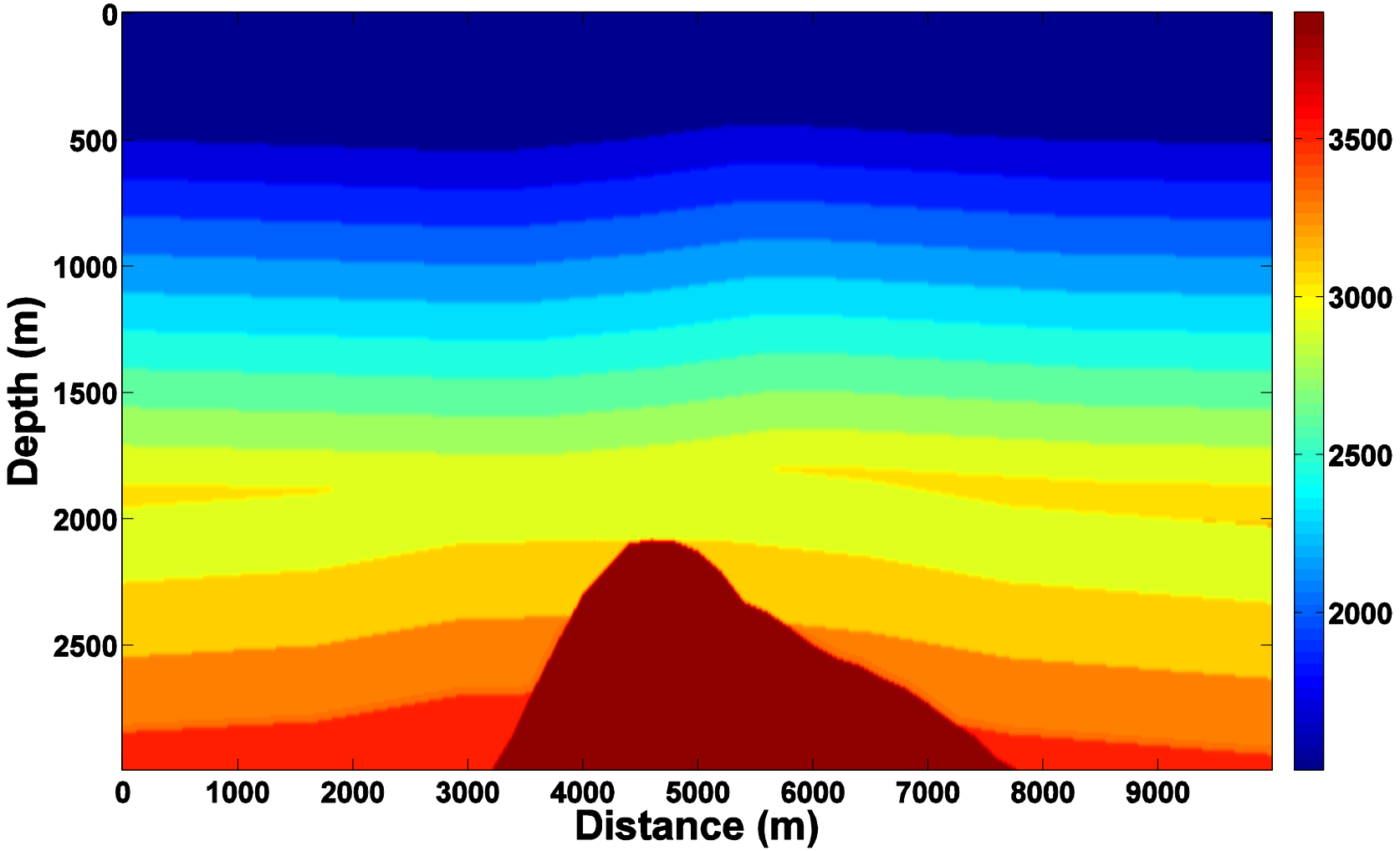
Iteration 60 (1 – 12 Hz)



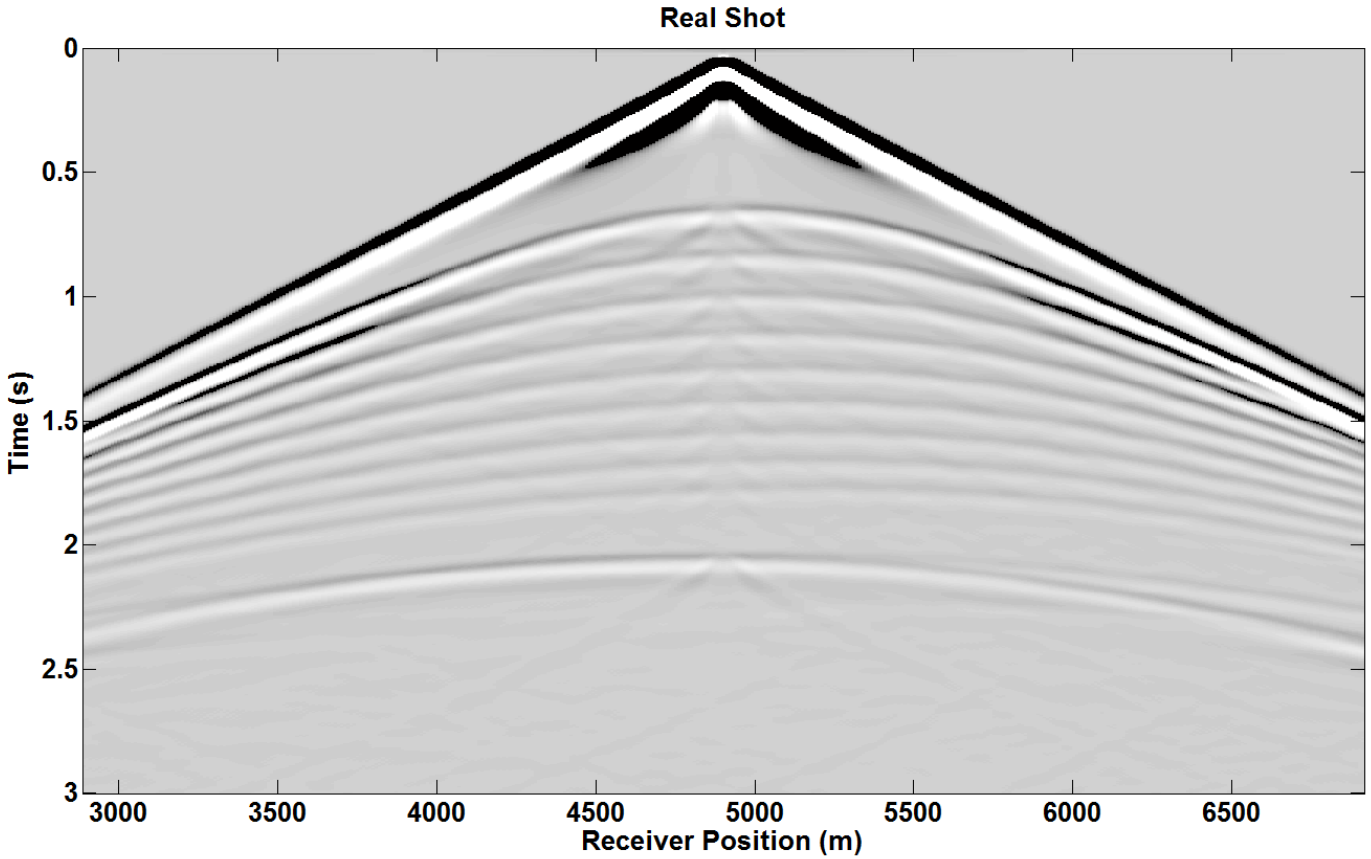
Iteration 99 (1 – 15 Hz)



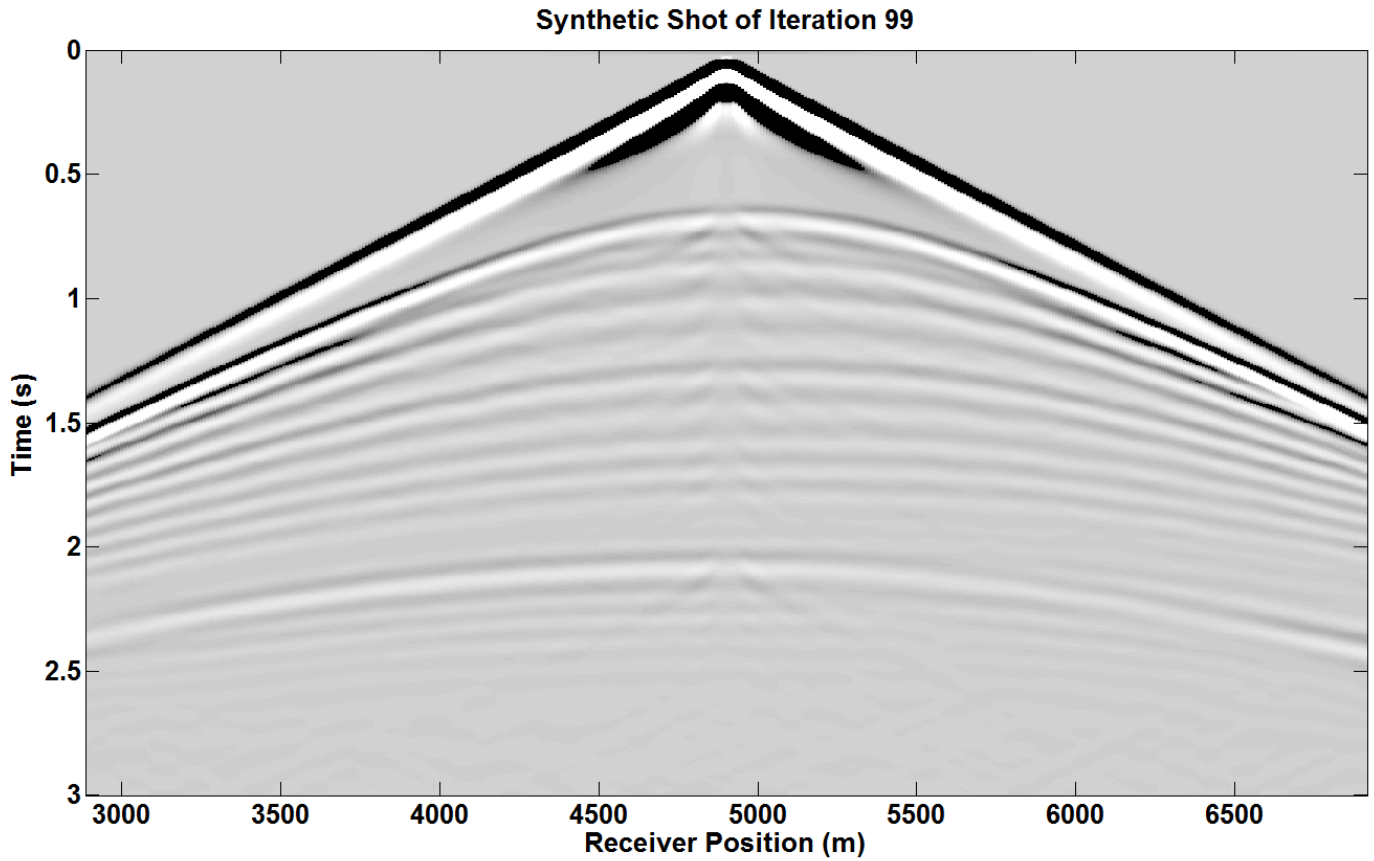
Real Model


0
500
1000
1500
2000
2500
Depth (m)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Distance (m)
3500
3000
2500
2000

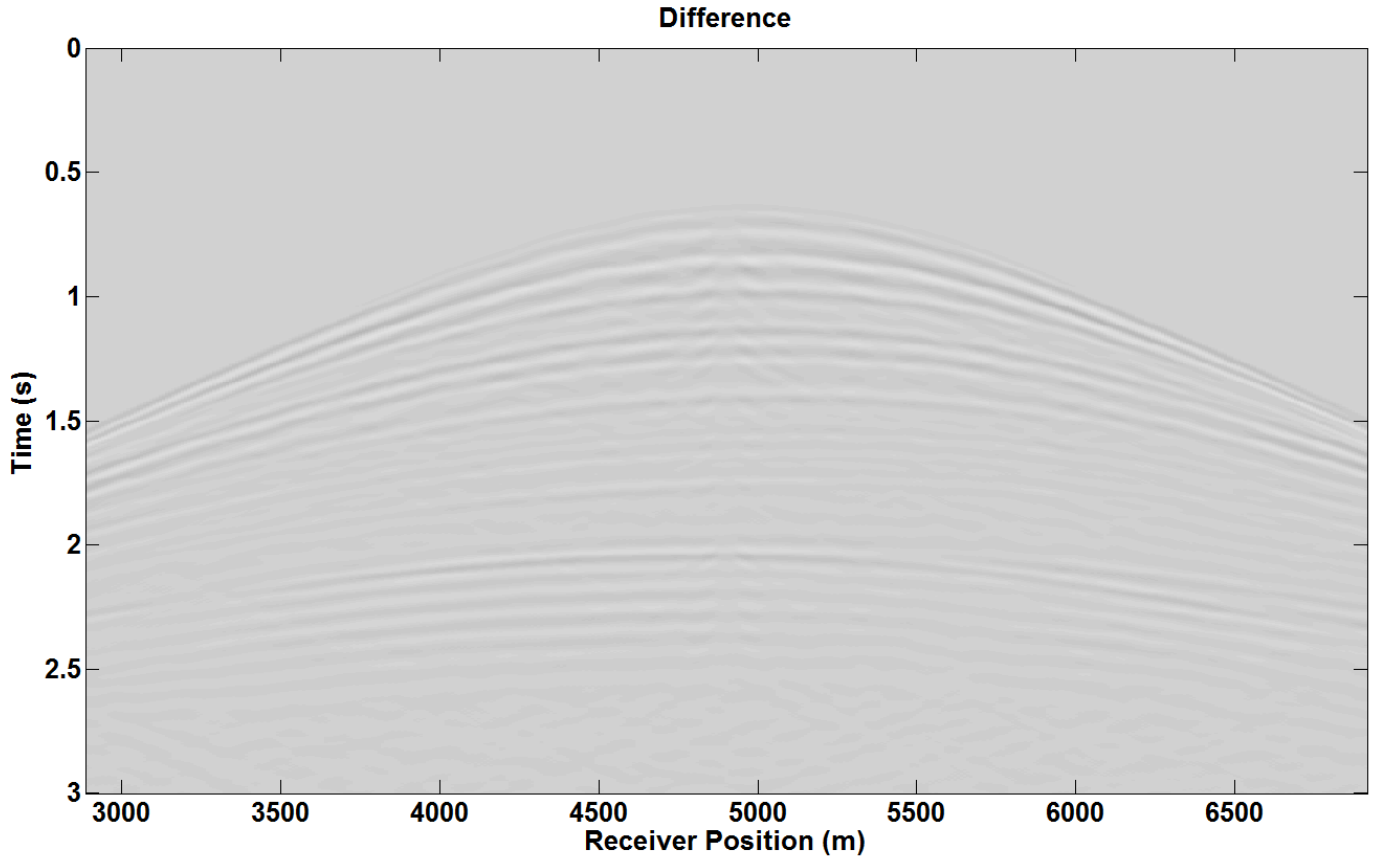
Real Shot (shot 50)



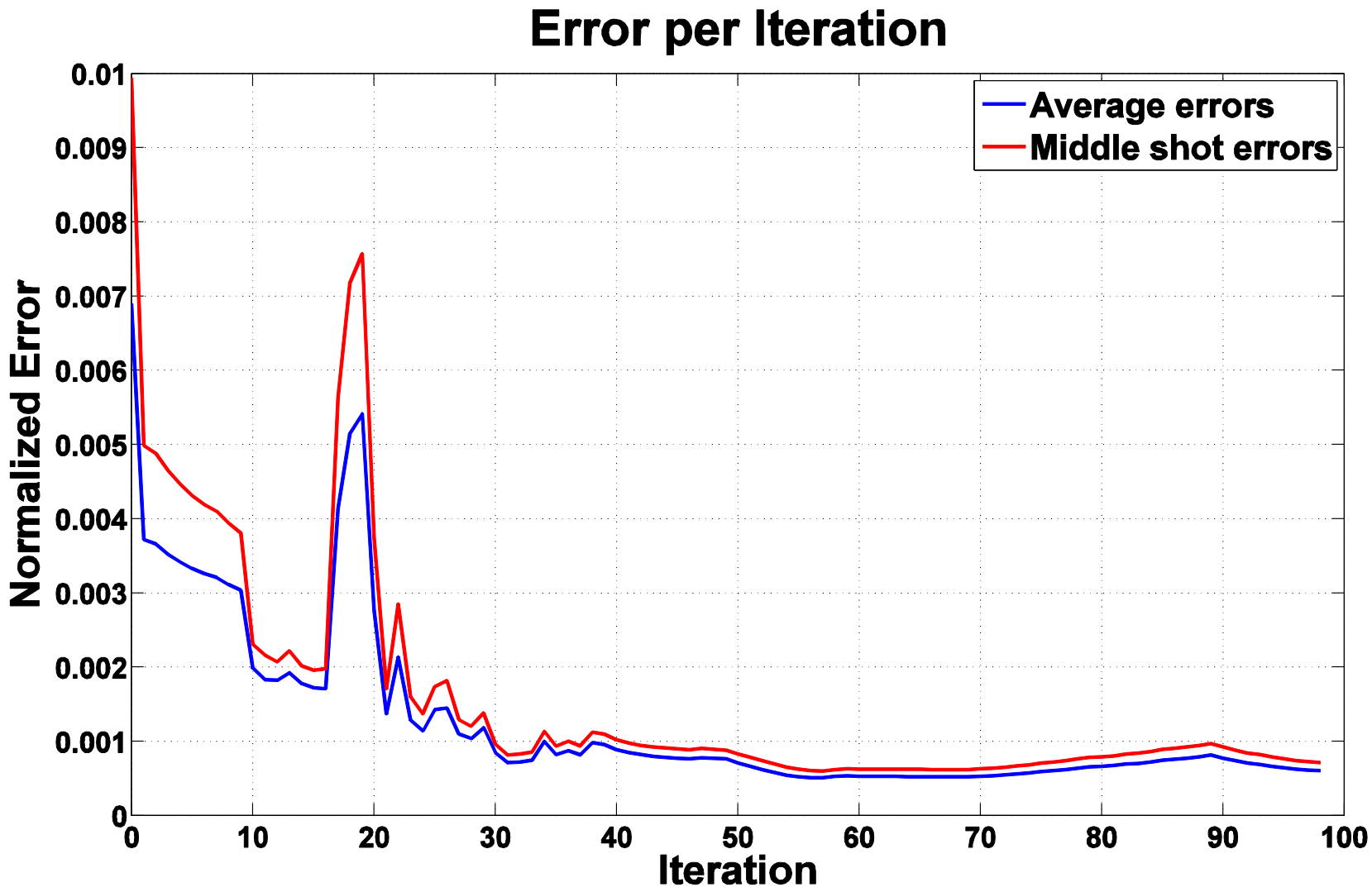
Synthetic Shot of Iteration 99



Difference

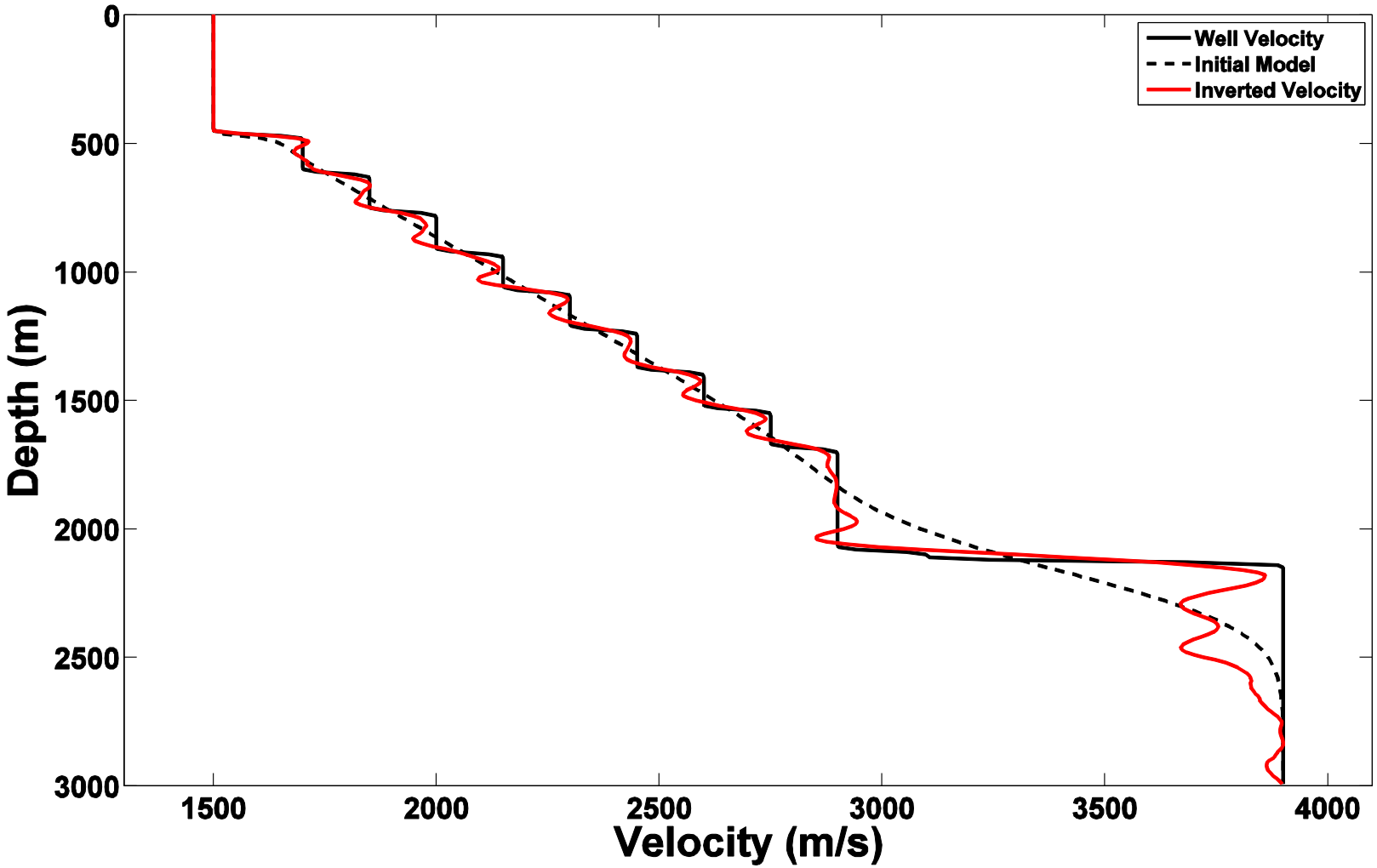

Difference
Time (s)
0
0.5
1
1.5
2
2.5
3
3000
3500
4000
4500
5000
5500
6000
6500
Receiver Position (m)

Error per Iteration (shots)



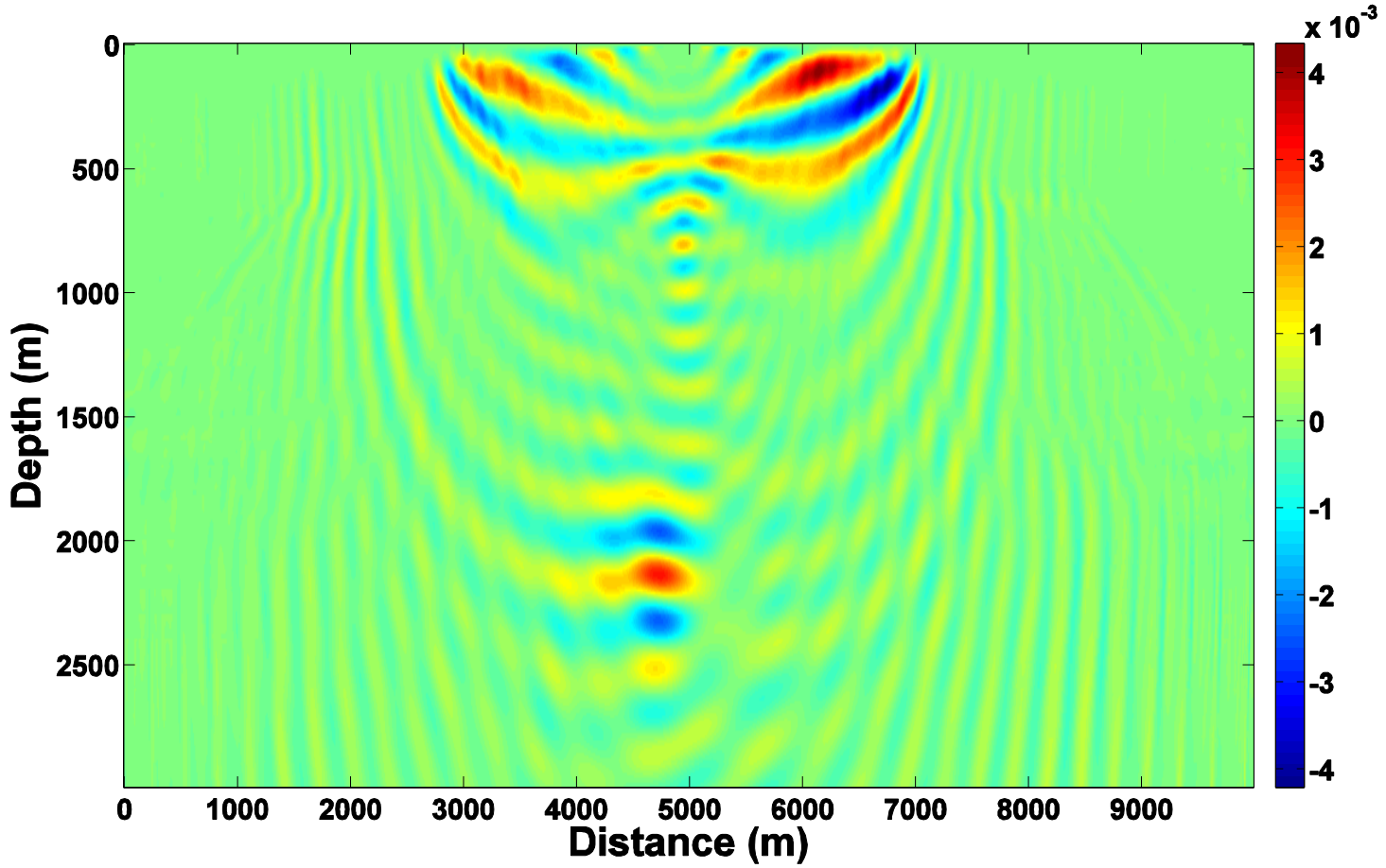
Error per Iteration (model)

1D Velocity QC

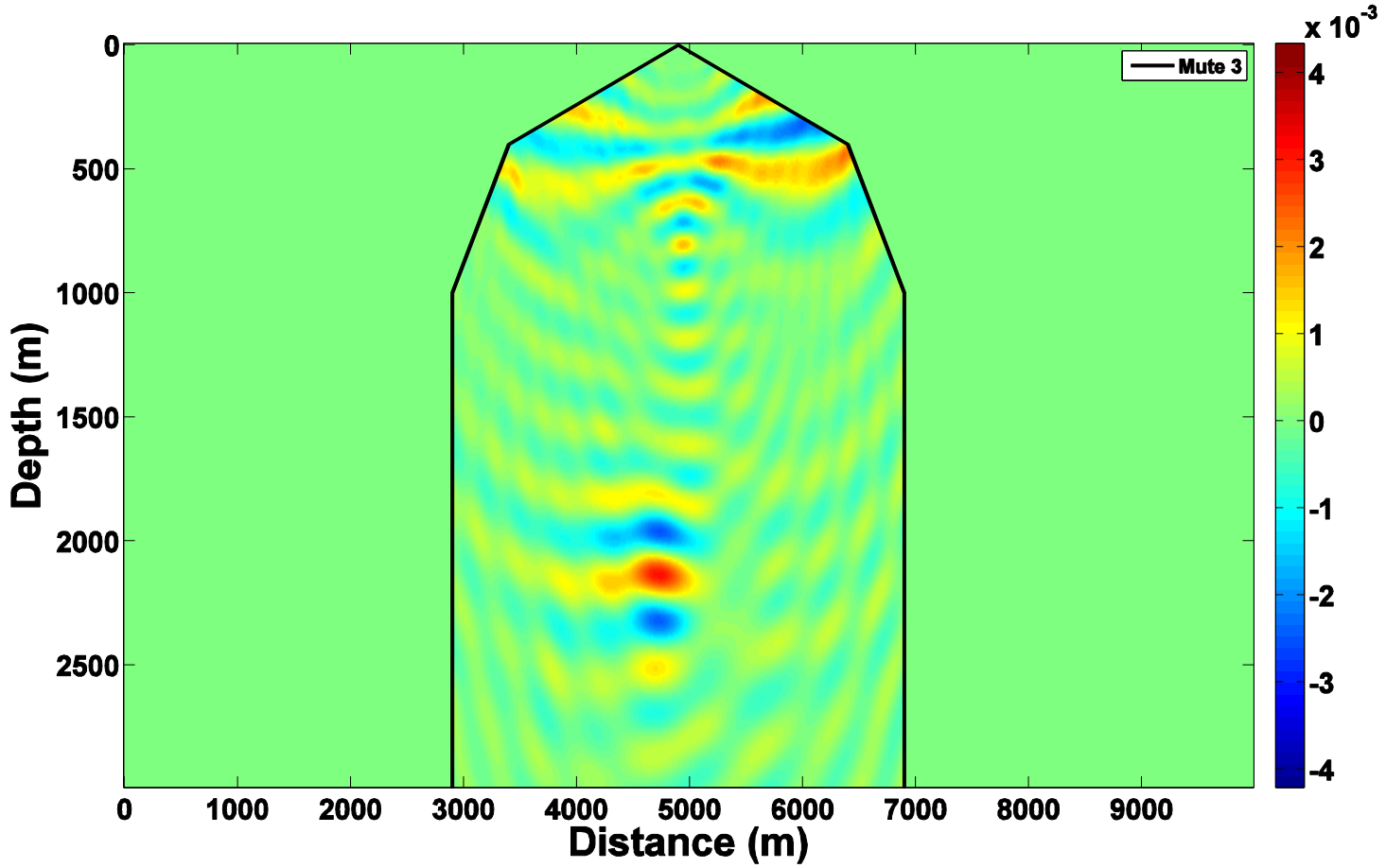


Mute – Third Test

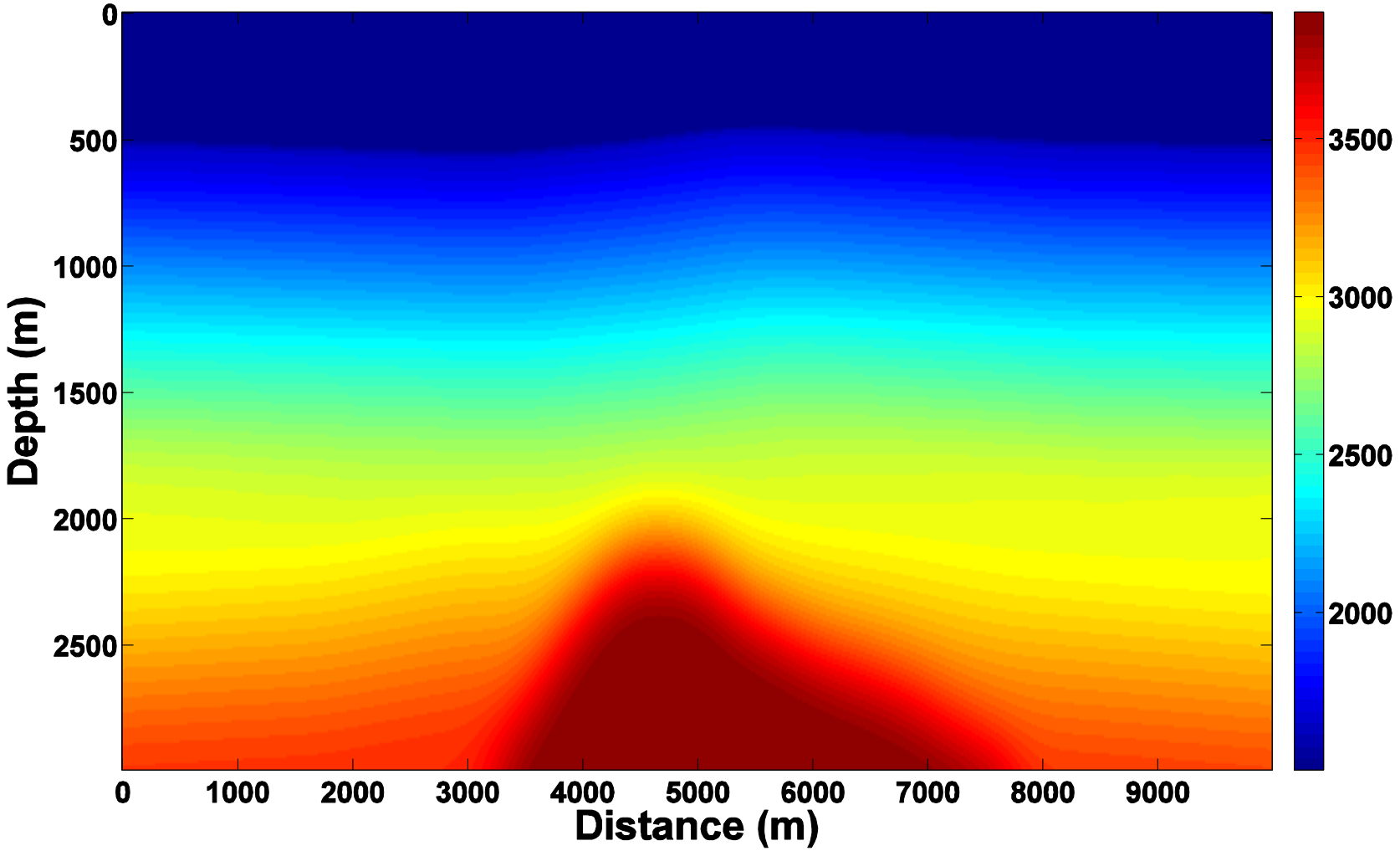
Migrated Residuals – Shot 50



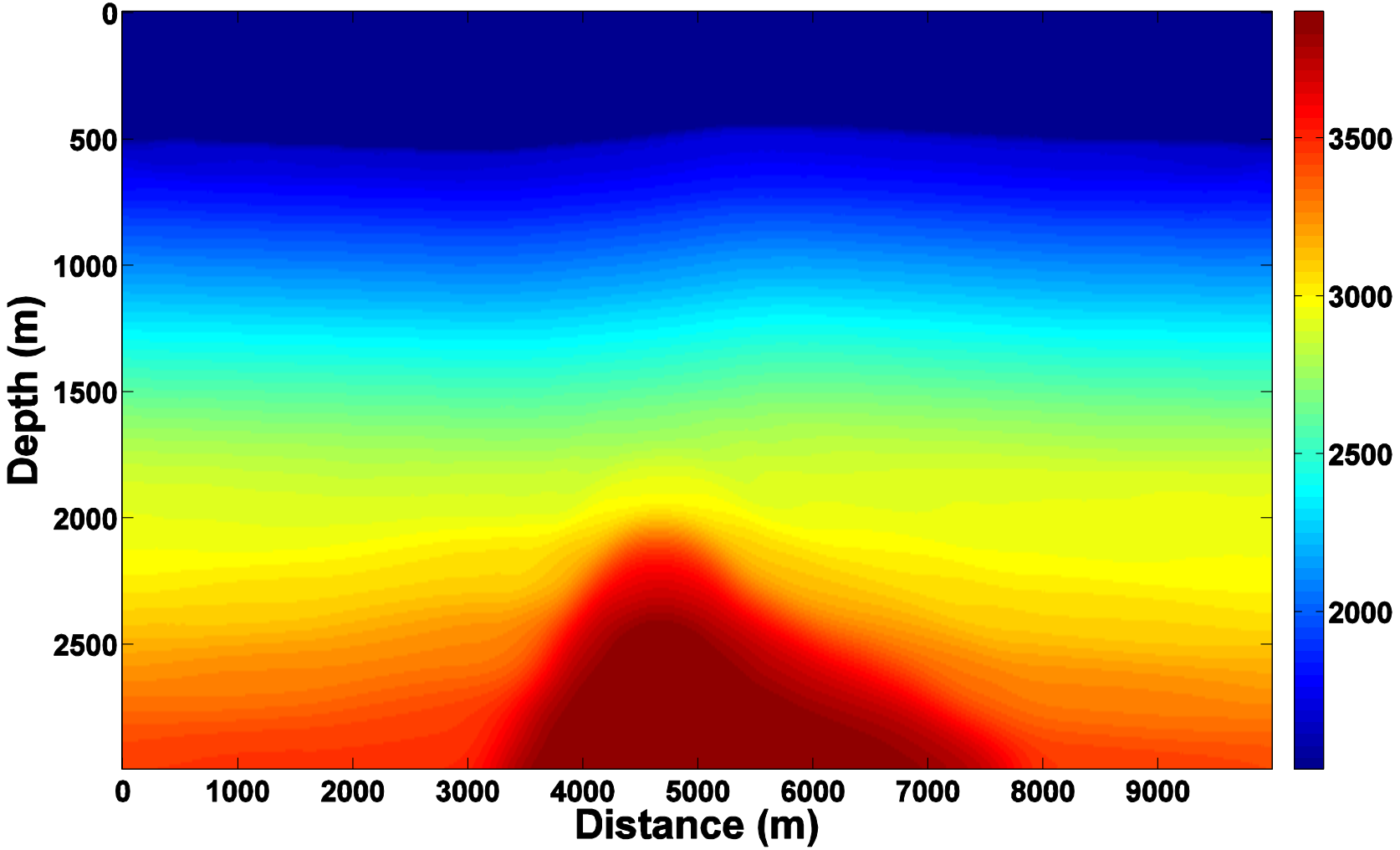
Muted Migrated Residuals – Shot 50



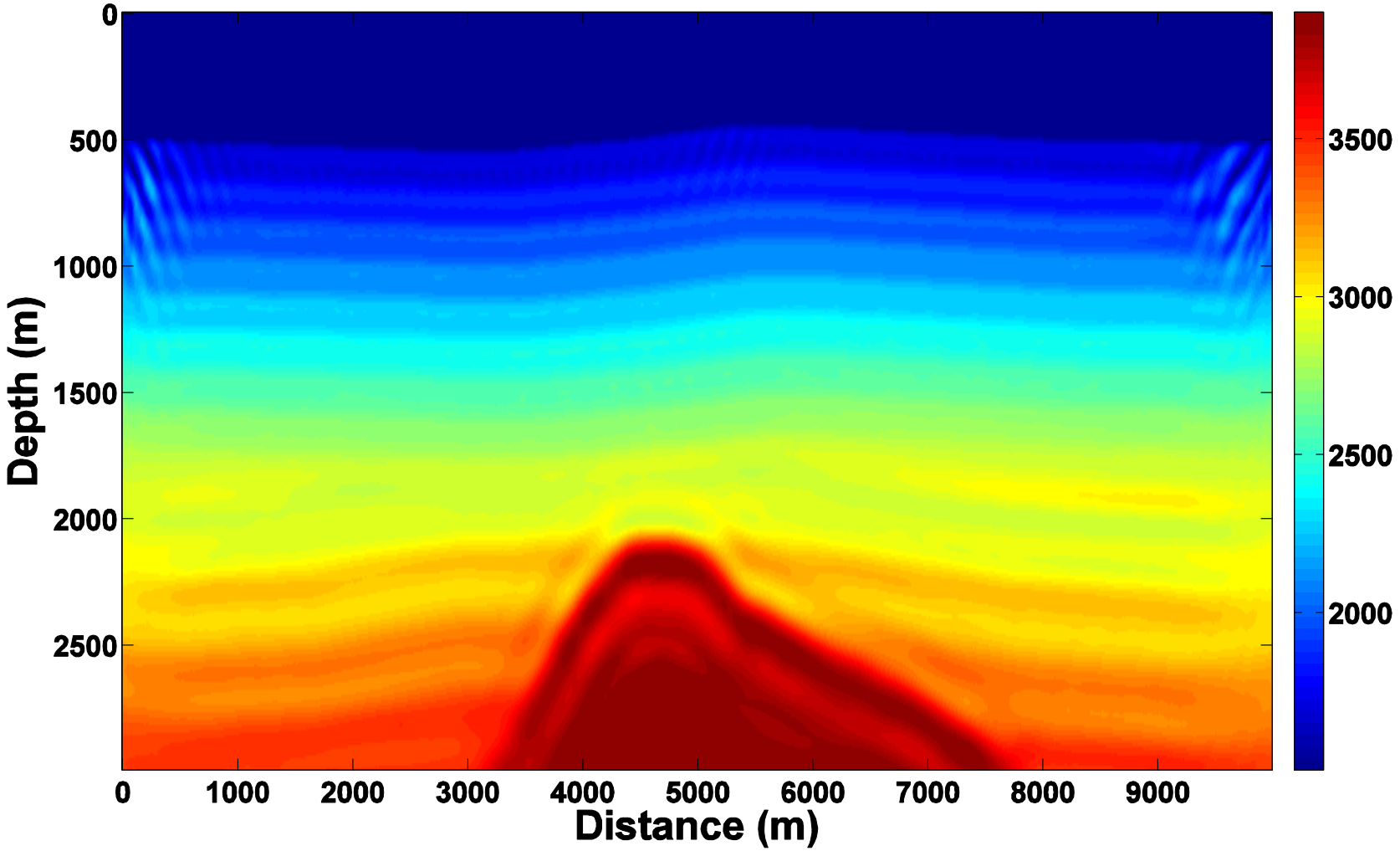
Initial Model



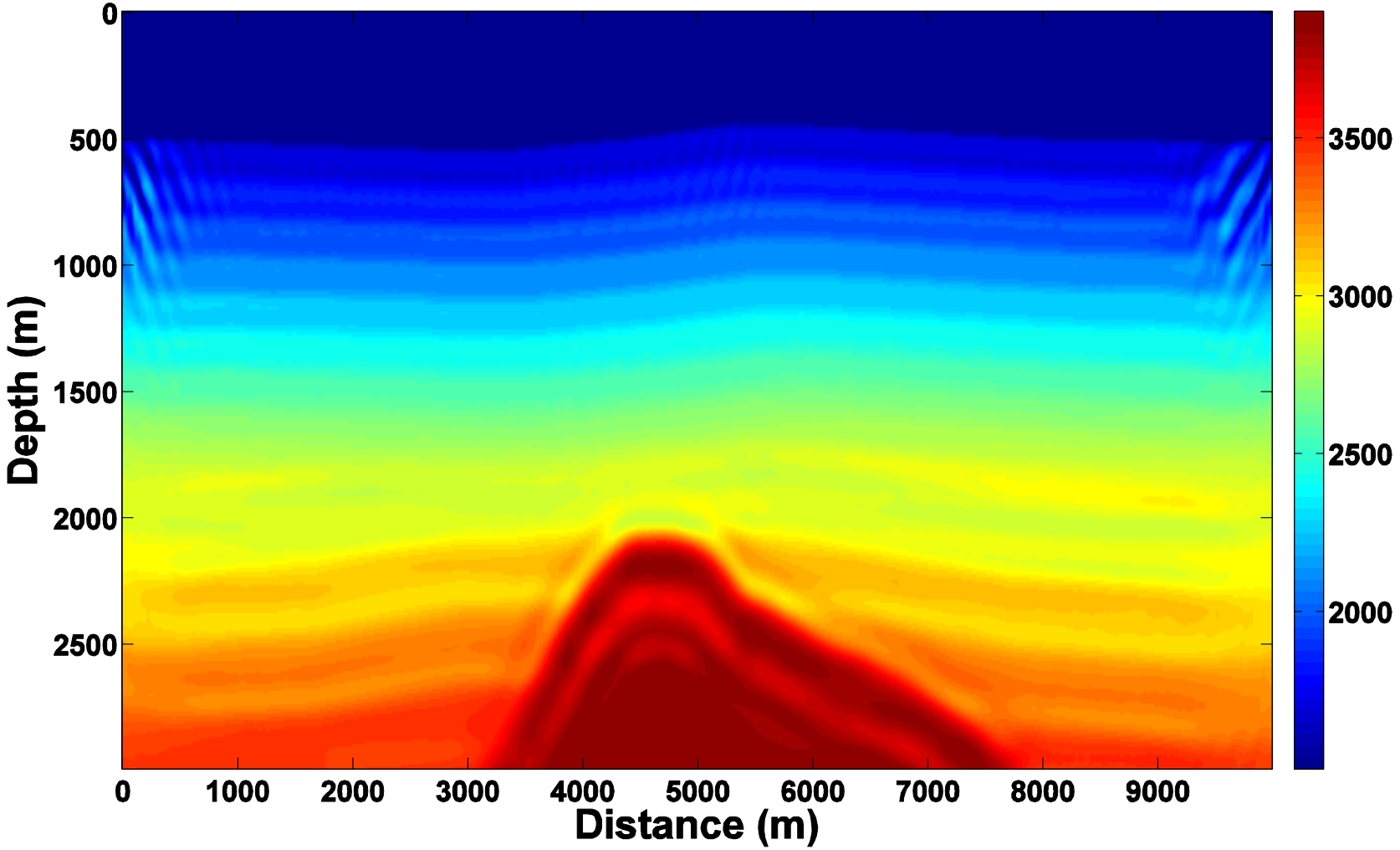
Iteration 1 (1 – 6 Hz)



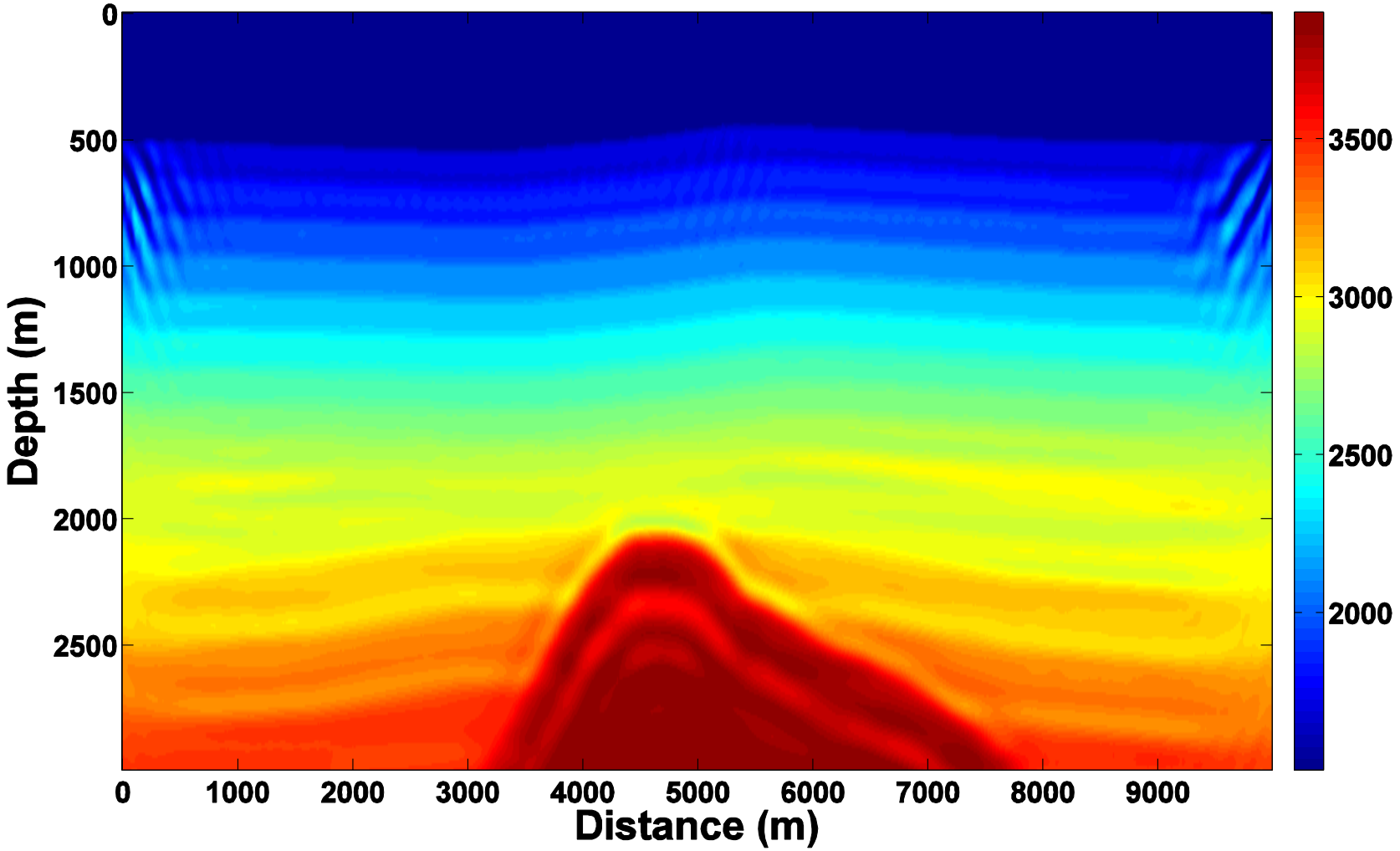
Iteration 40 (1 – 10 Hz)



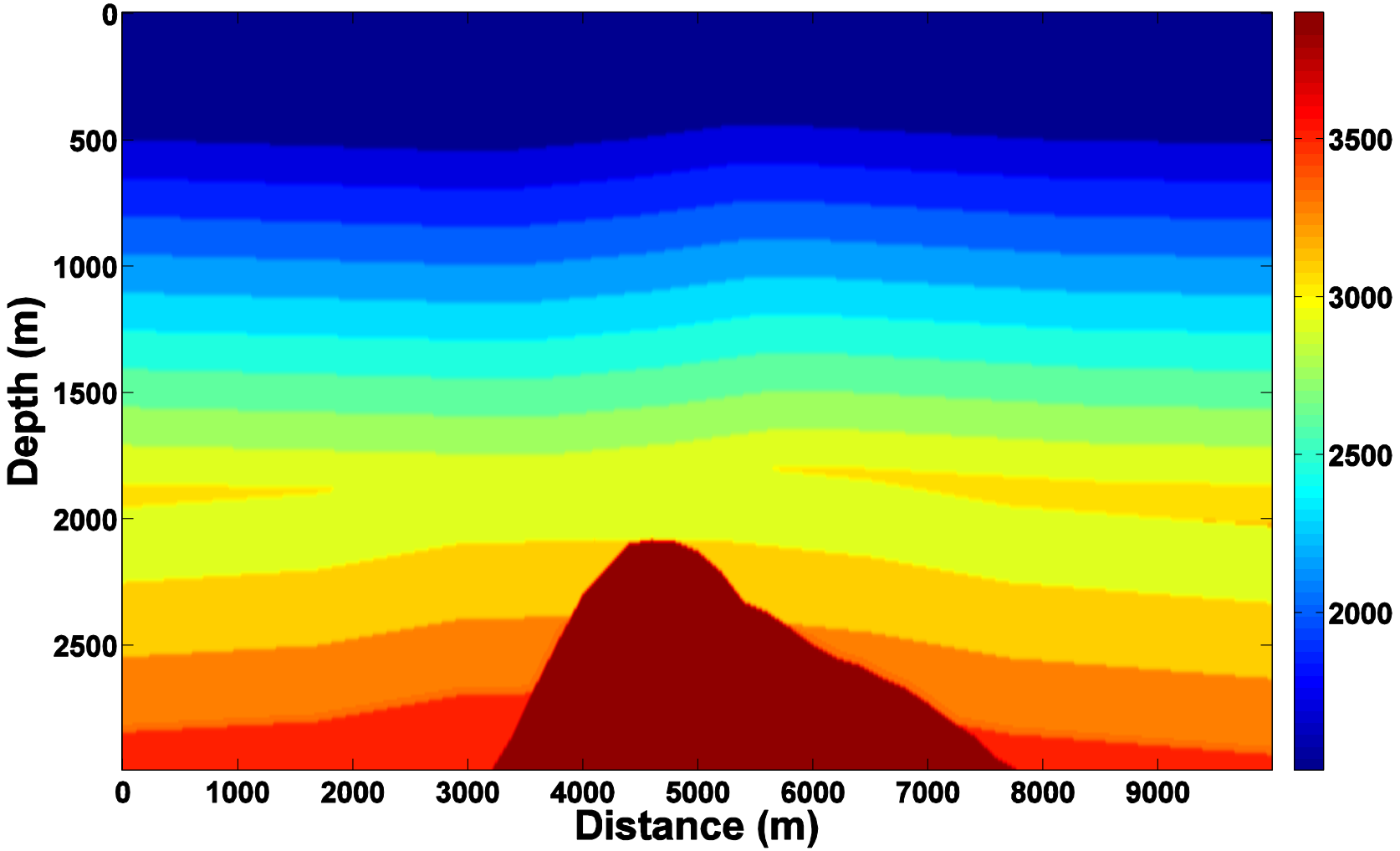
Iteration 85 (1 – 14 Hz)



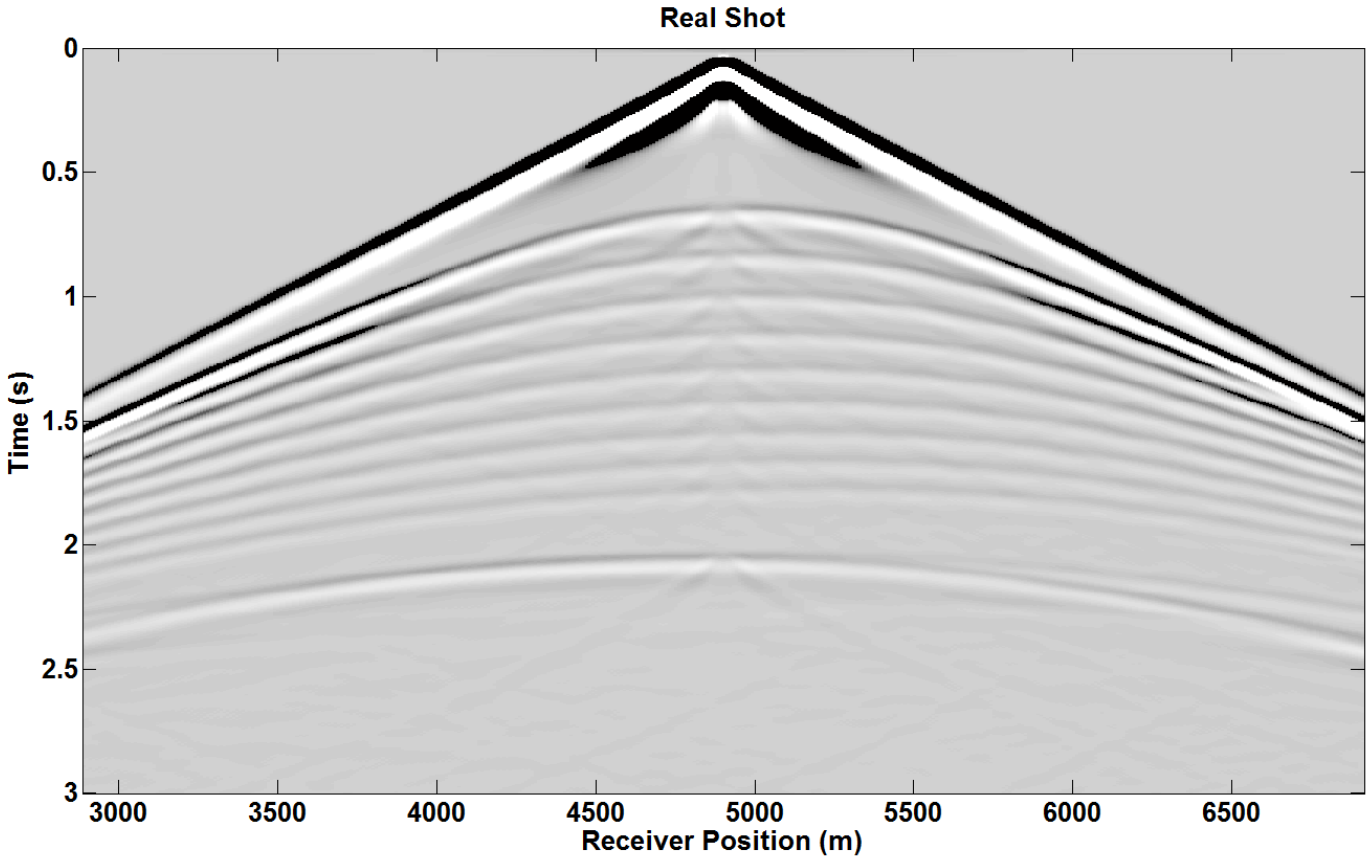
Iteration 112 (1 – 17 Hz)



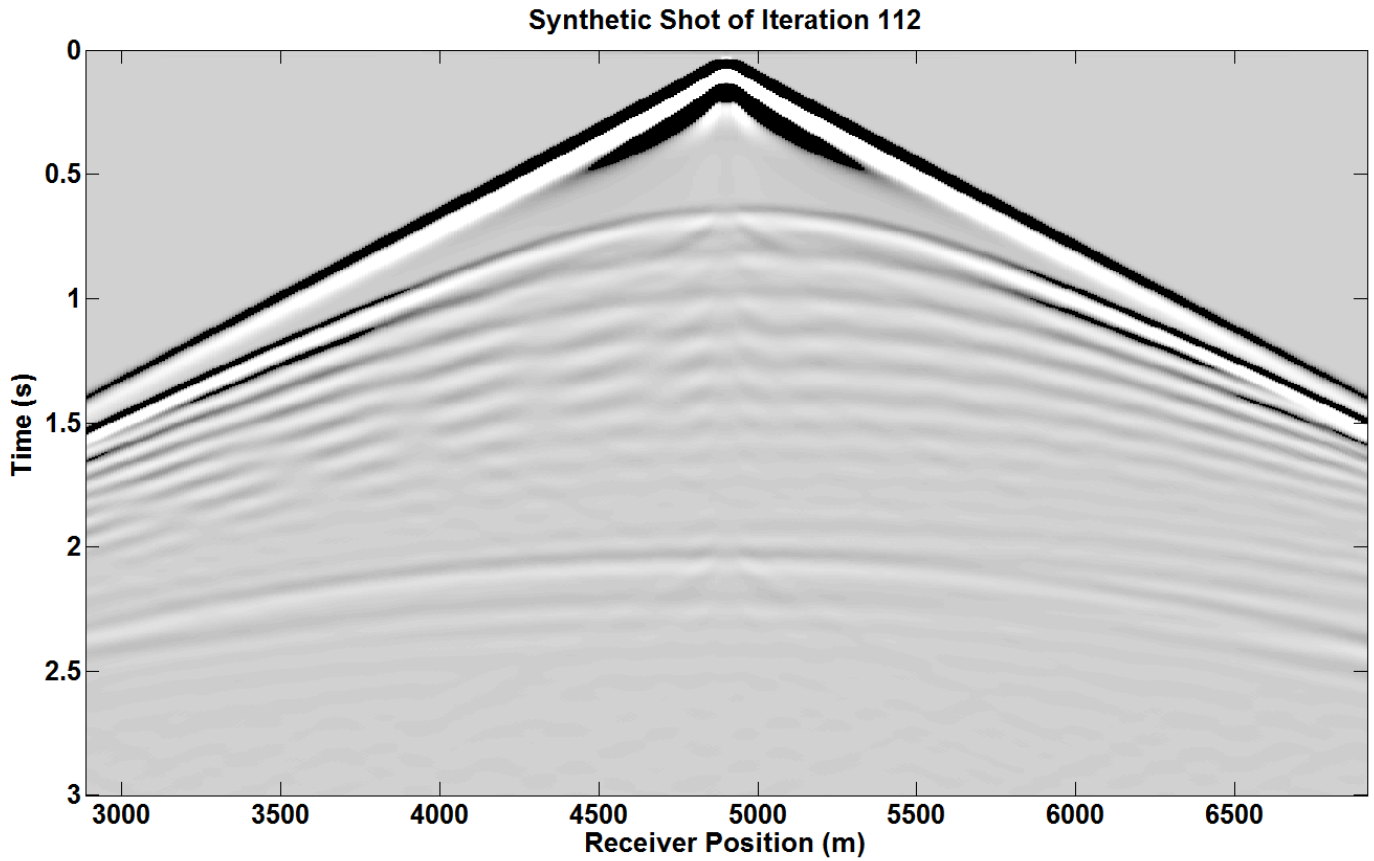
Real Model


0
500
1000
1500
2000
2500
Depth (m)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Distance (m)
3500
3000
2500
2000

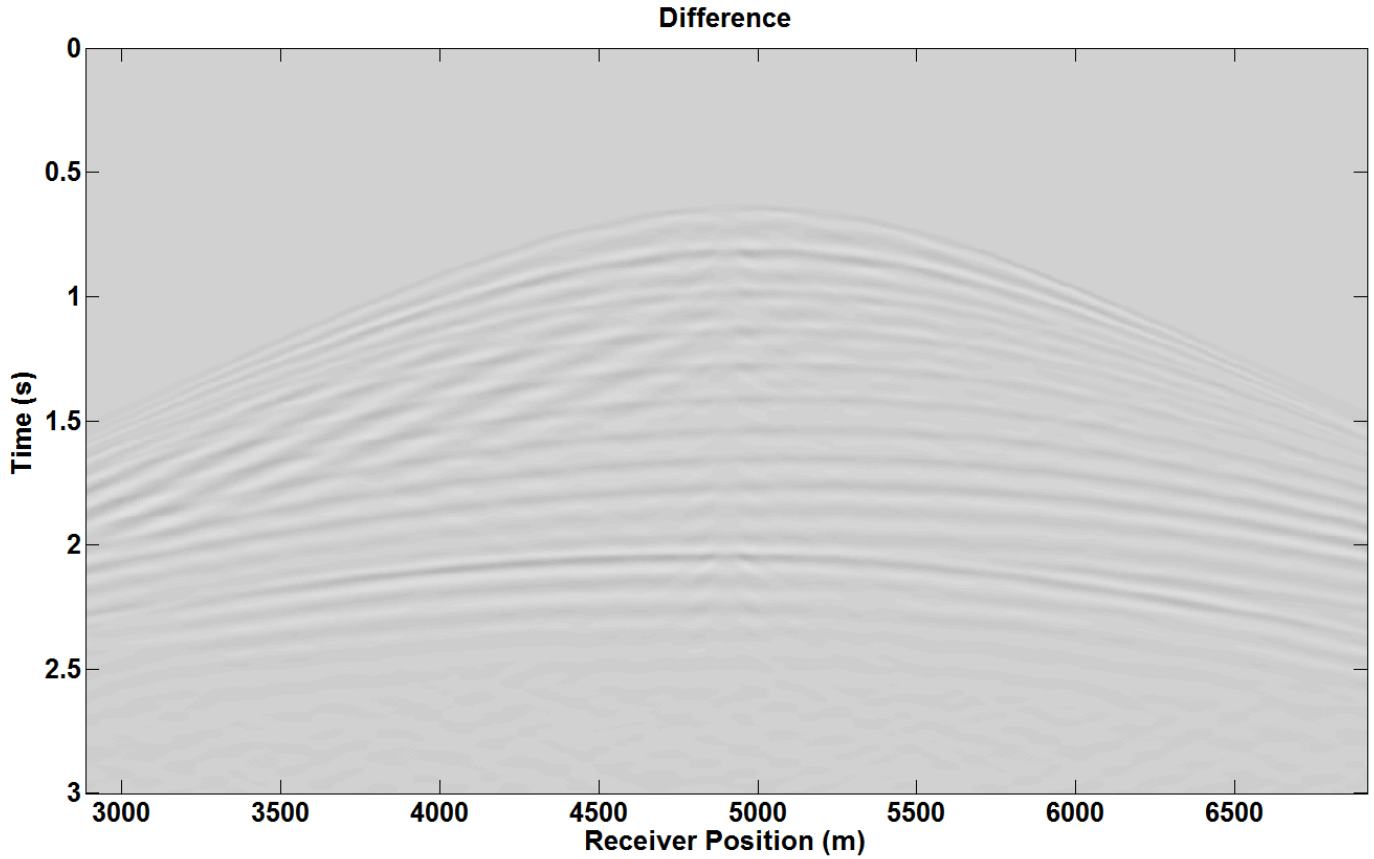
Real Shot (shot 50)



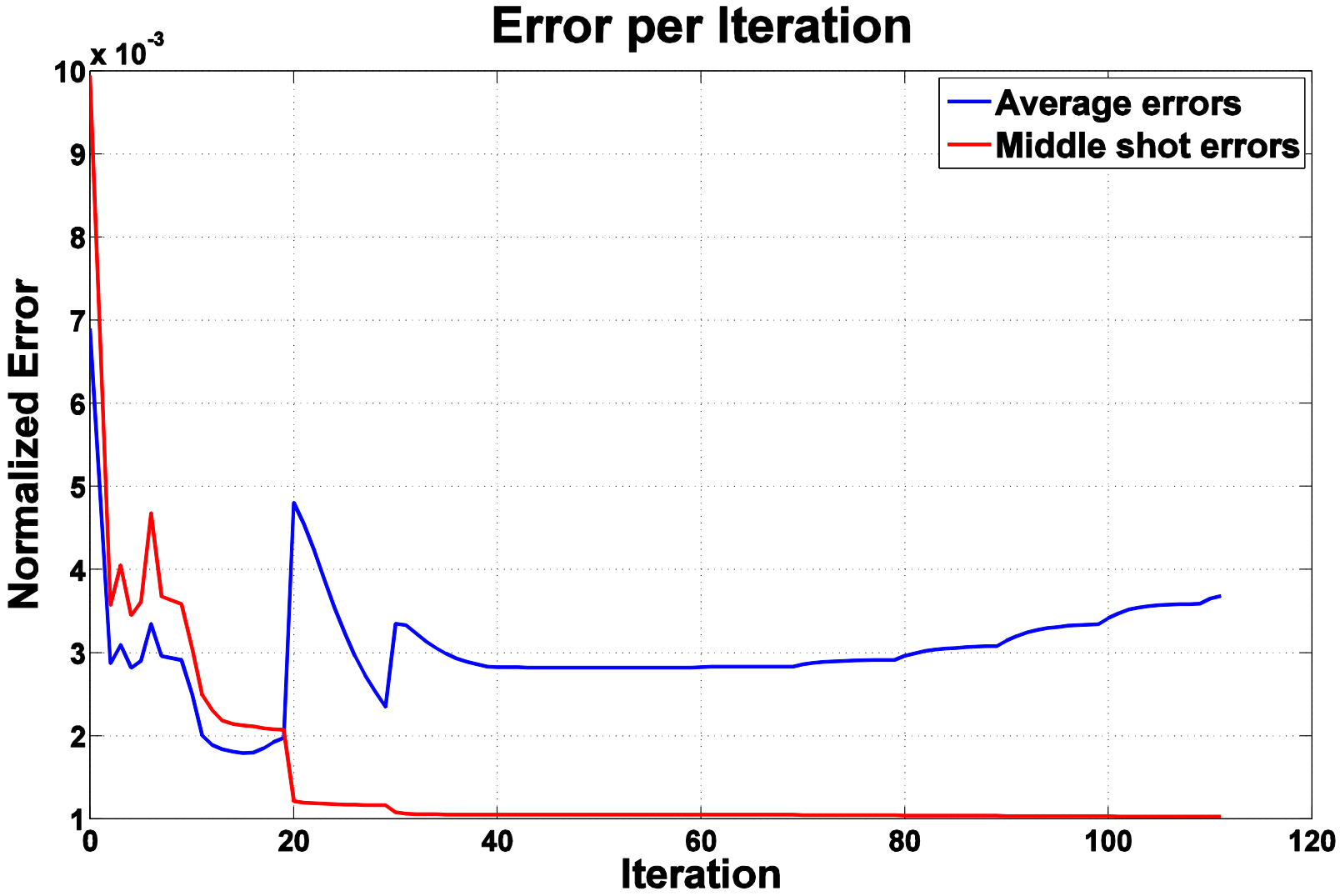
Synthetic Shot of Iteration 112



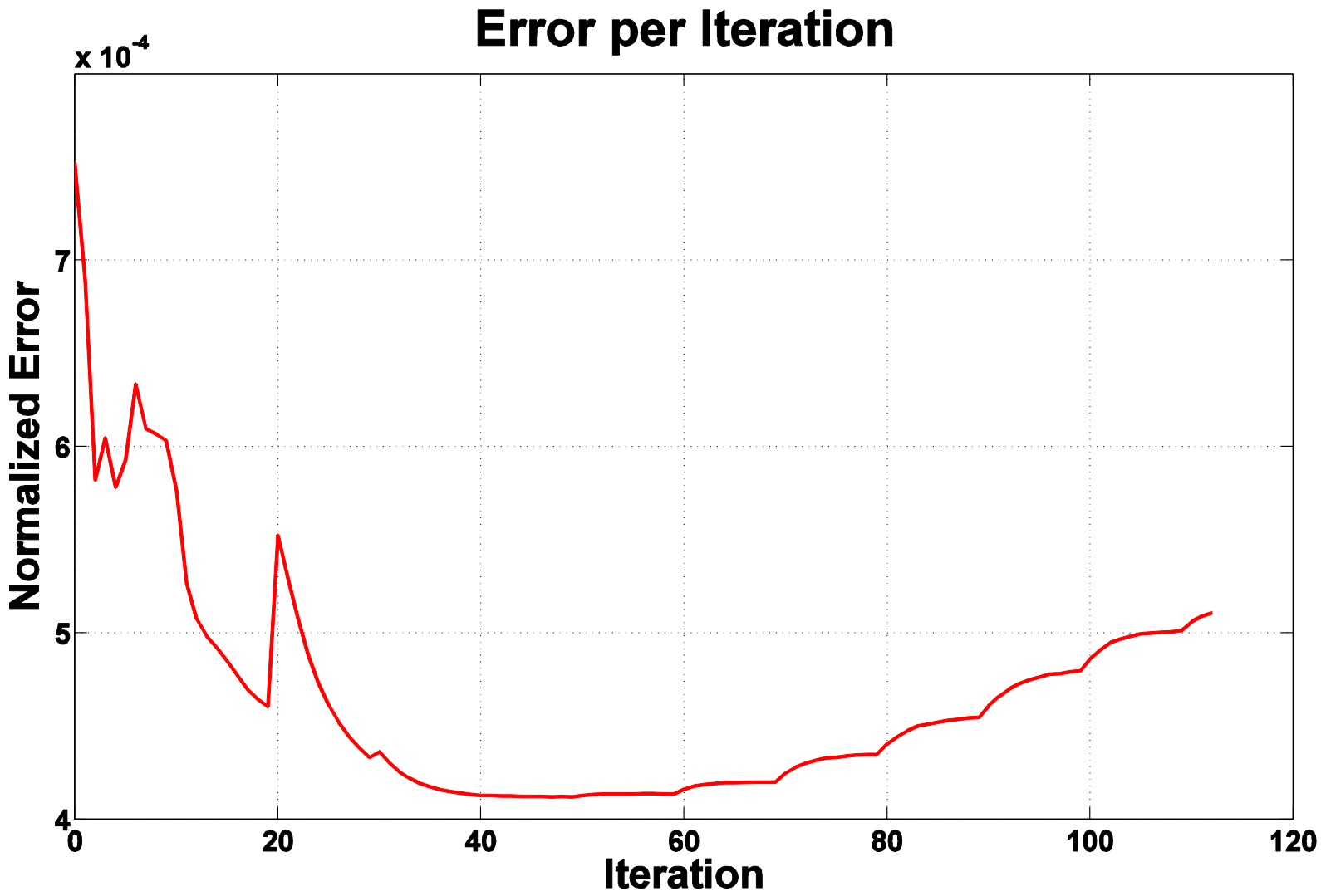
Difference


Difference
Time (s)
0
0.5
1
1.5
2
2.5
3
3000
3500
4000
4500
5000
5500
6000
6500
Receiver Position (m)

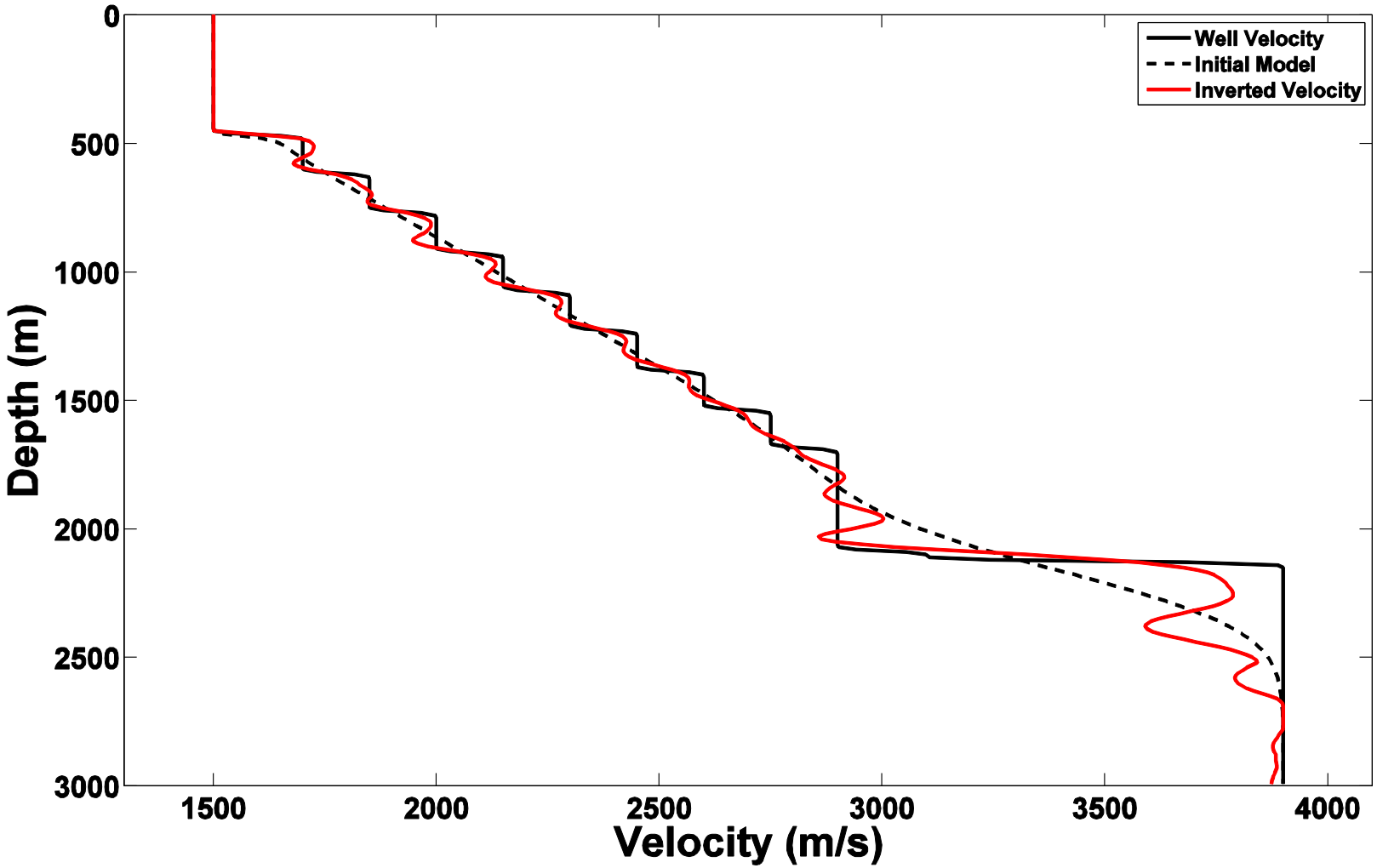
Error per Iteration (shots)



Error per Iteration (model)

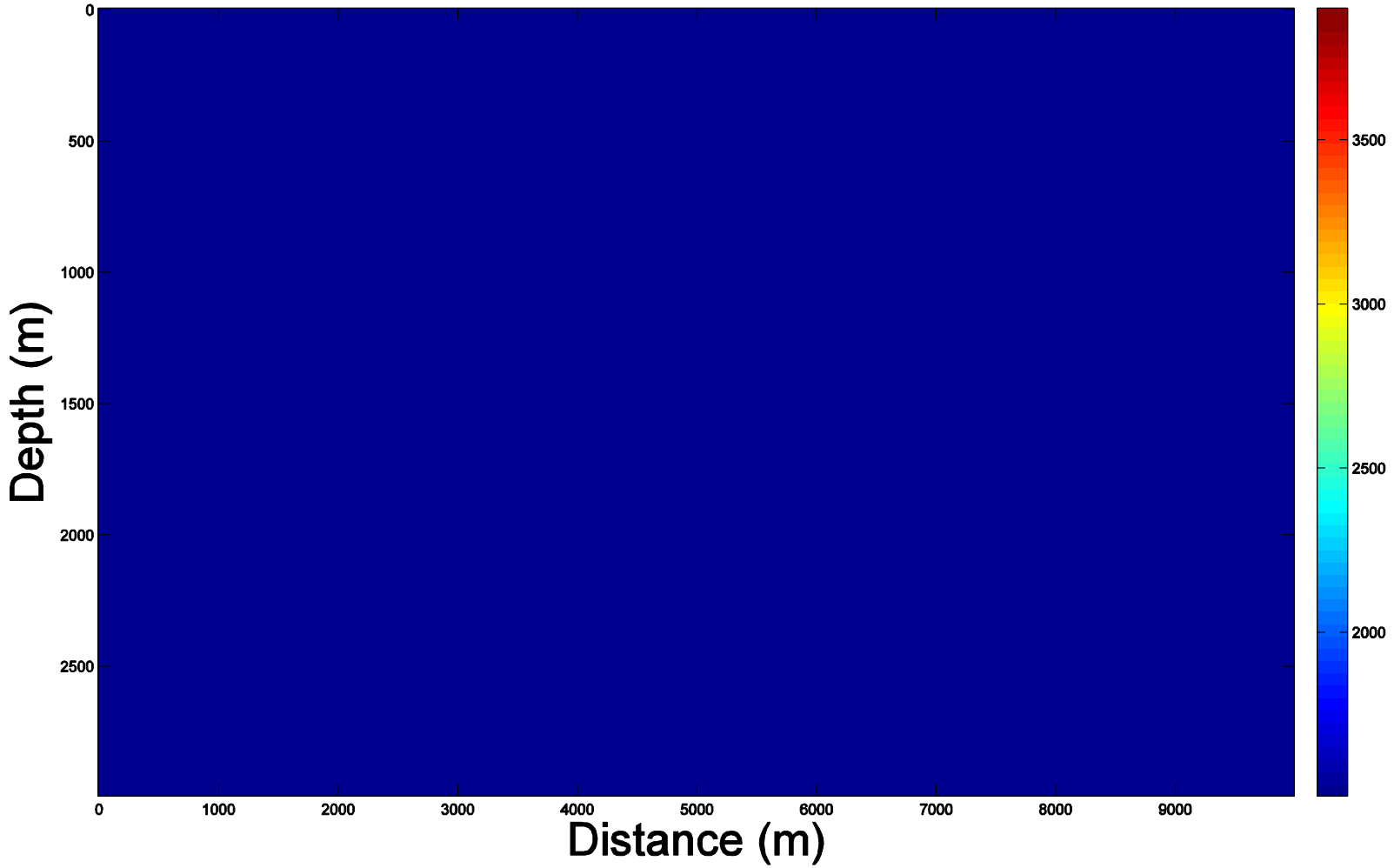


1D Velocity QC

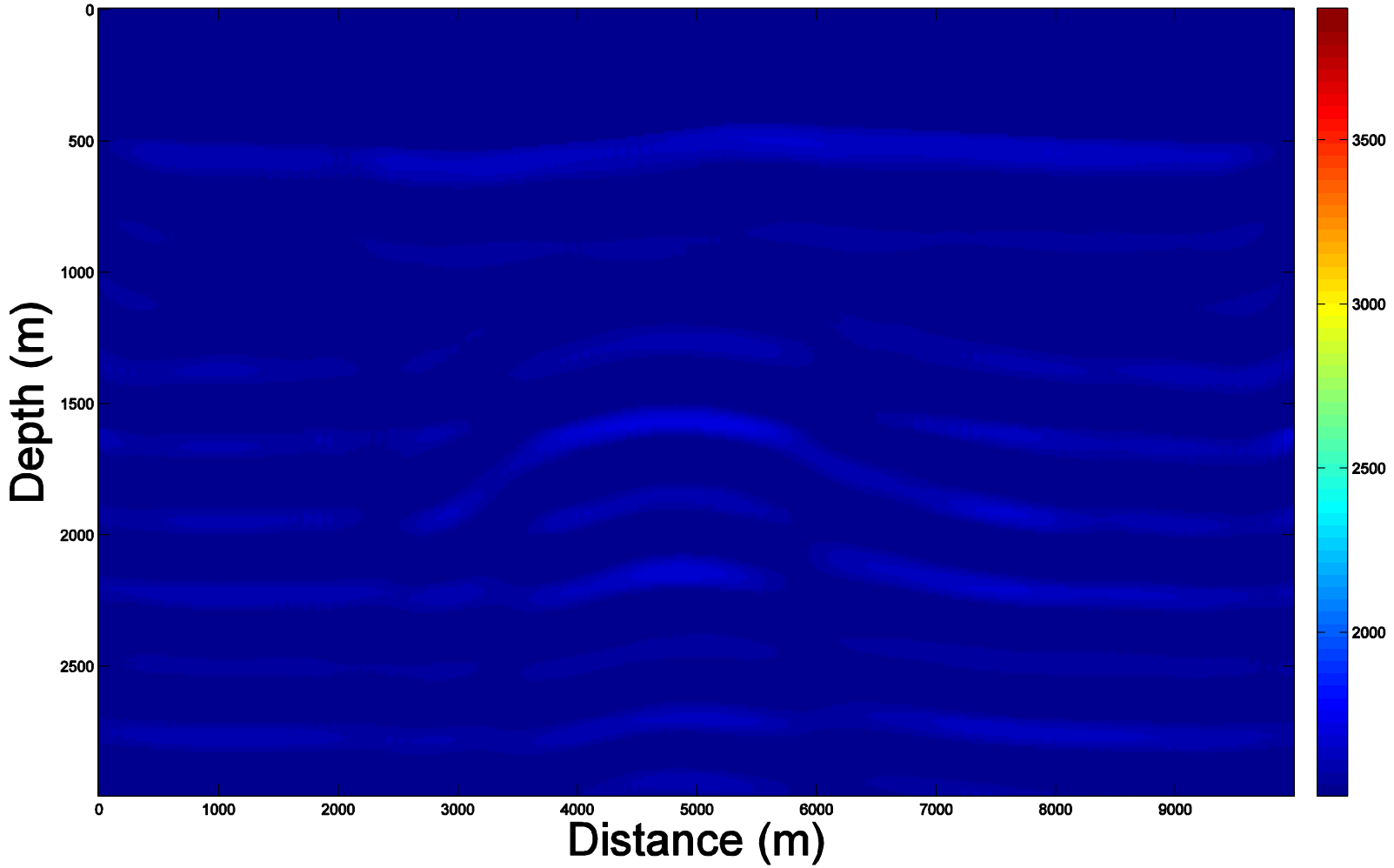


Constant Initial Velocity Model

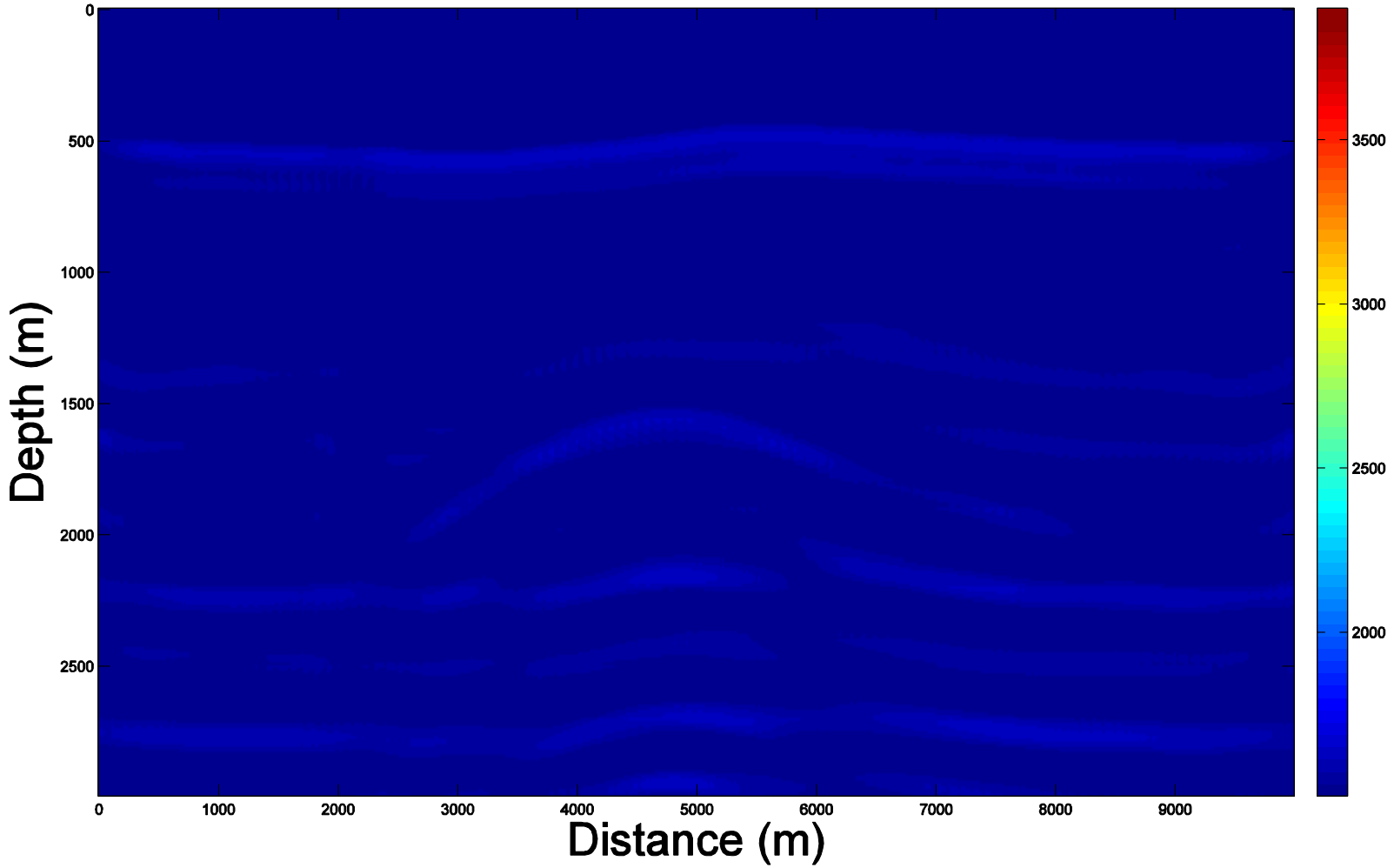
Initial Model - Constant



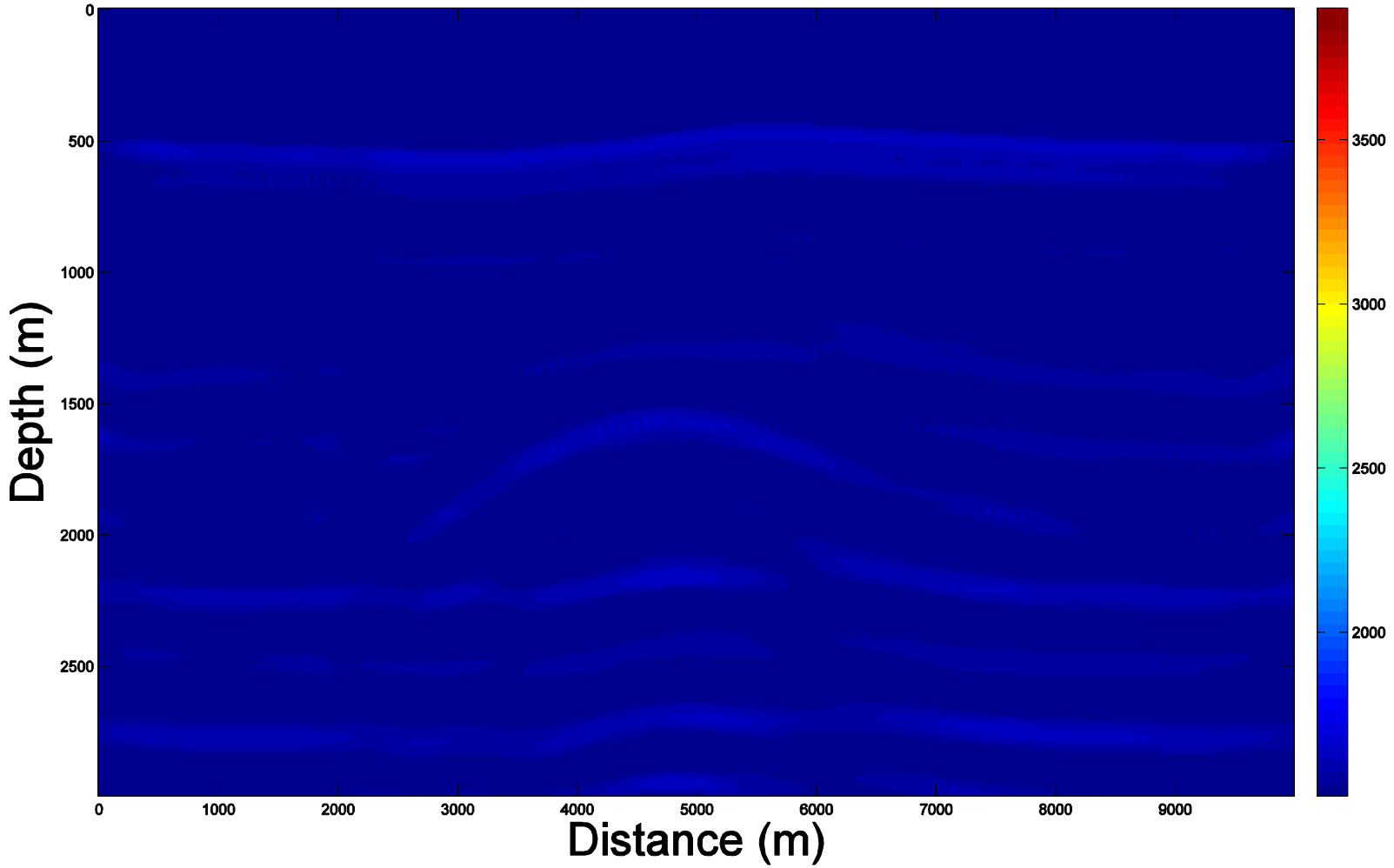
Iteration 10 - Constant



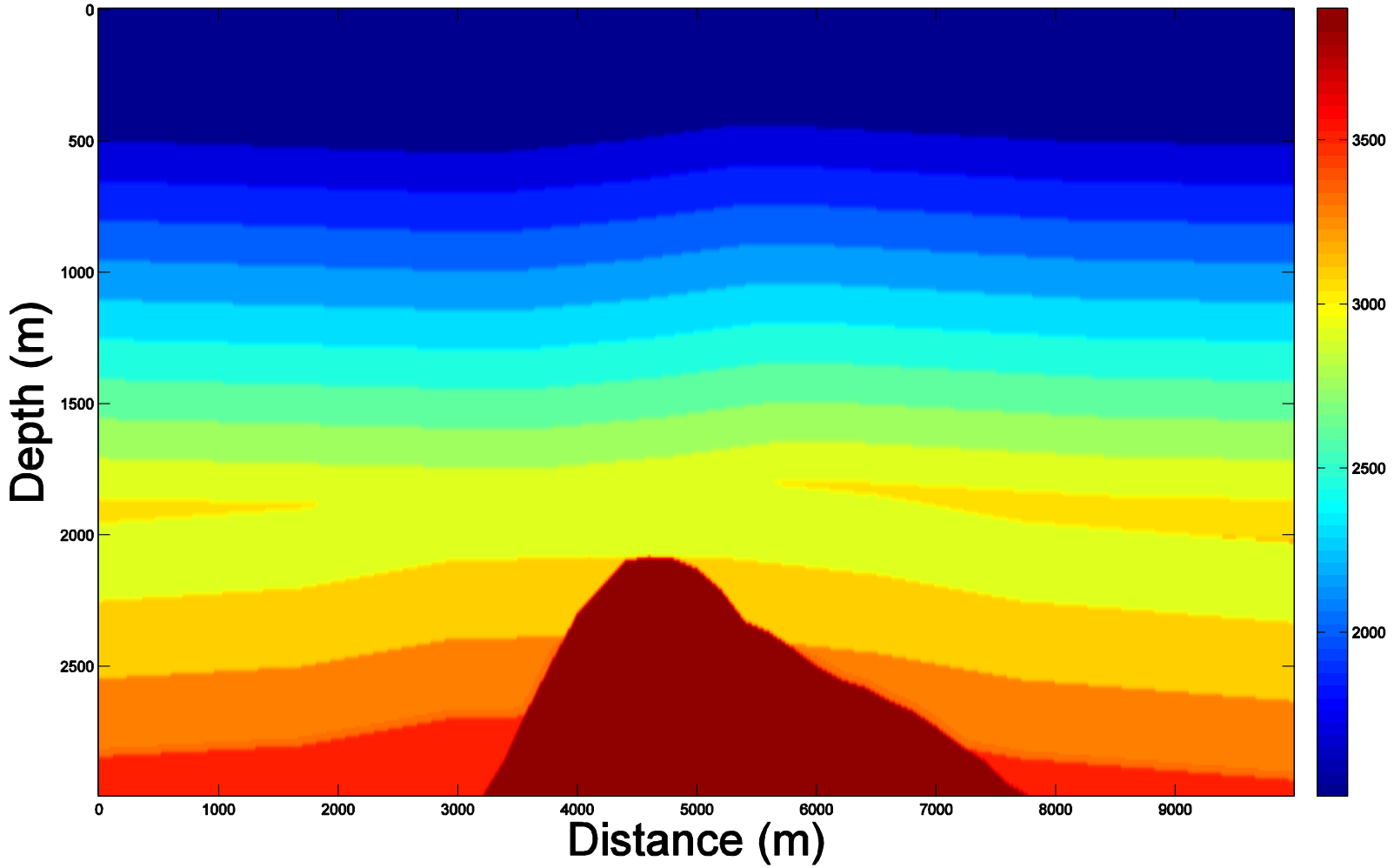
Iteration 35 - Constant



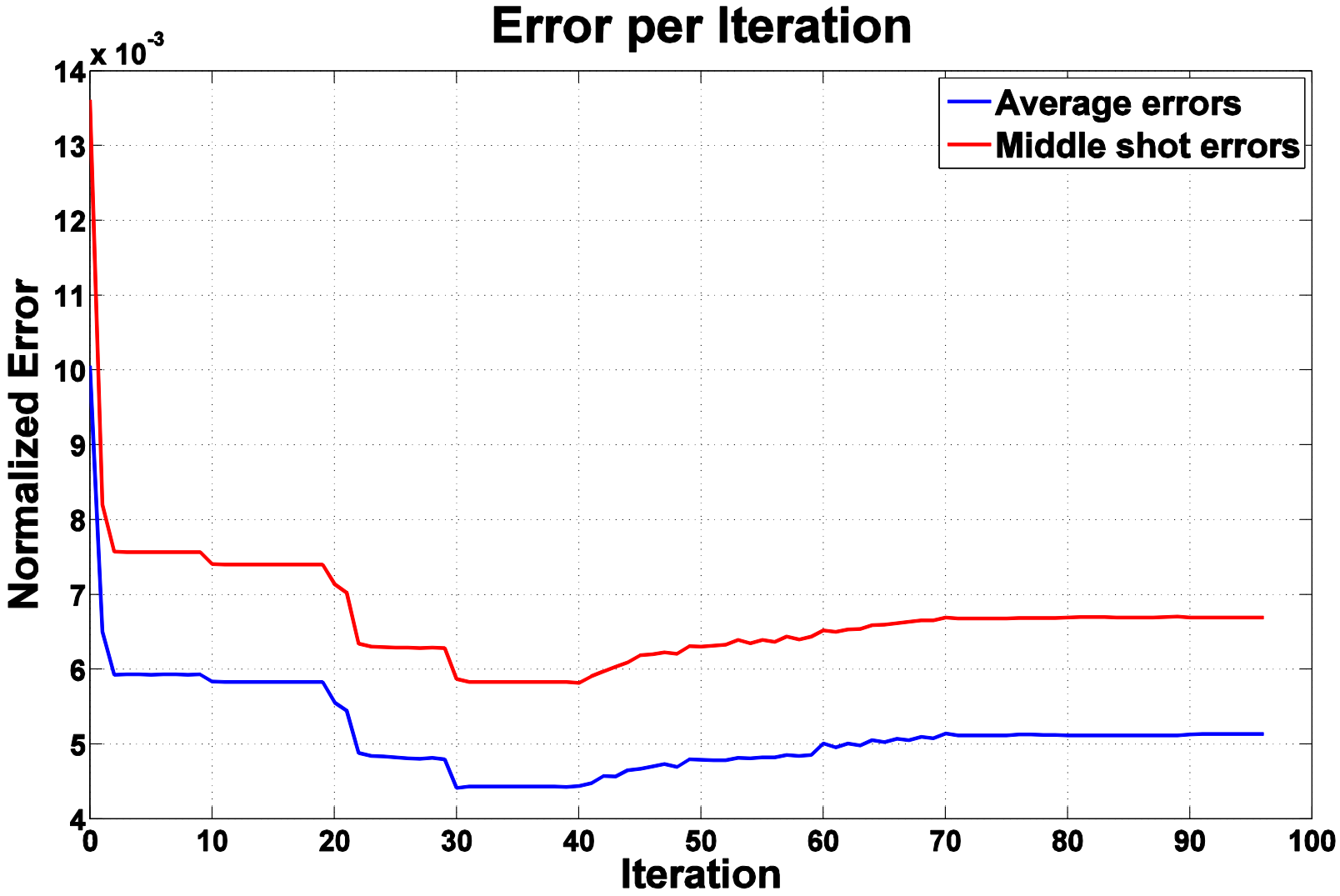
Iteration 97 - Constant



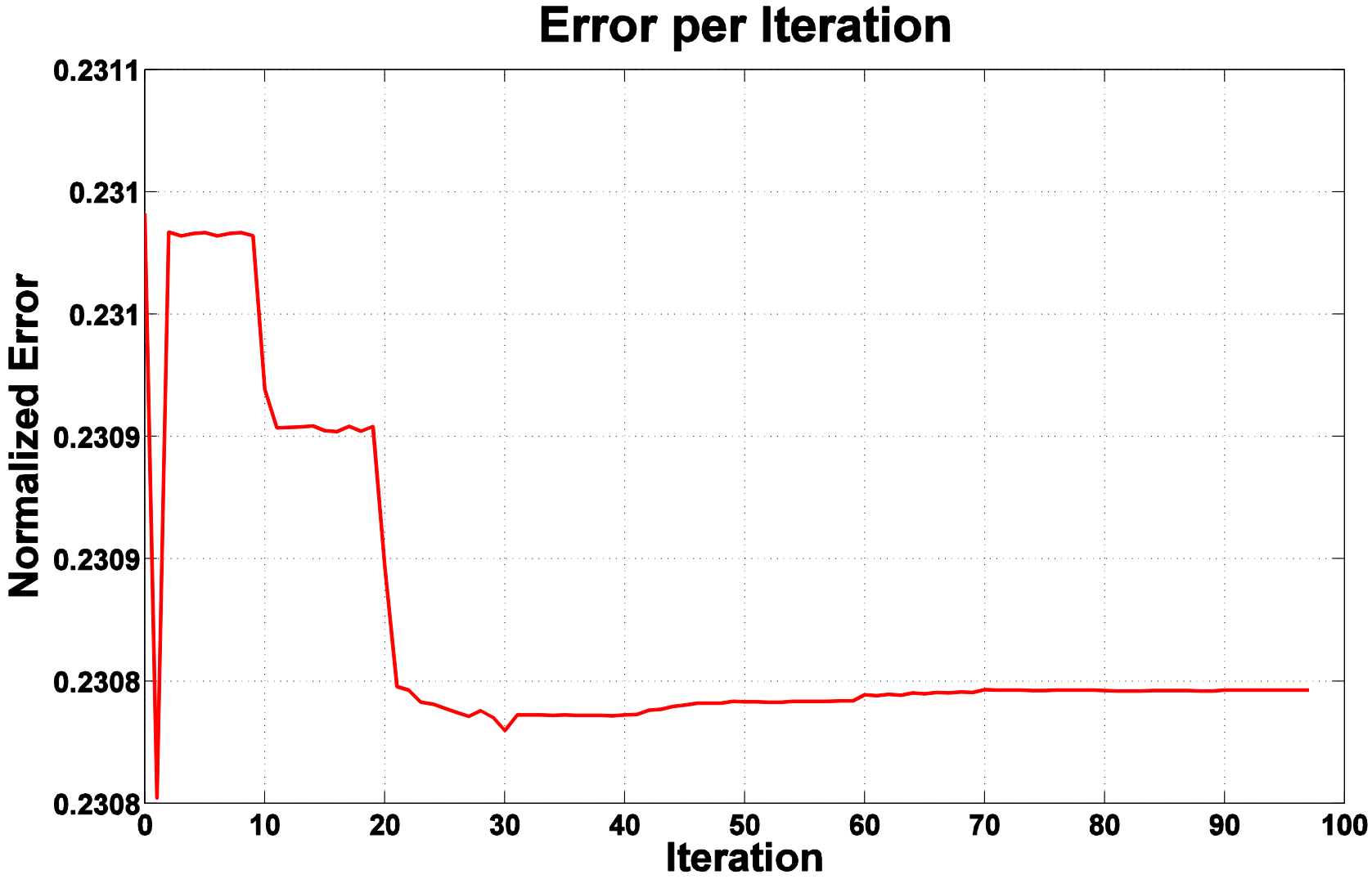
Real Model


Depth (m)
0
500
1000
1500
2000
2500
Distance (m)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
3500
3000
2500
2000

Error per Iteration (shots)



Error per Iteration (model)



Actual Conclusions

- Velocity model is converging (at least for good initial velocity model)
- Line search is sensible to number of points for quadratic fit
- Water bottom artifacts may drive the line search to find a local minimum
- Wrong mute may drive the line search to “wrong” minimum
- Mute must be chosen carefully
- “Shadows” around high velocity body

Future

- Sonic log initial model (flat layers)
- Interpolated sonic logs as initial model
- Constant velocity initial model
- Different mutes
- Higher frequencies

Acknowledgements

- CREWES sponsors
- Larry Lines and Rob Ferguson
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- Kevin Hall
- Staff members and colleagues