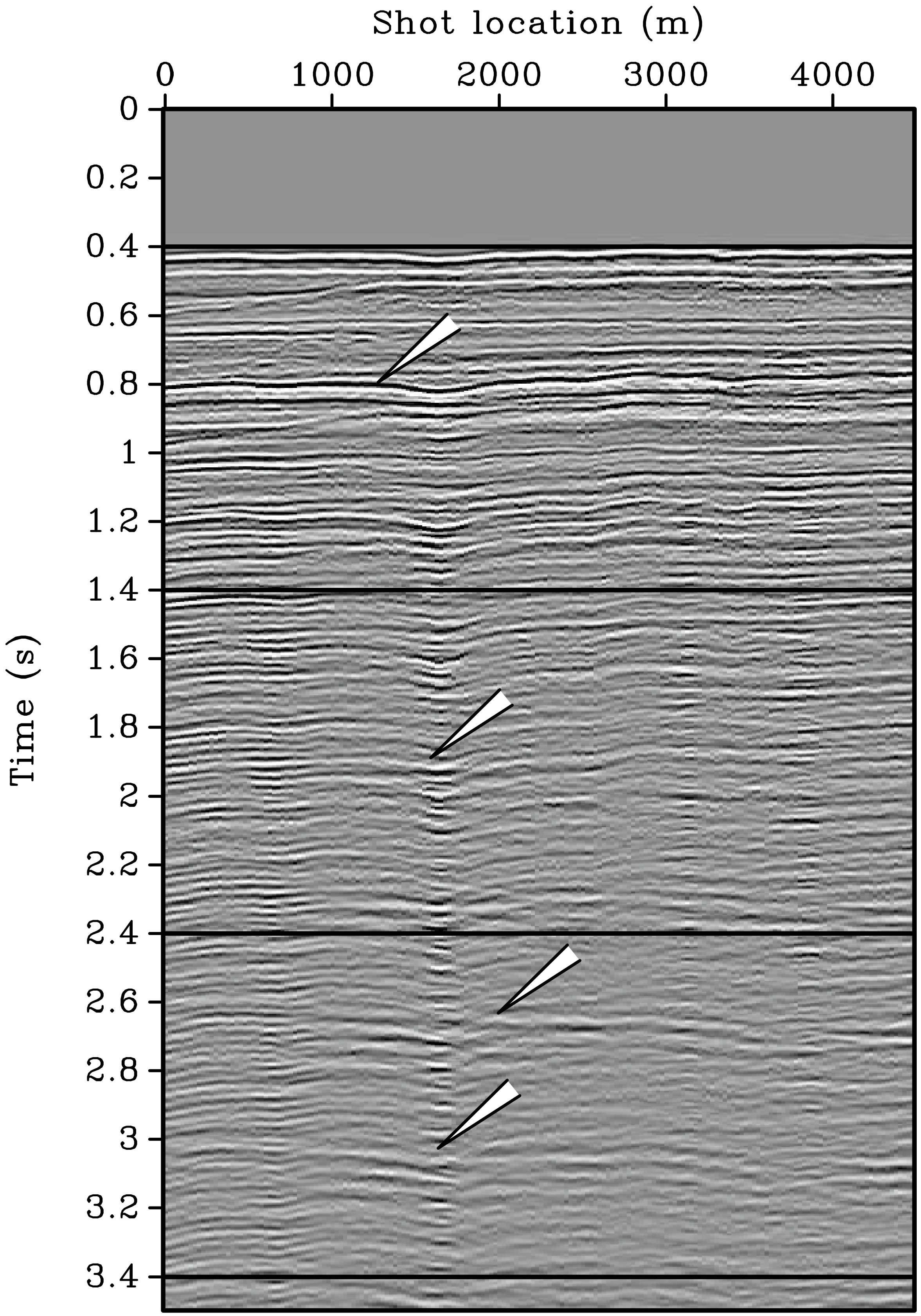
SINBAD Consortium 2010

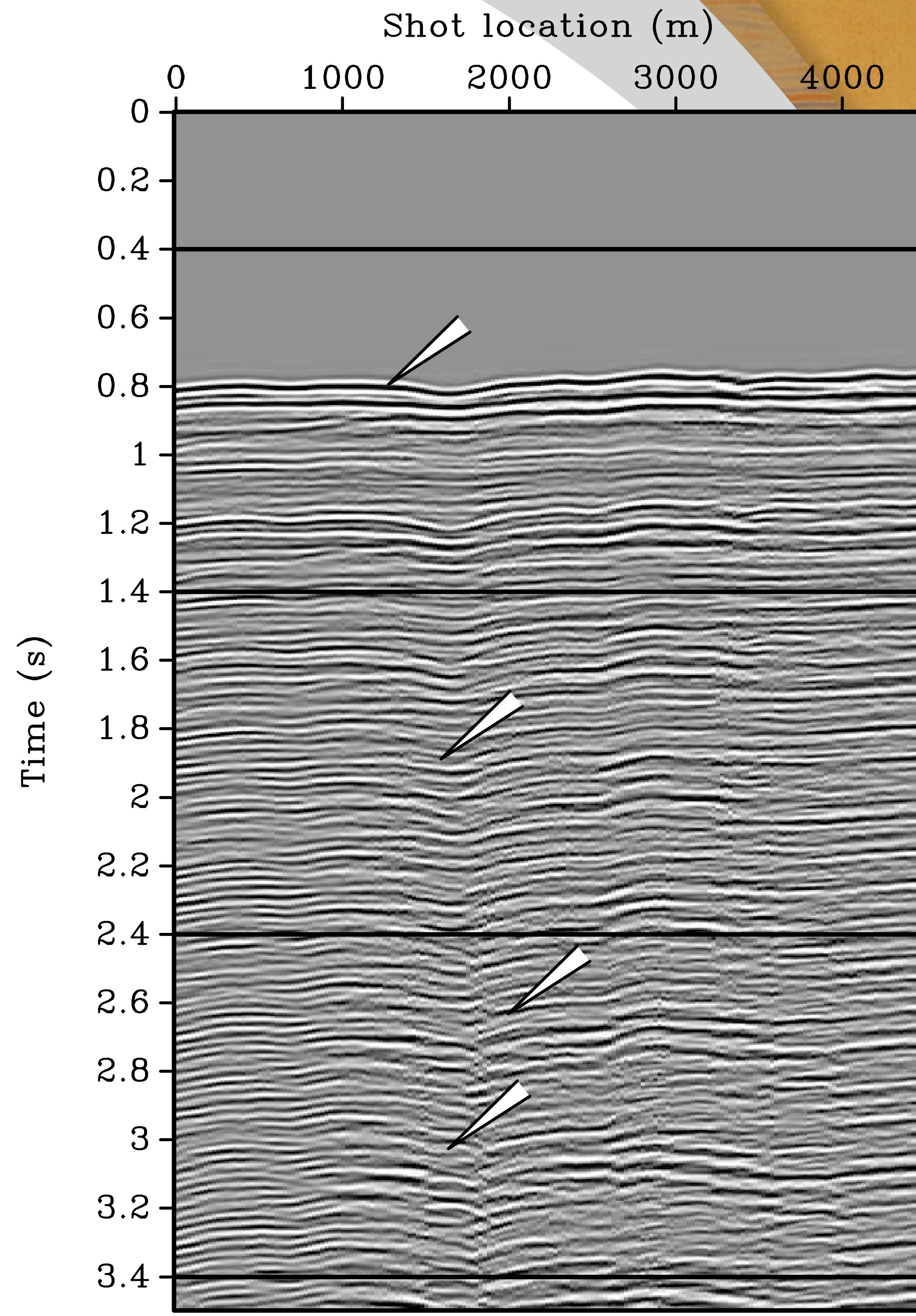
Estimation of Primaries by Curvelet-domain Matched Filtering and Sparse Inversion

Mufeed H. AlMatar

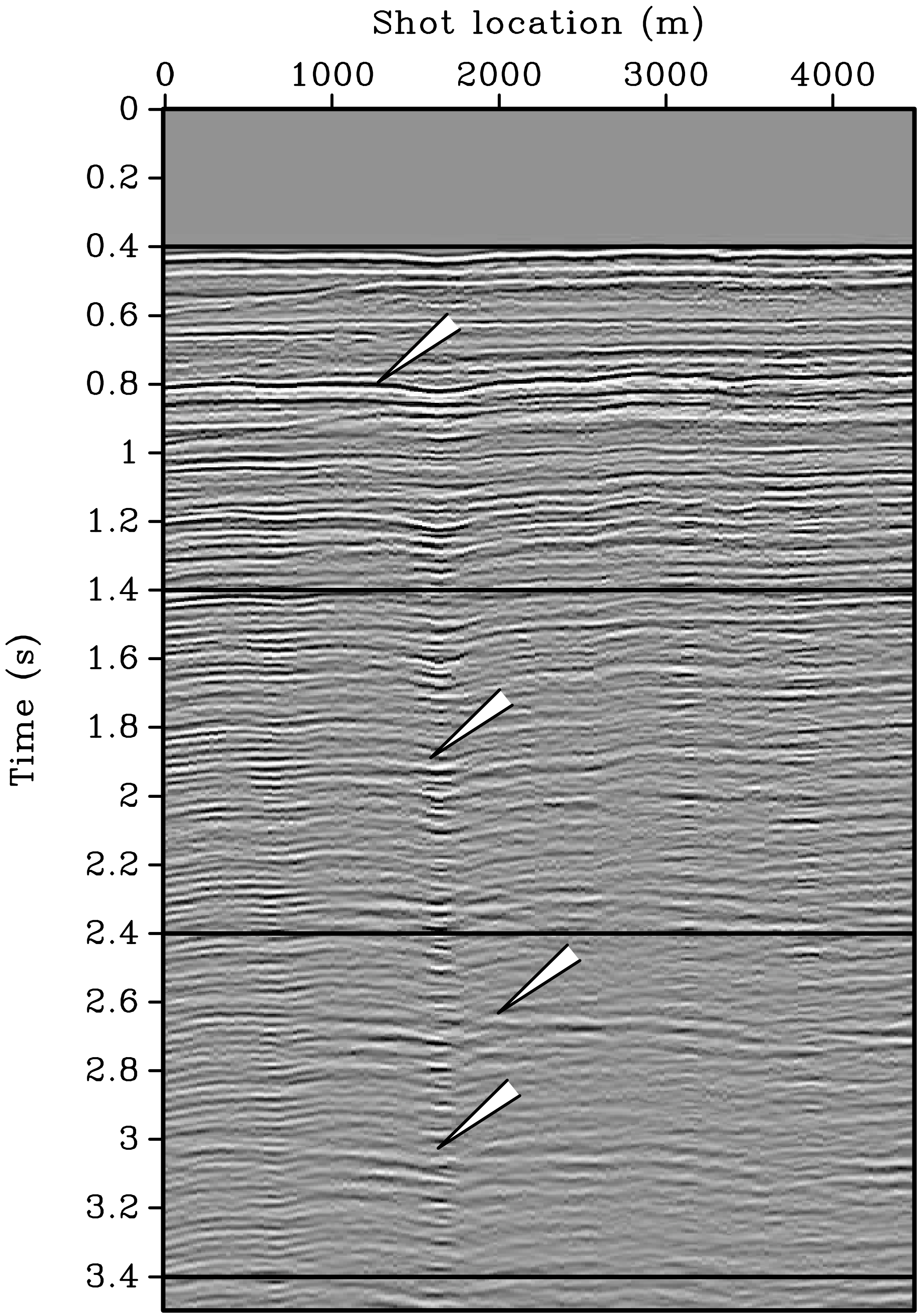
SLIM
University of British Columbia



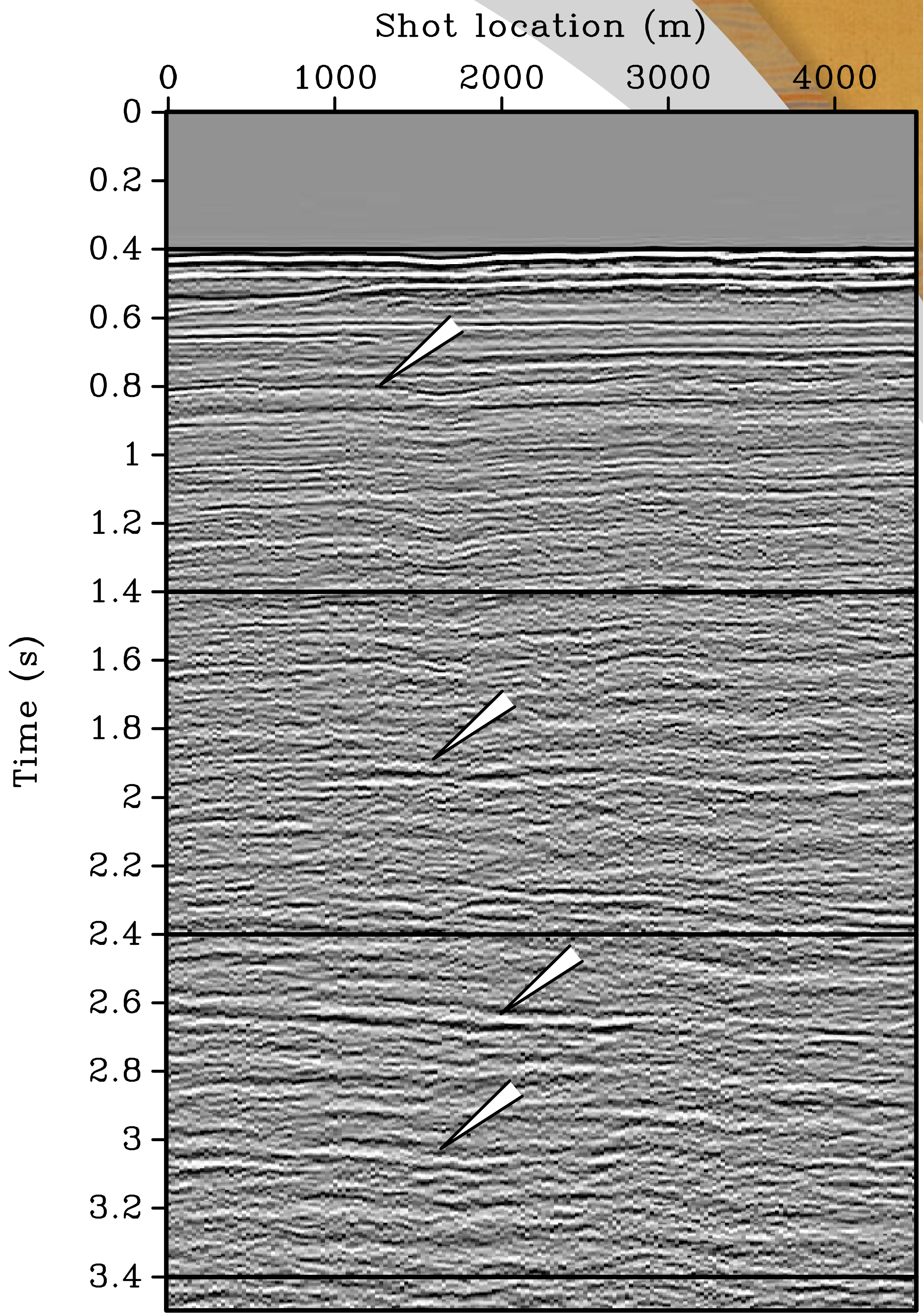
Total Data



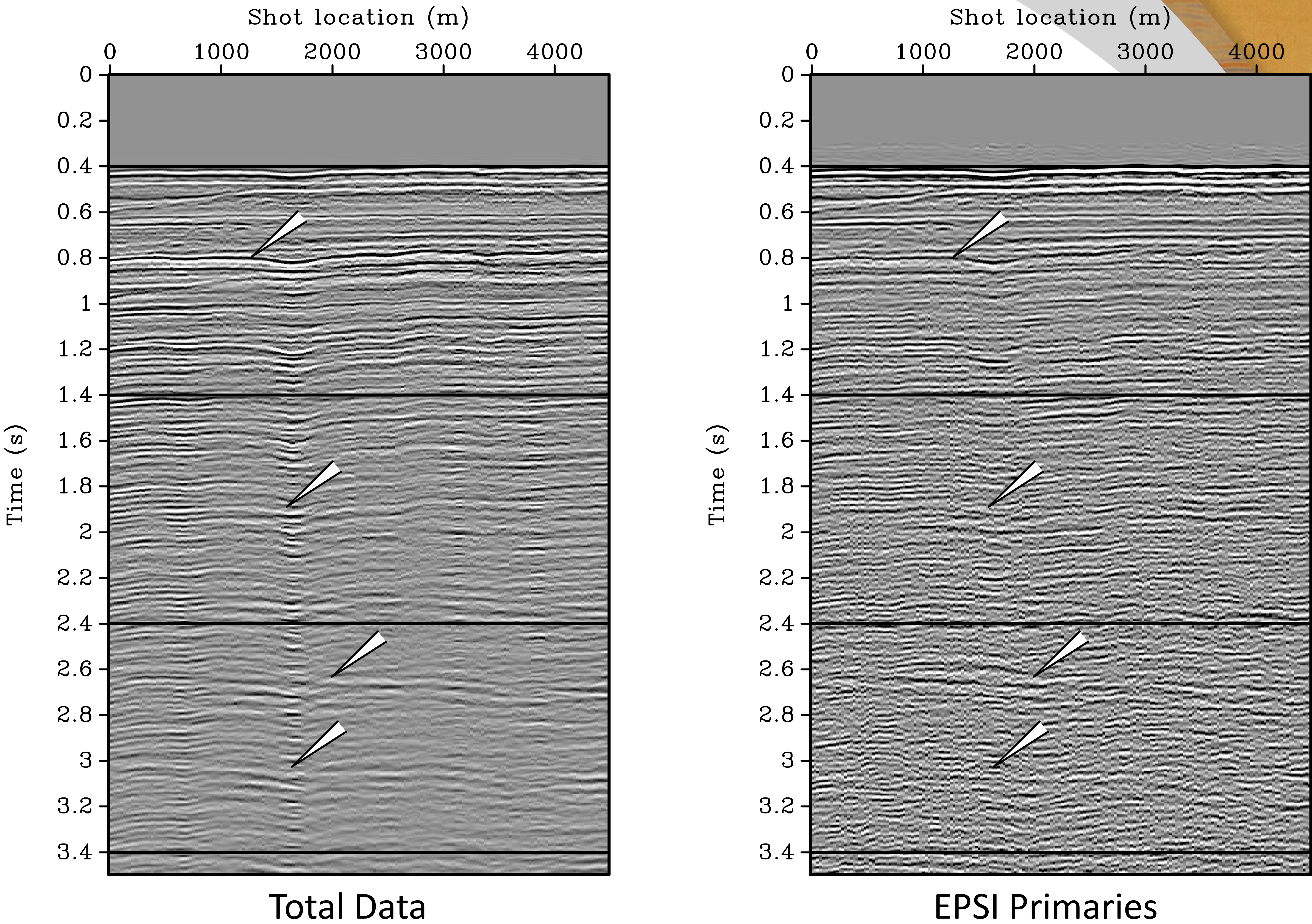
SRME Multiple Prediction



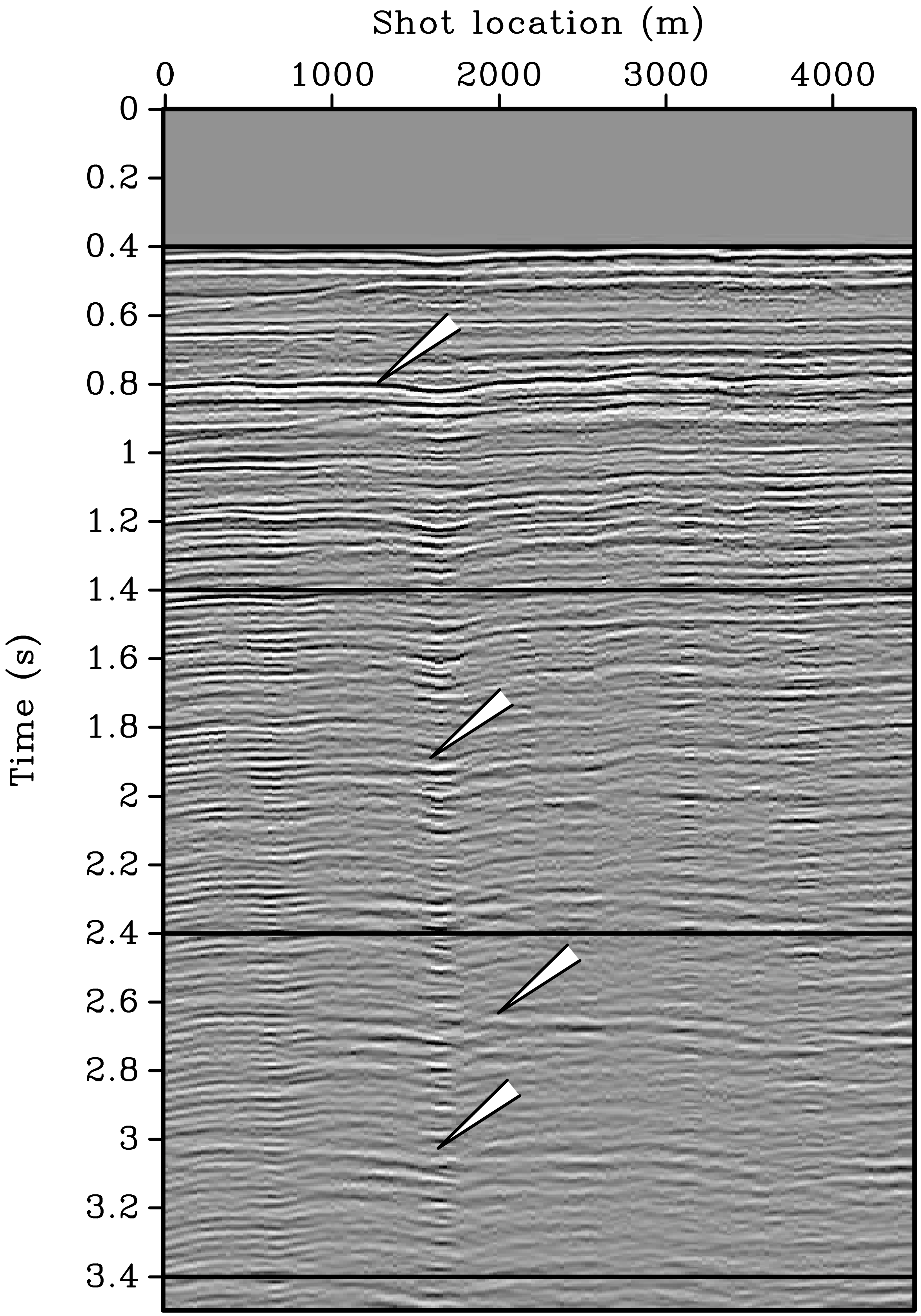
Total Data



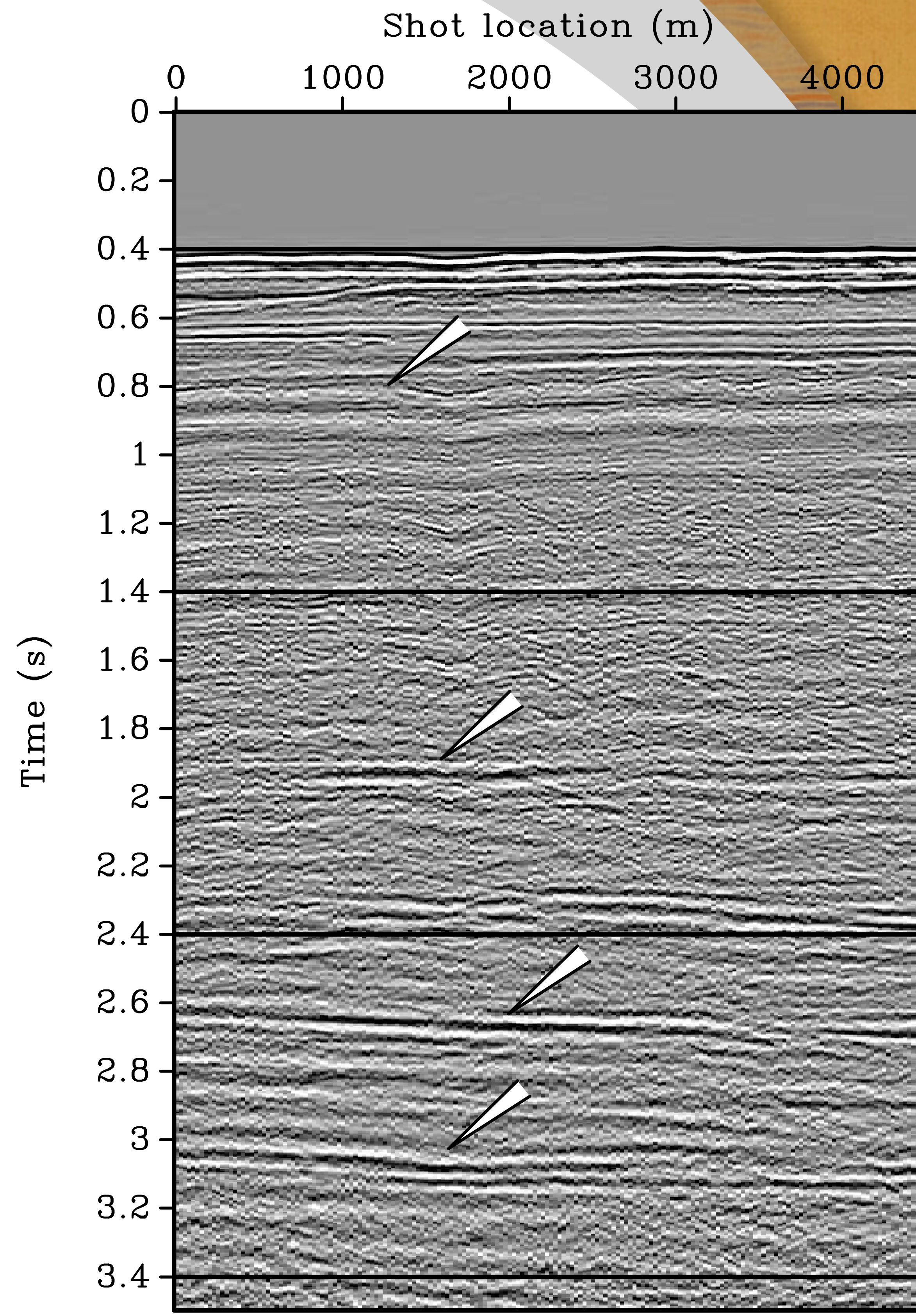
SRME Primaries


Shot location (m)
0
1000
2000
3000
4000
Time (s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
Total Data
Shot location (m)
0
1000
2000
3000
4000
Time (s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
EPSI Primaries

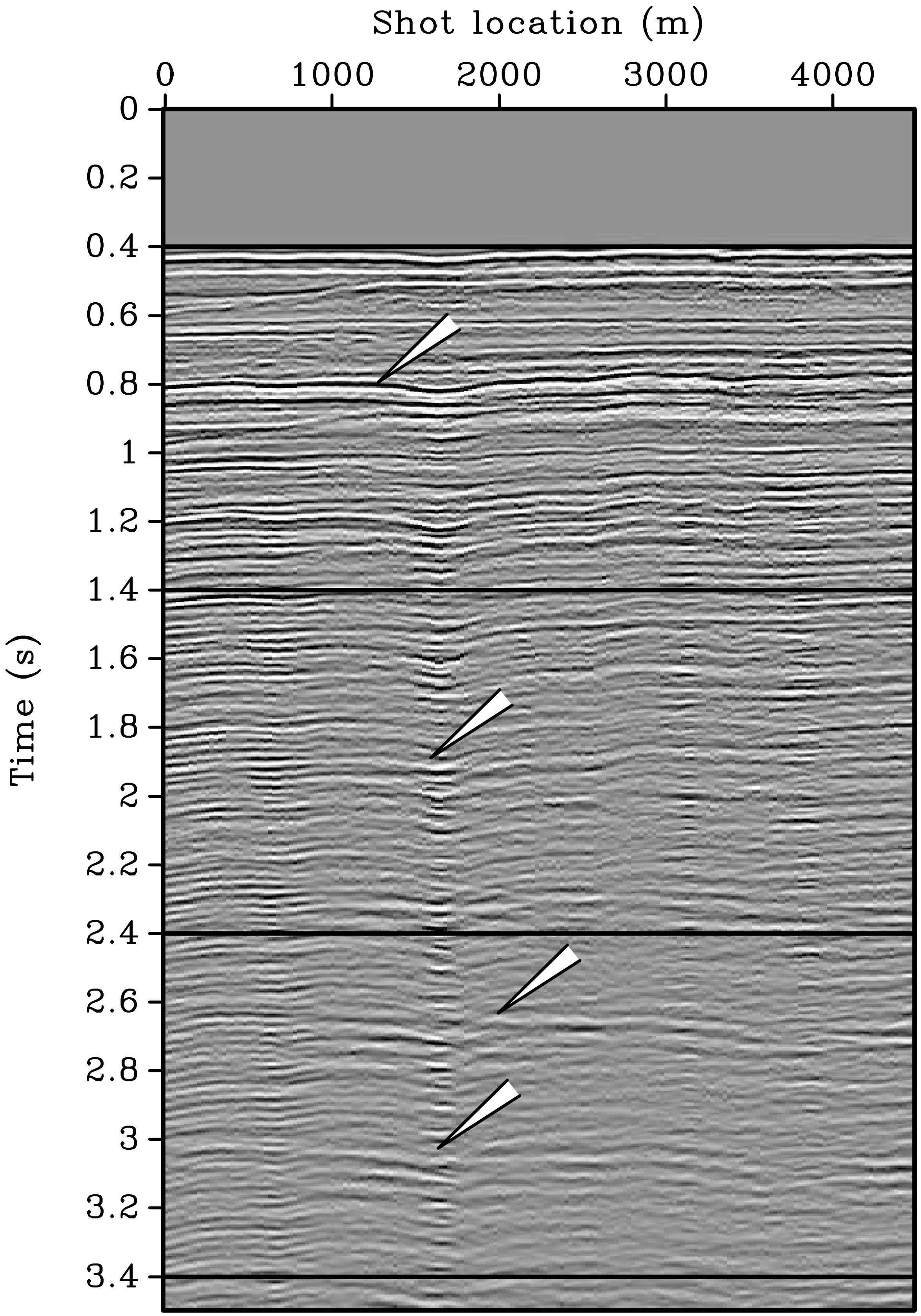
SLIM



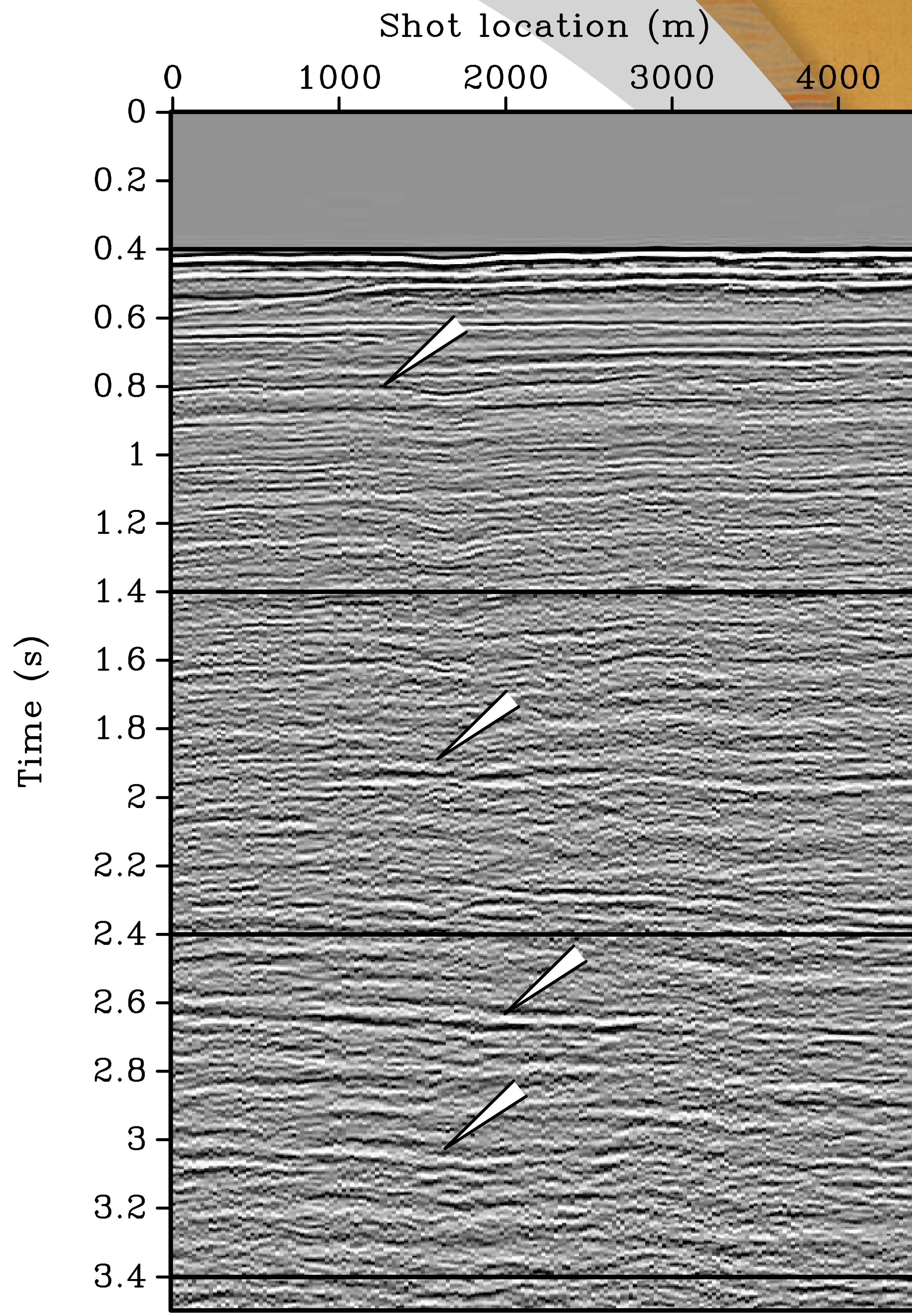
Total Data



Bayesian Primaries



Total Data



SRME Primaries

SLIM

Outline

- Curvelet domain matched filtering
- EPSI & Matching Surface Reflectivity
- Results
- Future Works

Introduction

Successful Matching

(i) control possible overfitting

(ii) handle data with non-unique dips

(iii)apply wavefield separation after matching stably

Herrmann et al (2007)

SLIM

Theory

The Fourier Transform of f

$$(\Psi f)(x) = \int_{R^d} e^{-ix\cdot\zeta} a(x,\zeta) \hat{f}(\zeta) d\zeta$$

The pseudodifferential operator

The symbol of the pseudodifferential operator

Theory

Inverse Curvelet Transform

Diagonal Weighting

$$(\Psi f)(x) \approx \overbrace{C^T}\,\overbrace{D_\Psi}\,\underbrace{C}\, f(x)$$

Forward Curvelet Transform

Curvelet Matching Formulation

$$g = \Psi f$$

$$z = \underset{z}{\operatorname{argmin}} \frac{1}{2} ||g - Bz||_2^2$$

$$B := C^T diag(Cf)$$

Curvelet Matching Formulation

SLIM

$$g = \Psi f$$

$$z = \underset{z}{\operatorname{argmin}} \frac{1}{2} ||g - Bz||_2^2 + \frac{\lambda^2}{2} ||Lz||_2^2$$

$$B := C^T diag(Cf)$$

$$L = [D_1^2 D_2^T D_\theta^T D_{scale}^T]^T$$

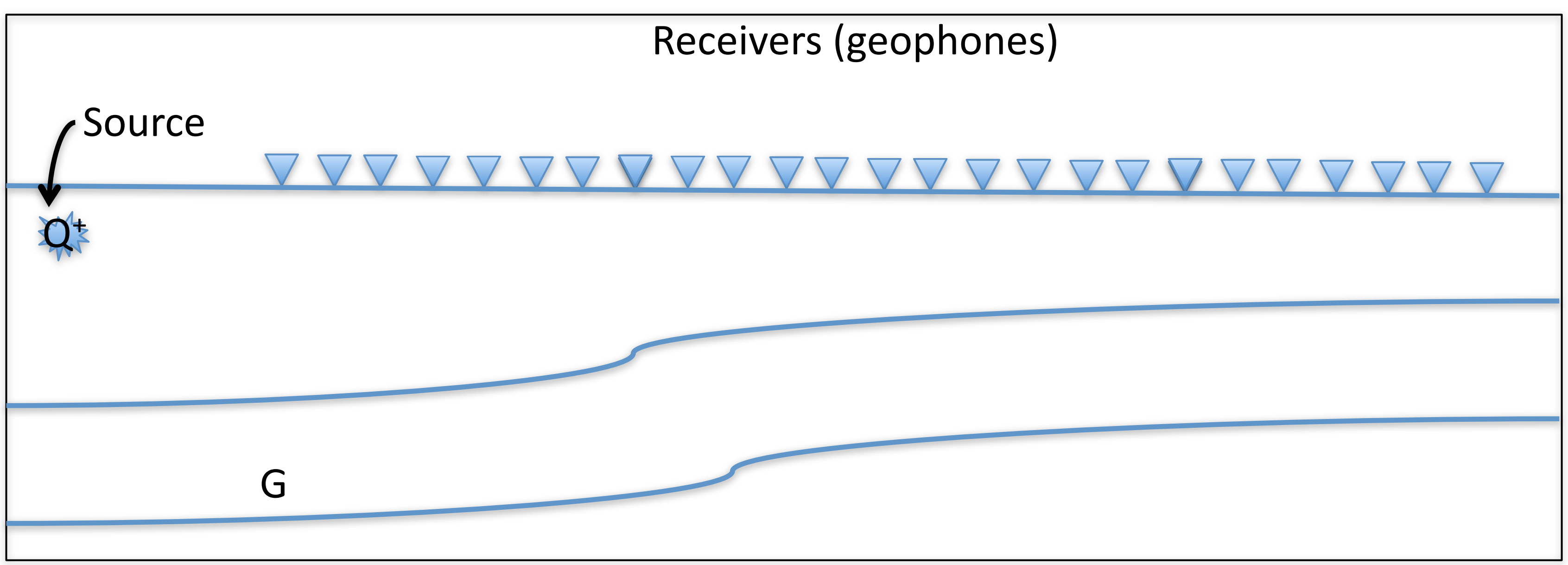
Estimation of primaries by sparse inversion

$$\underbrace{\widehat{\mathbf{G}}}_{\text{surface-free data}} \overbrace{\left[\widehat{\mathbf{Q}} + \mathbf{R}\widehat{\mathbf{P}}\right]}^{\text{downgoing wavefield}} \approx \overbrace{\widehat{\mathbf{P}}}^{\text{upgoing wavefield}}$$

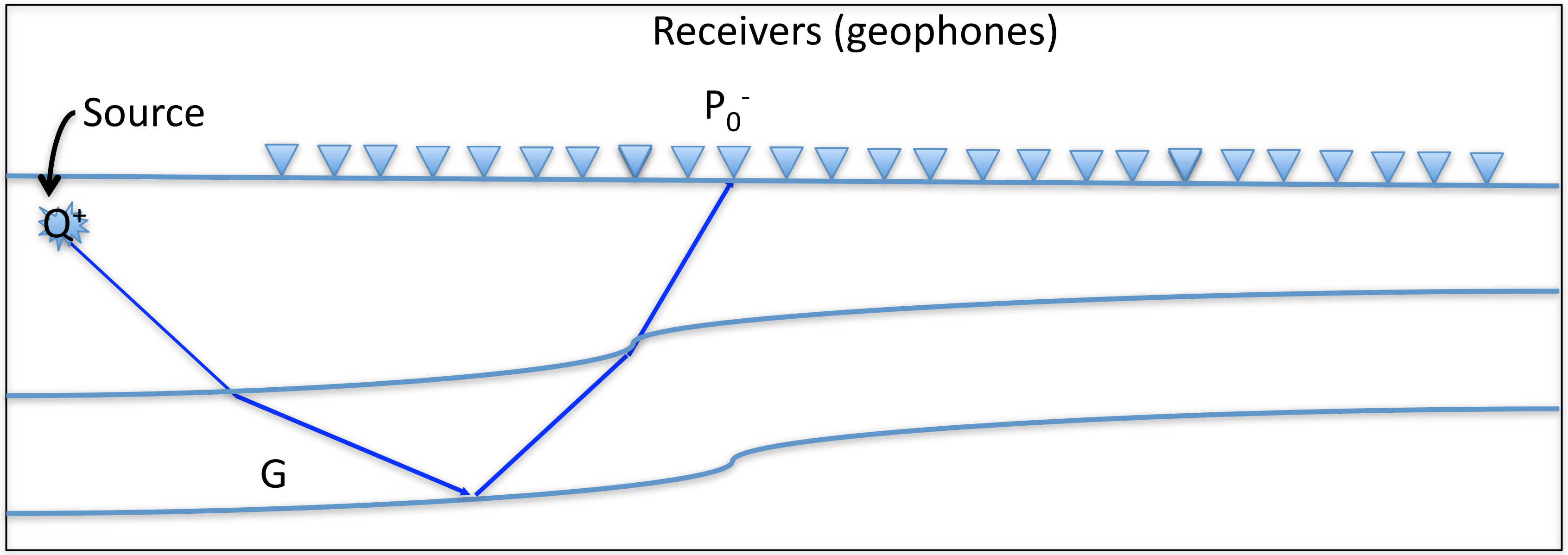
unknown source function

unknown reflection operator

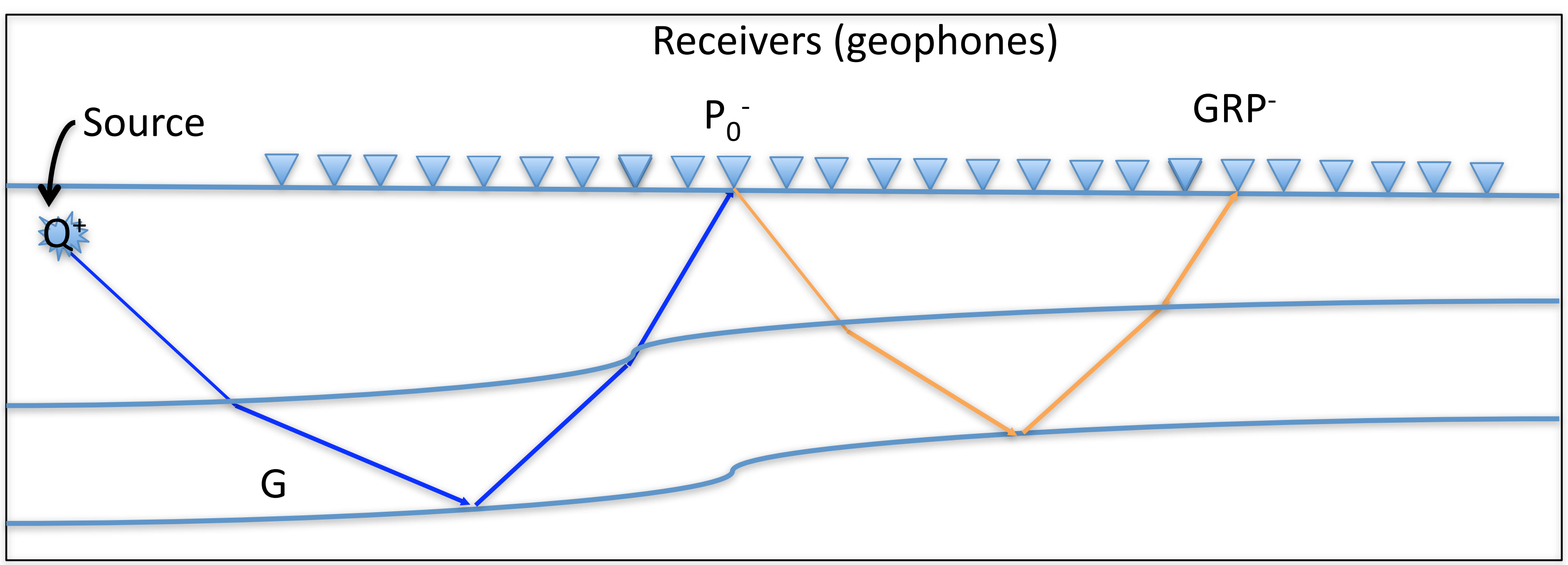
EPSI (1D Case)



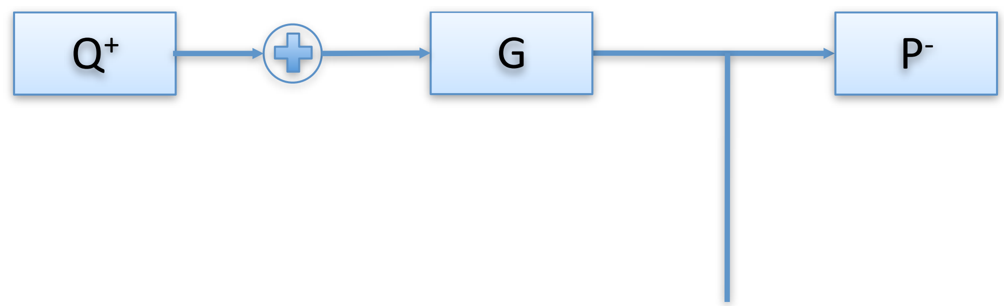
EPSI (1D Case)

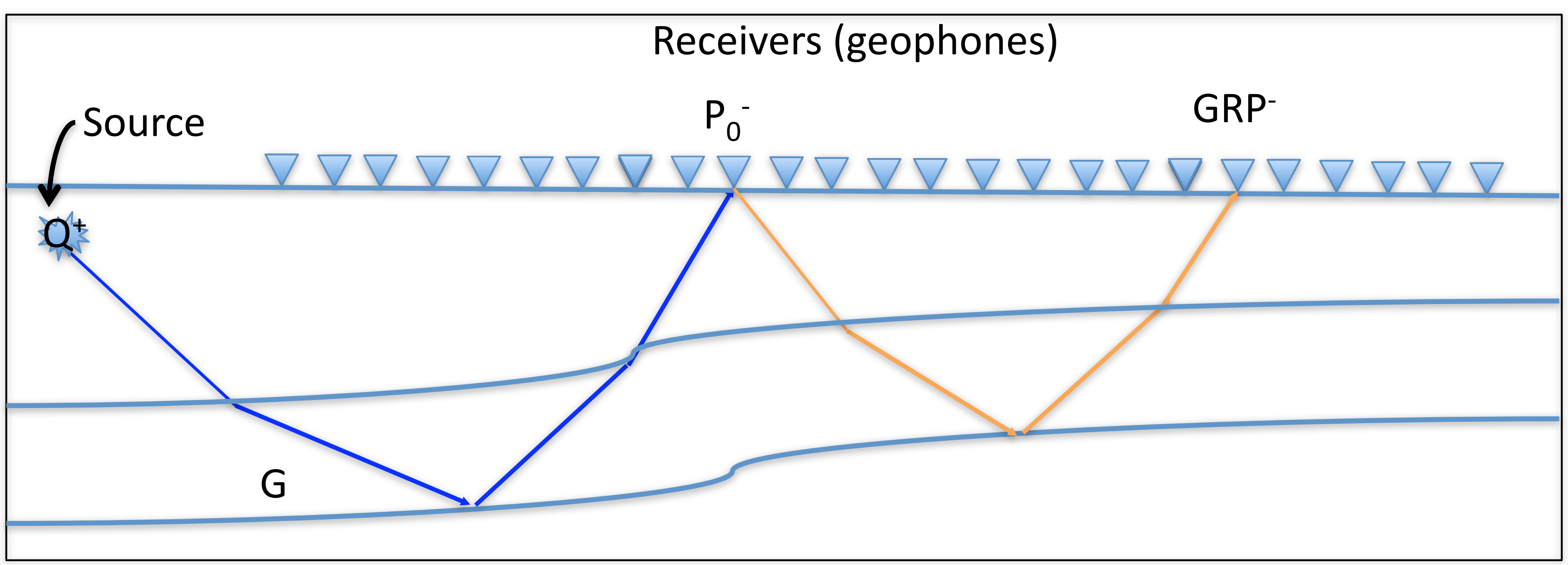


EPSI (1D Case)

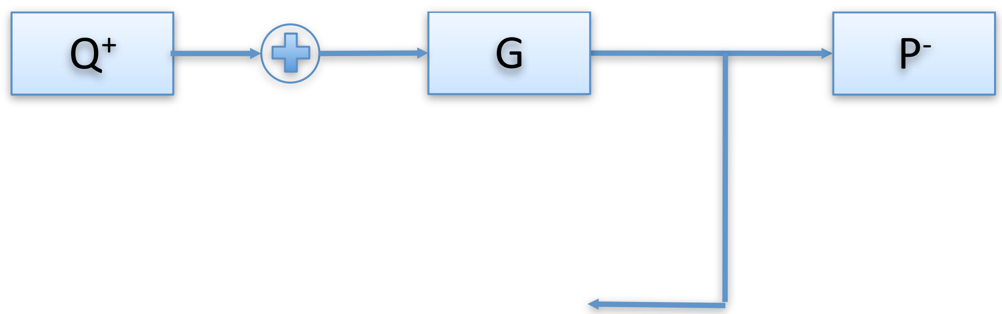


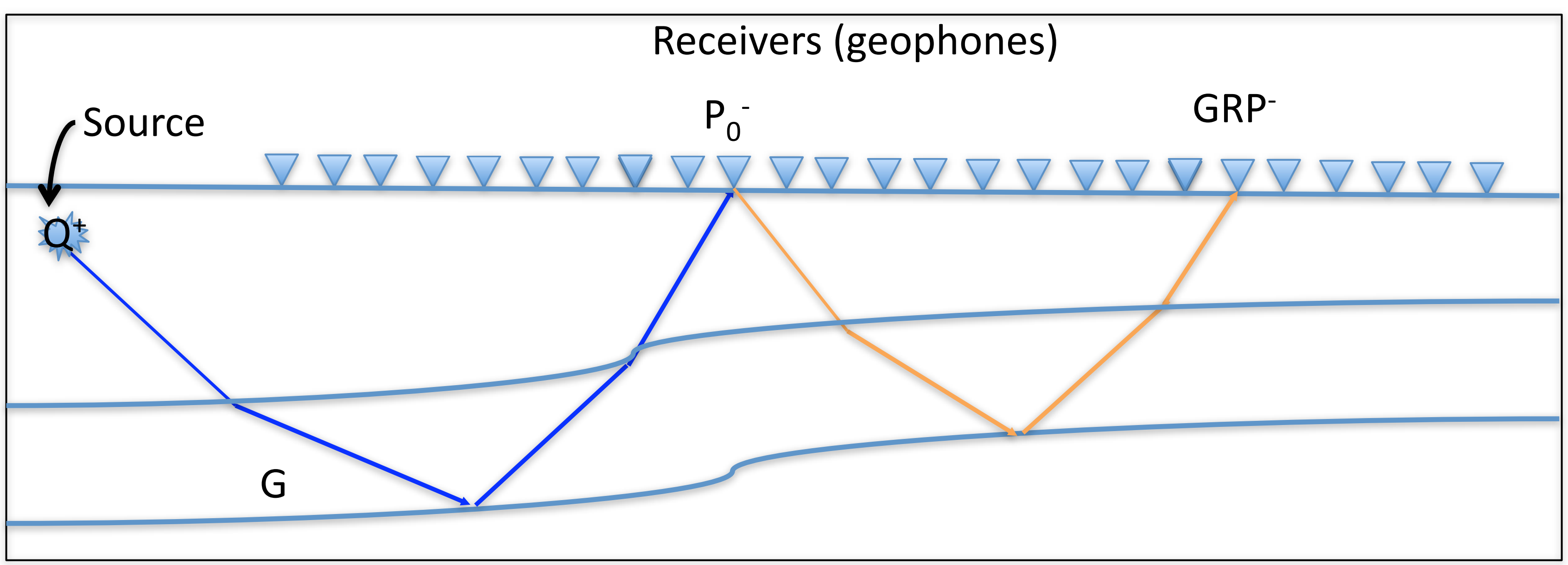
EPSI (1D Case)



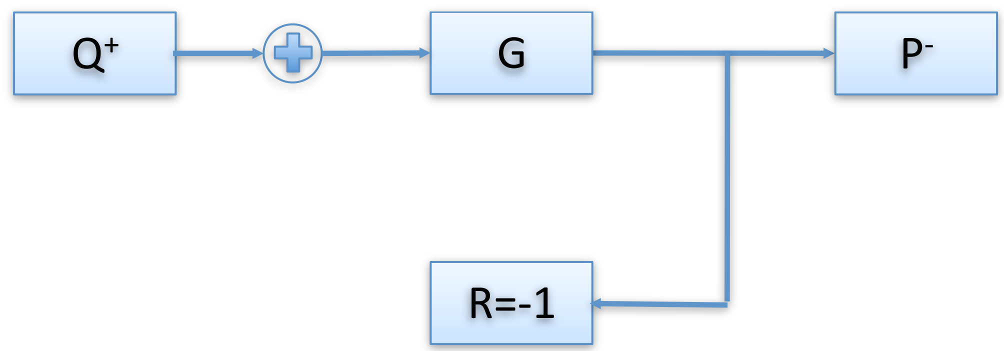


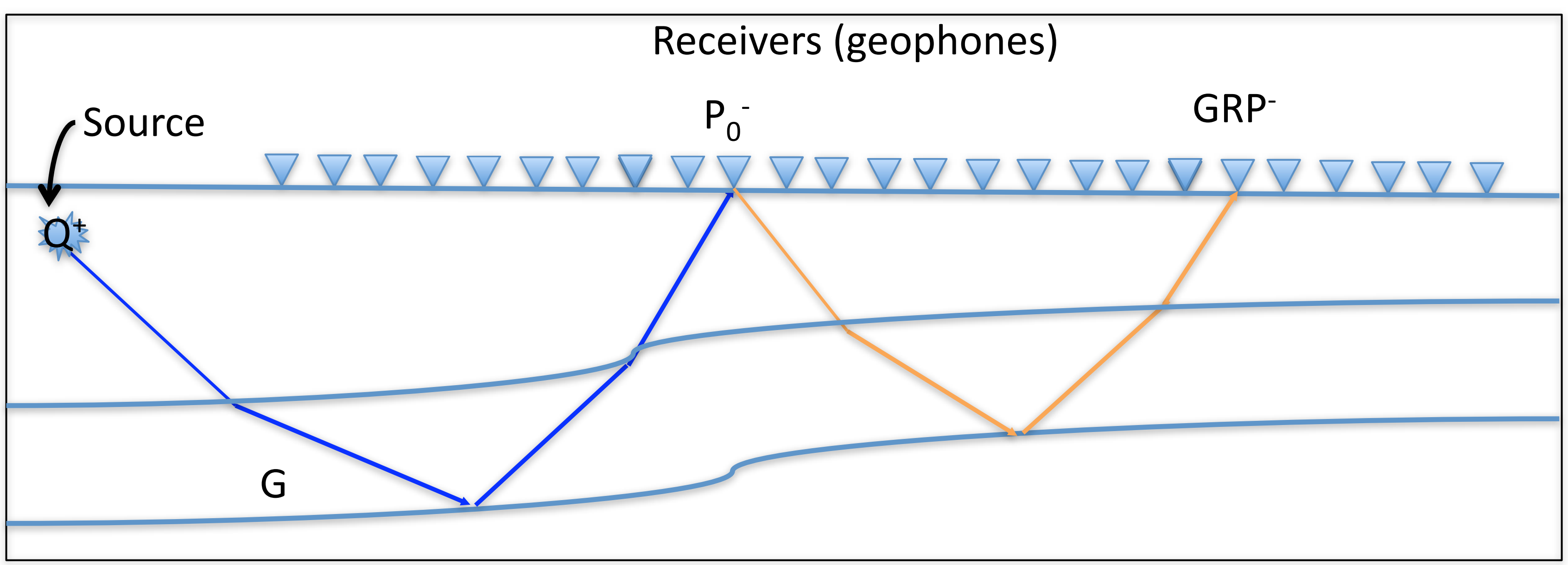
EPSI (1D Case)



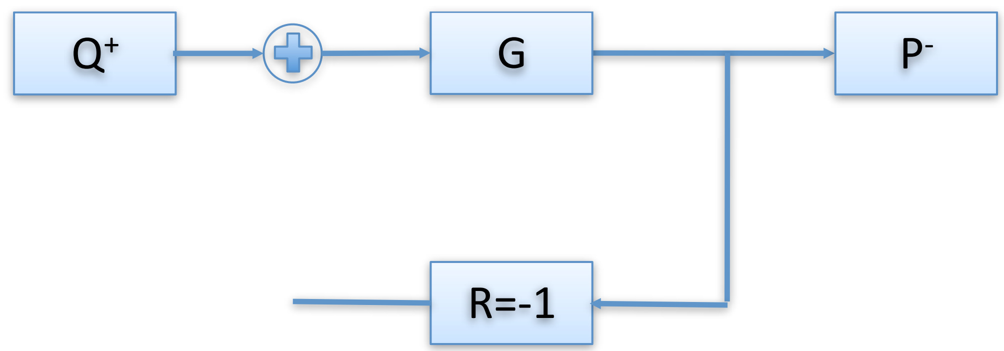


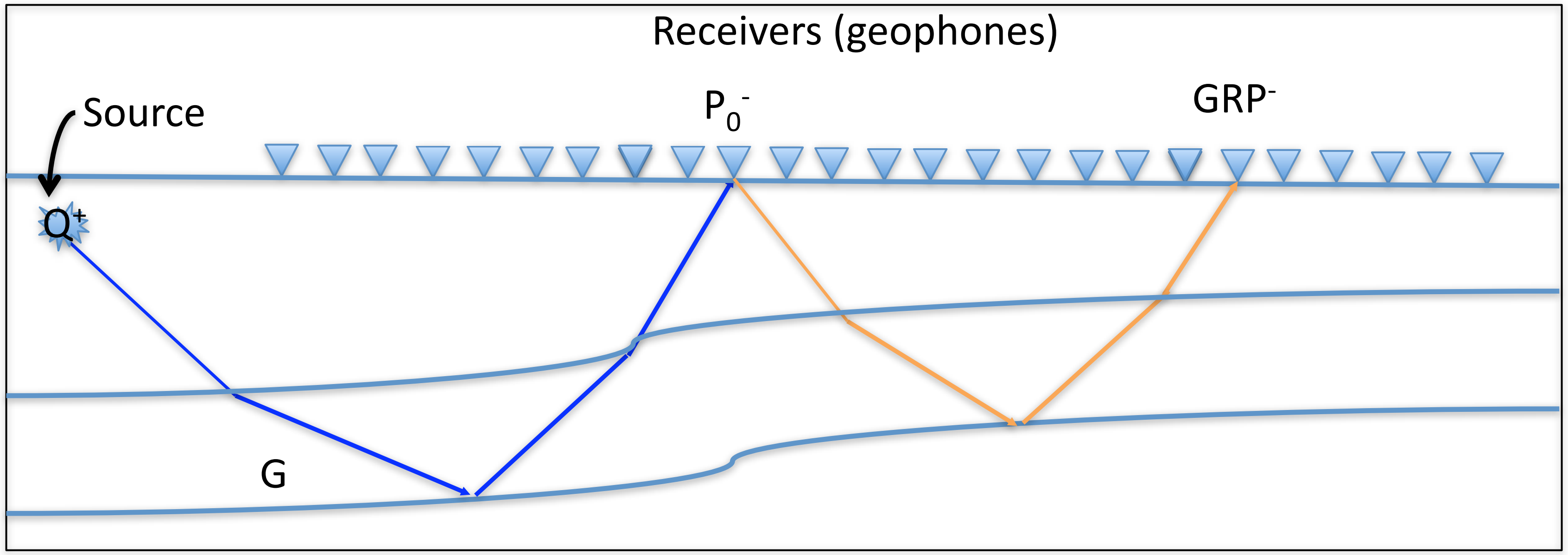
EPSI (1D Case)



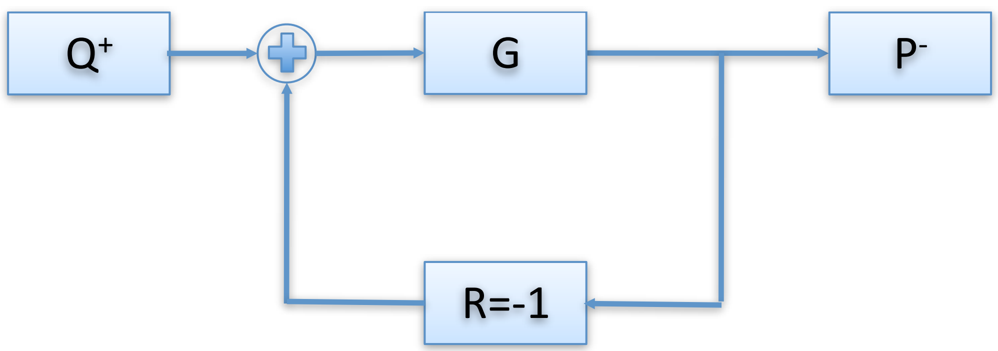


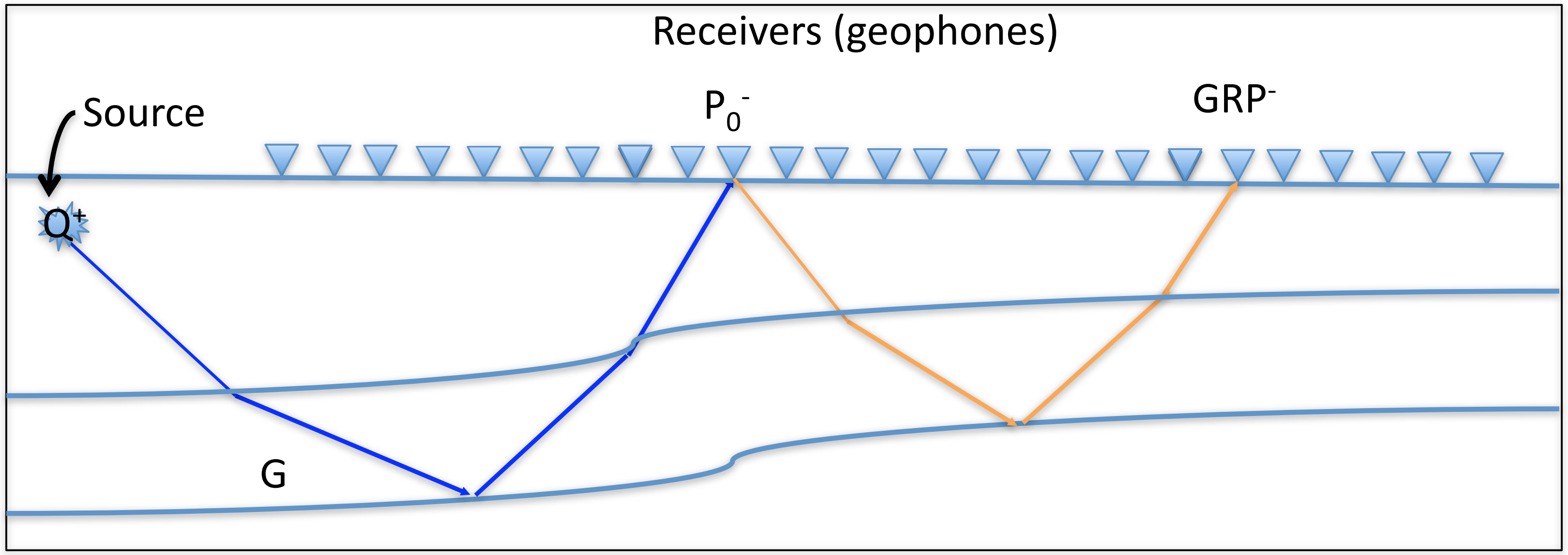
EPSI (1D Case)



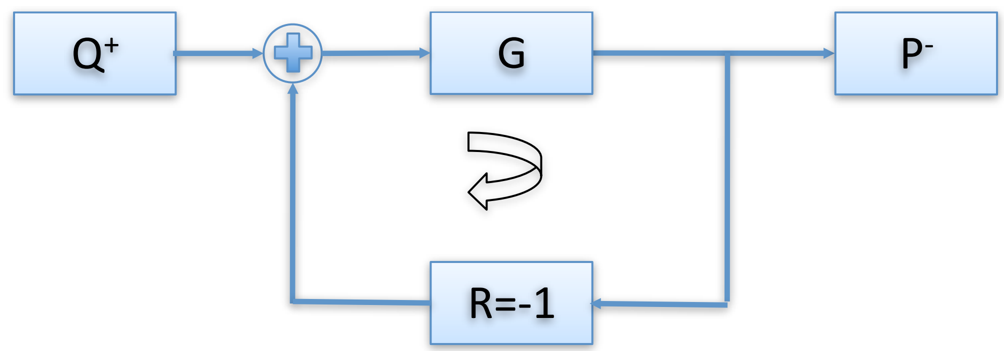


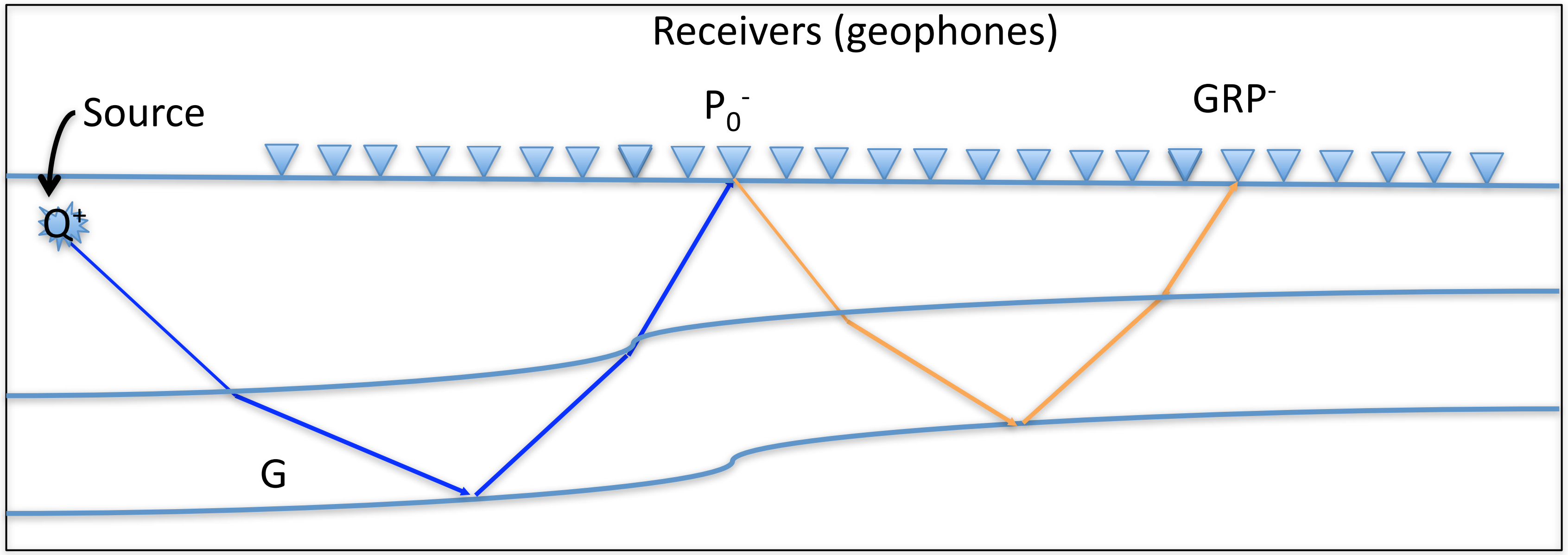
EPSI (1D Case)





EPSI (1D Case)





Estimation of primaries by sparse inversion

Solution via tri-convex optimization

Fix the source $\mathbf{Q}$, assume $\mathbf{R} = -\mathbf{I}$ for now.
Solve for the Green's function $\mathbf{G}$

$$\widetilde{\mathbf{x}} = \arg\min_{\mathbf{x}} \|\mathbf{x}\|_1 \quad \text{subject to} \quad \|\mathbf{A}[\widehat{\mathbf{Q}}]\mathbf{x} - \mathbf{b}\|_2 \leq \sigma$$

$$\widehat{\widetilde{\mathbf{g}}} := \text{vec}(\widehat{\widetilde{\mathbf{G}}}_{1\dots n_F}) = \mathbf{F}_t \mathbf{S}^* \widetilde{\mathbf{x}}$$

Estimation of primaries by sparse inversion

Fix the Green's function $\mathbf{G}$,
solve for the source $\mathbf{Q}$.

$$\widetilde{\widehat{\mathbf{q}}} = \arg\min_{\widehat{\mathbf{q}}} \tfrac{1}{2}\|\widetilde{\mathbf{y}} - \mathbf{B}[\widehat{\widetilde{\mathbf{G}}}]\widehat{\mathbf{q}}\|_2^2 + \lambda_F \|\mathbf{L}_F \widehat{\mathbf{q}}\|_2^2$$

$$\mathbf{B}[\widehat{\widetilde{\mathbf{G}}}] := \text{blockdiag}([\widehat{\widetilde{\mathbf{G}}}\mathbf{I}]_{1\cdots n_f}])$$

$$\widetilde{\mathbf{y}} = \text{vec}([\widehat{\mathbf{P}} - \widetilde{\widehat{\mathbf{G}}}\widehat{\mathbf{P}}]_{1\cdots n_F})$$

Curvelet-domain matching

When $\mathbf{R} \neq -\mathbf{I}$, we can use curvelet-domain matching, i.e,

$$\hat{\mathbf{P}} - \hat{\mathbf{G}}\hat{\mathbf{Q}} \quad = \quad \hat{\mathbf{G}}R\hat{\mathbf{P}}$$

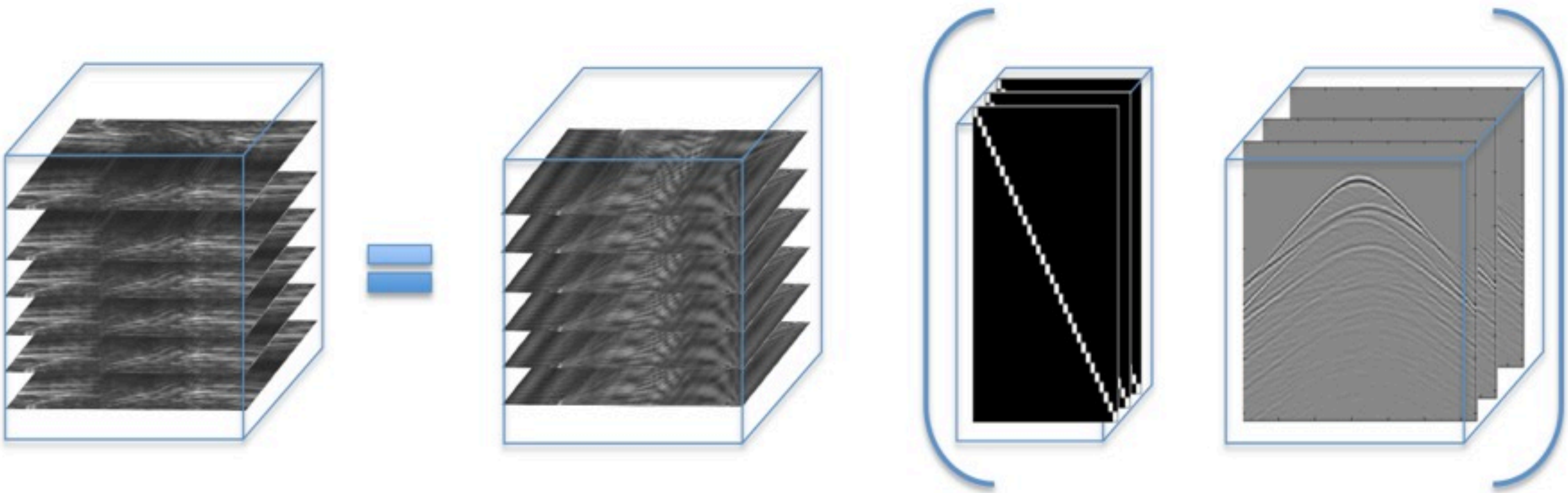
with,

$$\mathbf{R} \quad \approx \quad \mathbf{C}^* \operatorname{diag}(z)\mathbf{C}$$

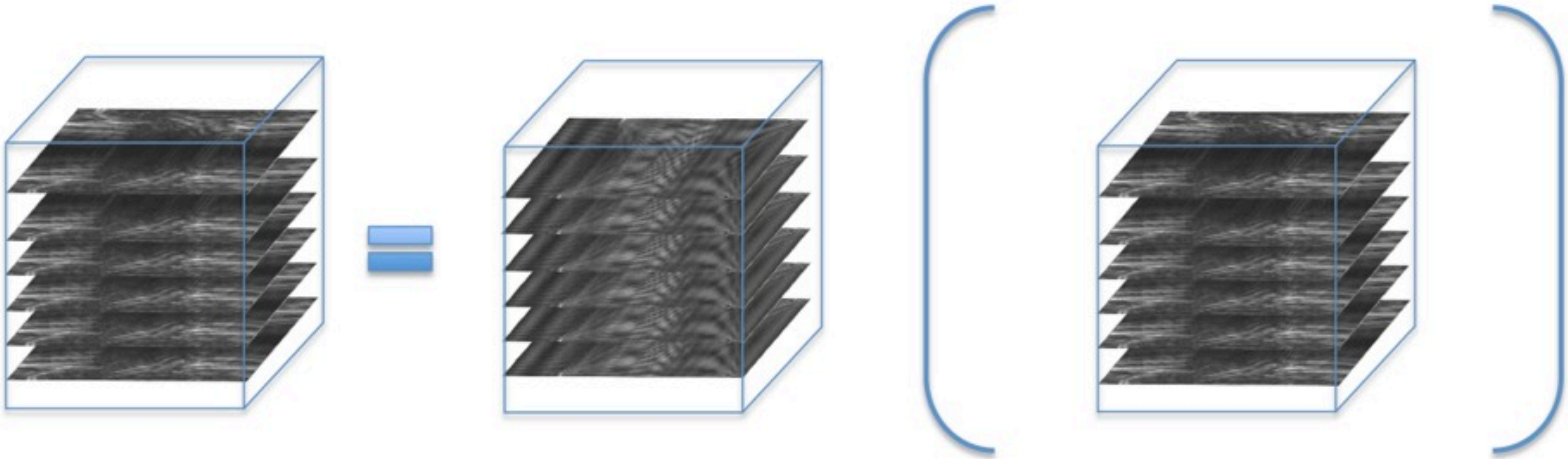
to get:

$$\hat{\mathbf{P}} - \hat{\mathbf{G}}\hat{\mathbf{Q}} \quad = \quad \hat{\mathbf{G}}[C^* \widehat{\operatorname{diag}(z)} C\mathbf{P}]$$

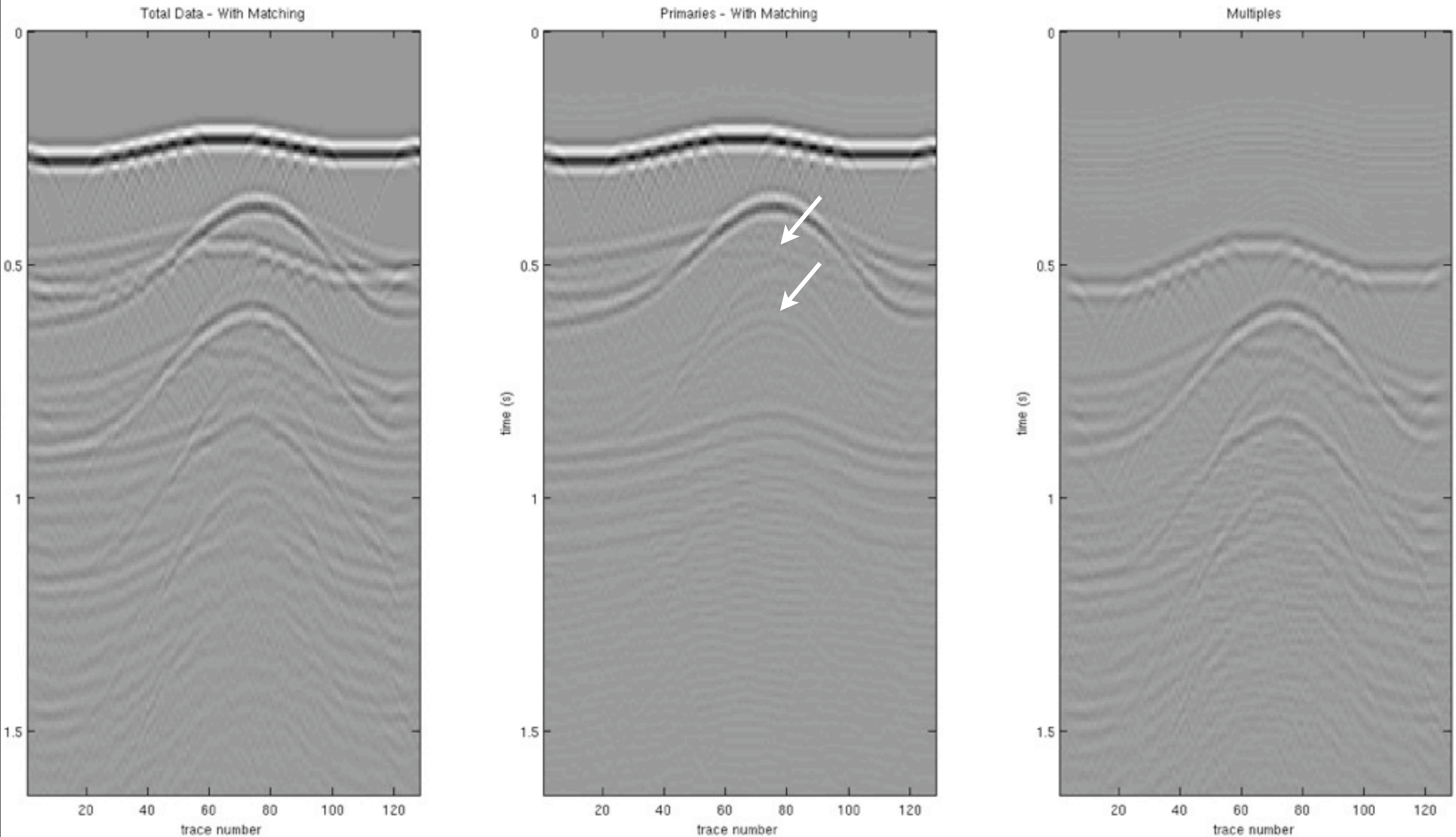
$$\hat{\mathbf{b}} = \hat{\mathbf{G}} \quad [C^* \, \widehat{\mathrm{diag}(z)} C\mathbf{P}]$$



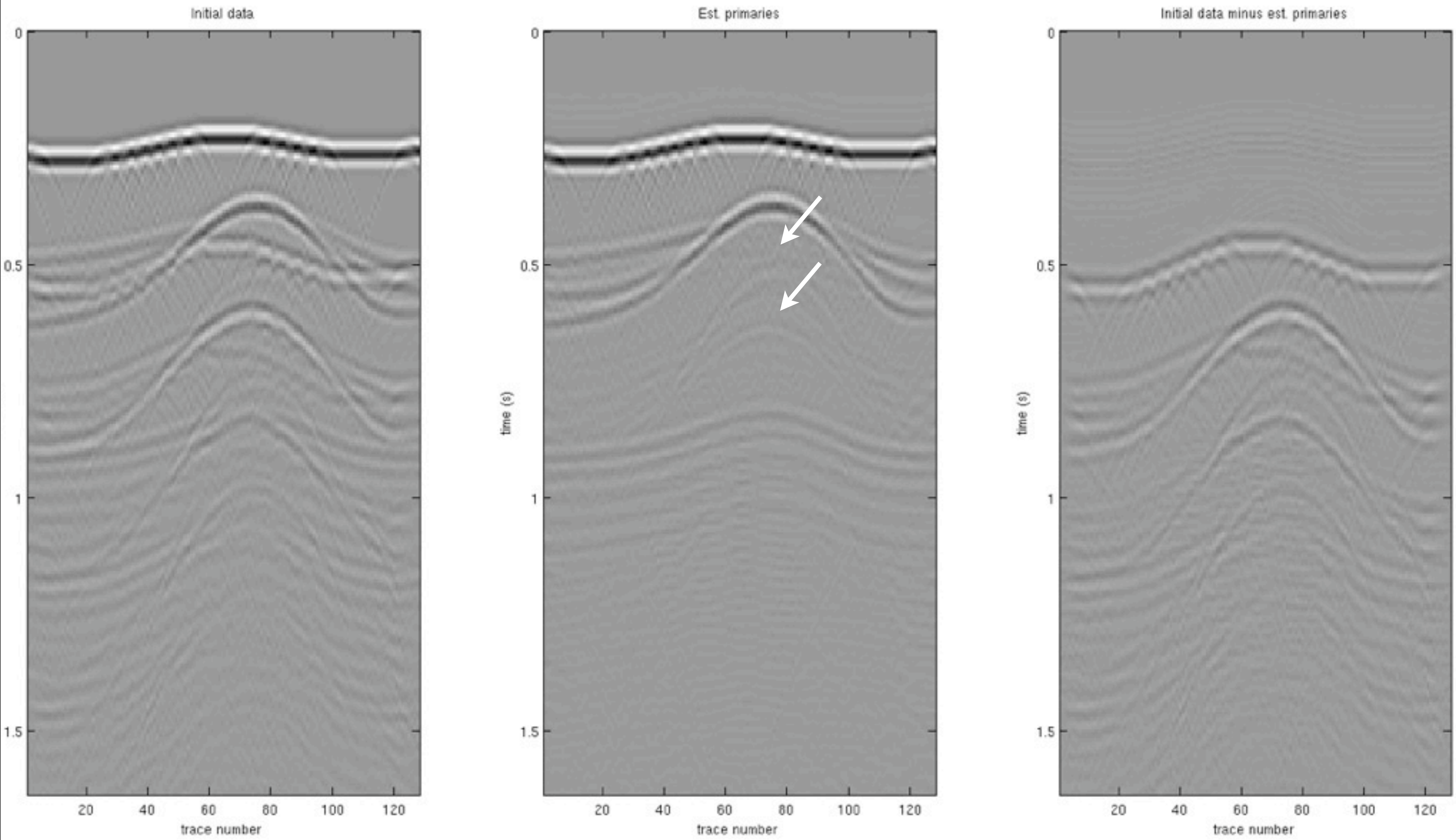
$$\hat{\mathbf{b}} = \hat{\mathbf{G}} \quad [C^* \, \widehat{\mathrm{diag}(z)} \, C\mathbf{P}]$$

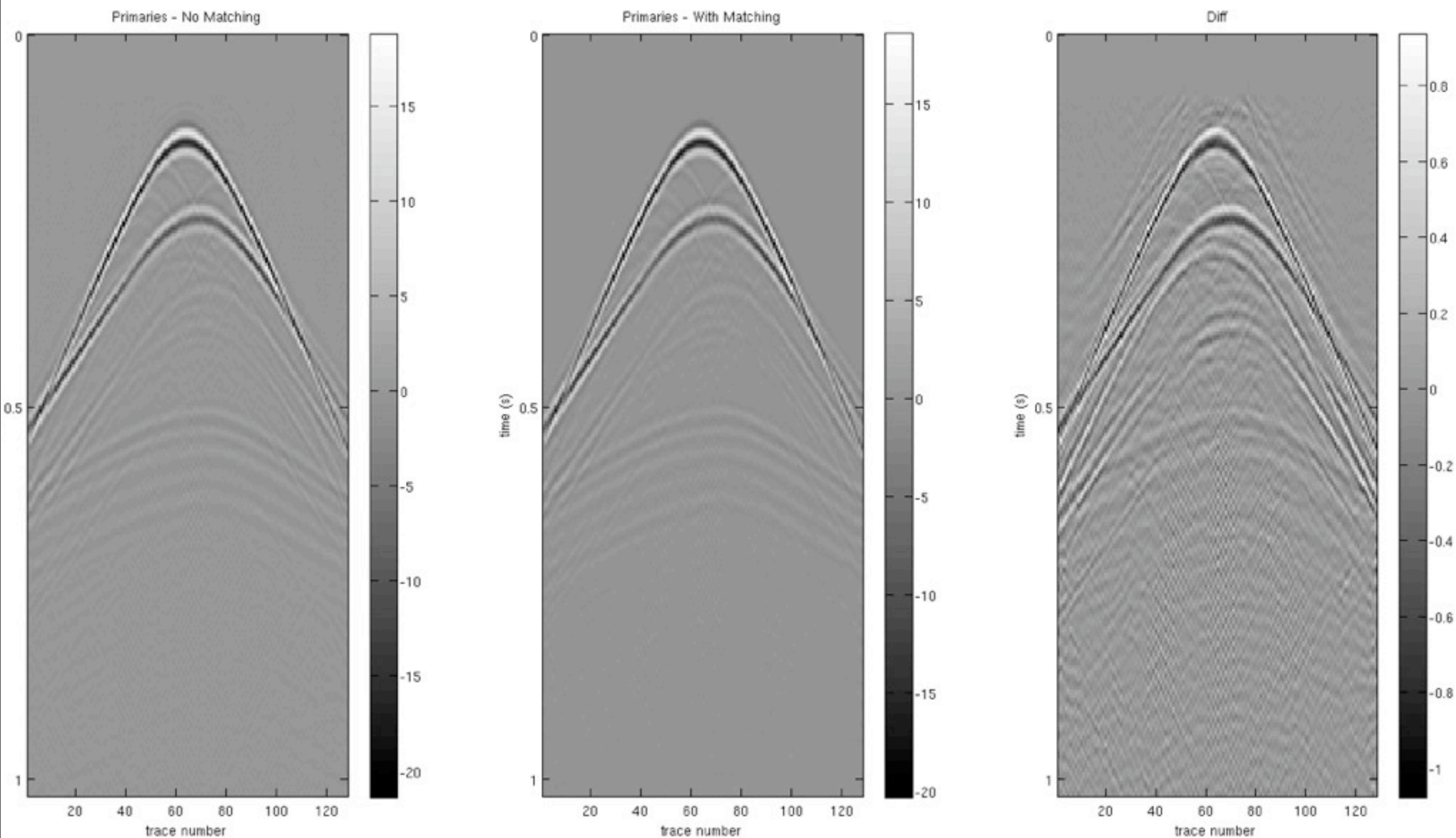


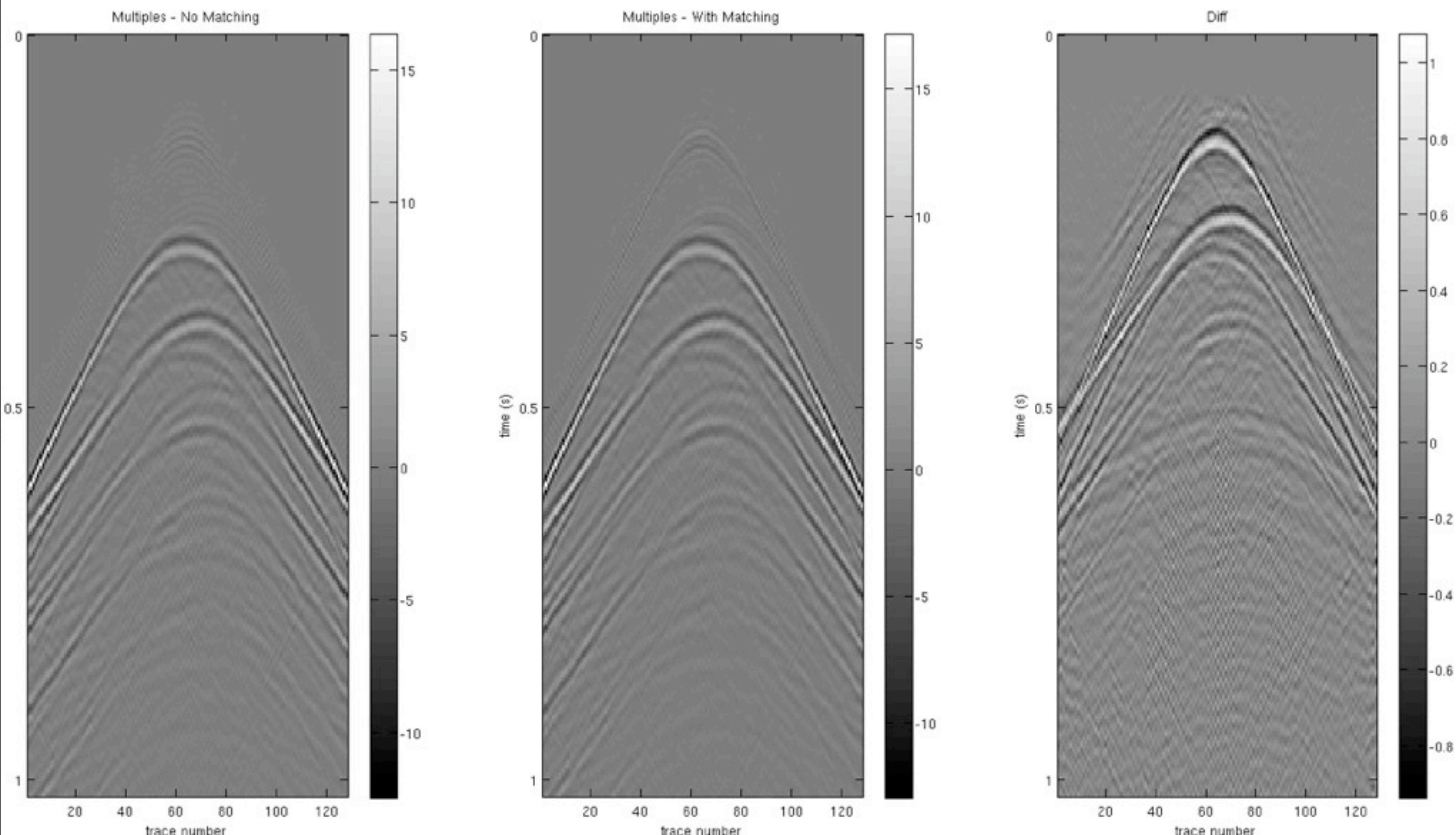
No Matching


Total Data - With Matching
Primaries - With Matching
Multiples
time (s)
trace number
0
0.5
1
1.5
20
40
60
80
100
120

With Matching




Primaries - No Matching
Primaries - With Matching
Diff
time (s)
trace number



Multiples - No Matching
Multiples - With Matching
Diff
time (s)
trace number

Future Works

- Faster formulation

$$\mathbf{P} - \mathbf{GQ} = C^* \operatorname{diag}(z) C \mathbf{GP}$$

- Frequency regularization
- Bayesian separation.

Acknowledgements

SINBAD

NSERC CRSNG

This work was in part financially supported by the Natural Sciences and Engineering Research Council of Canada Discovery Grant (22R81254) and the Collaborative Research and Development Grant DNOISE II (375142-08). This research was carried out as part of the SINBAD II project with support from the following organizations: BG Group, BP, Chevron, ConocoPhillips, Petrobras, Total SA, and WesternGeco.